



BOOK OF ABSTRACTS



29th COLLOQUIUM OF AFRICAN GEOLOGY



Windhoek, Namibia

2023

THEME: *“The earth sciences and Africa’s development: current realities, future projections”*

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29th Colloquium of African Geology, 26 – 29 September 2023 | Windhoek, Namibia

29th COLLOQUIUM OF AFRICAN GEOLOGY (CAG29)

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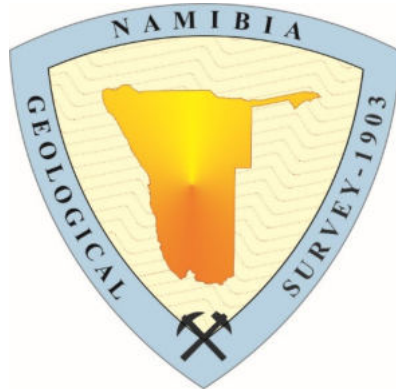


The Lion's Claw, a distinctive rock formation at the World Heritage site of /Ui-//aes, also known as Twyfelfontein in the Kunene Region, Namibia



Some of the delegates at the CAG29, on the 29th of September 2023 at Mercure Hotel, Windhoek

Spearheaded by the Geological Survey of Namibia (GSN)



Under the auspices of the Geological Society of Africa (GSAf)



THEME: “The earth sciences and Africa’s development: current realities, future projections”

Editors: Ester Shalimba, Ben Mapani, Justus Haukongo, Giesberta Shaanika, Anna Nguno, Ute Schreiber

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We would also like to extend our sincere gratitude and appreciation to the distinguished sponsors and in-kind contributors of the CAG29 event for their invaluable support and contribution. Their collaborative efforts have allowed us to gather leading experts, researchers, and professionals to explore and share groundbreaking insights in the realm of African geology. We acknowledge and salute these sponsors and in-kind contributors for their dedication to fostering innovation and knowledge within the geoscience community.



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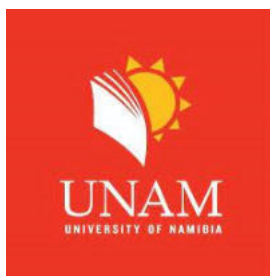


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INTRODUCTION

The Geological Survey of Namibia is the principal organizer of the 29th Colloquium of African Geology (CAG29) on behalf of the GSAf, as well as in cooperation with various stakeholders, including the Young Earth Scientists (YES) Network Namibia, the Geoscience Department-University of Namibia, the Geoscience Council of Namibia, the Namibian Hydrogeological Association, and the Department of Mining and Process Engineering-Namibia University of Science and Technology. The Local Organizing Committee (LOC) is quite dynamic and diverse in its composition, with representatives from associations, institutions, mining companies, governmental and non-governmental organizations, and the media.

The Colloquium of African Geology (CAG) is a major biennial meeting organized under the auspices of the Geological Society of Africa (GSAf). Professor W. Q. Kennedy, assisted by Dr. Tom Clifford, convened the very first CAG at the University of Leeds, England, in March 1964. There was a pulse of excitement that electrified the assembled audience from Africa, Europe, North and South America, Australia, and New Zealand when Prof. Kennedy announced his new concept of a 'Pan-African thermo-tectonic event'.

Since then, there have been 28 events, 18 of which were held in Europe, and only 10 in Africa, specifically in South Africa, Ethiopia, Tanzania, Nigeria, Eswatini, Zimbabwe, Morocco (twice), Mozambique and Tunisia.

With the inspiring theme "The earth sciences and Africa's development: current realities, future projections", CAG29 was held at the Conference Centre of Mercure Hotel (formerly known as Safari Hotel), Windhoek, from September 26th to 29th, 2023.



Folded schist and marble of the Pan-African Damara Orogenic Belt) in the Ugab Valley, Namibia

ORGANIZING COMMITTEES

The Local Organizing Committee (LOC) is comprised of the dynamic individuals from different organizations and institutions.

Patron

- Dr. Leake Hangala

Executive committee

1. Mrs. Anna Nguno (Geological Survey of Namibia (GSN) / Geoscience Council of Namibia): Chair
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9. Ms. Ester Shalimba (University of Namibia): Scientific Programme Second Vice Chair
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11. Ms. Kombada Mhopjeni (Geological Survey of Namibia / UNESCO Windhoek): National and International Committee Vice Chair
12. Dr. Roger Swart (BlackGold Geosciences cc / Geoscience Council of Namibia): Field Trip, Courses and Workshops Chair
13. Mrs. Mary Barton (Odikwa Investments CC): Field Trip, Courses and Workshops Vice Chair
14. Mr. Vilho Shafombabi (Navachab Gold Mine): Sponsorship / Fundraising / Exhibitions Chair
15. Ms. Inge Mbidi (Geological Survey of Namibia): Sponsorship / Fundraising / Exhibitions Vice Chair
16. Mrs. Ester Gustavo (Namibian Hydrogeological Association / SLR Environmental Consulting-Namibia): Social Events Chair
17. Ms. Emilia Shiweda (B2Gold): Social Events Vice Chair
18. Ms. Josephine Uushona (Geological Survey of Namibia / YES-Network-Namibia): Student & Early Career Geoscientist Chair
19. Ms. Halleluya Ekandjo (iCRAG at University College Dublin, Ireland): Student & Early Careers Geoscientist Vice Chair
20. Mr. Mbili Tshiningayamwe (University of Namibia): Student & Early Careers Geoscientist Second Vice Chair

Secretariat Members

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2. Mr. Joshua Nakale (GSN-BGR): Website and Apps
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8. Ms. Alina Kadhila (NAMWATER)
9. Mr. Martin Hipangwa (GSN)
10. Mrs. Ester Kapuka (GSN)
11. Mr. Moses Tuutaleni Angombe (GSN- McGill University, Canada)
12. Ms. Josephine Uushona (GSN)

Honorary / Advisory committee

1. Dr. Leake S Hangala, former Permanent Secretary of the Ministry of Mines and Energy in Namibia
2. Ms. Zenzi Awases, WiMAN-President, Vice-President Association of Women in Mining in Africa (AWIMA)
3. Dr. Roy Miller, former Head of the Geological Survey of Namibia.
4. Mr. Ibrahim Shaddad, Director General, African Minerals and Geosciences Centre
5. Prof. Aberra Mogessie, former President of the Geological Society of Africa
6. Dr. Absai Vatuva, Head of UNAM Geology Department, Namibia
7. Ms. Gloria Simubali, Head of the Geological Survey of Namibia
8. Mr. Arnold Bittner, Managing Director of SLR Namibia & Technical Discipline Manager of African Water Services
9. Prof. Hassina Mouri, University of Johannesburg, South Africa

MESSAGE FROM THE PRESIDENT OF THE GEOLOGICAL SOCIETY OF AFRICA (GSAF)

The Colloquium of African Geology (CAG) is a major biennial meeting, held under the auspices of the Geological Society of Africa, where earth scientists from around the globe have the opportunity to present their research on topics of African geology to an international forum of their peers. It also offers an opportunity to initiate, develop and implement projects which promote interaction between Academia, Industry and Society.



The 28th Colloquium of African Geology (CAG28), hosted by Morocco, it was announced that the 29th Colloquium (CAG29) as well as the 19th Conference of the Geological Society of Africa would be hosted by Namibia during the final week of September 2023. The theme of the event will be:

“The earth sciences and Africa’s development: current realities, future projections”

The event will be attended by senior and early-career earth scientists from government, associations, mineral exploration and mining companies and civil societies, as well as representatives from politics and the media are welcome. Career scientists from African countries and other developing areas are especially encouraged to regard this event as an opportunity to present their research to a wide audience, with participations from different sectors, countries, and continents. Namibia, the host country, boasts an interesting, heterogeneous geology covering some 2.6 billion years of earth history, with a wide variety of mineral deposits and mineralization styles, that have contributed - and still contribute-immensely to the country’s economy. In addition, Namibia’s impressive geomorphic landscapes have great potential for geo-tourism, while the host city, Windhoek, is a culturally diverse centre of learning. Academically, the geoscientific sessions and excursions highlighted in this circular and following circulars promise to provide a deeper insight into the multi-faceted geological history of the African continent.

I therefore enjoin all geoscientists globally, to start making plans to attend what will be an interesting and geologically fulfilling event, which will be held in Namibia from September 26th to 29th 2023.

Prof. Olugbenga Okunlola
gbengaokunlola@yahoo.co.uk

MESSAGE FROM THE CHAIRPERSON OF THE ORGANIZING COMMITTEE



I cordially invite you to the 29th Colloquium of African Geology (CAG29), to be held in the beautiful city of Windhoek, Namibia, from September 26 to 29, 2023.

The theme of this year's colloquium is "The earth sciences and Africa's development: current realities, future projections." The Local Organizing Committee and the National and International Scientific Committee, with support from various sponsors, will endeavour to put together a programme that does justice to this important topic.

CAG29 is a unique opportunity to showcase Namibia's spectacular geology to Africa and the rest of the world. It is also a chance to network with the international geoscience community and to learn about the latest research in the field.

The Colloquium will feature a variety of sessions, including keynote addresses, oral presentations, poster sessions, and field trips, exhibitions and meetings (including expert working groups). There will also be opportunities for networking and socializing. Whether you are from industry, government, or academia, you will find something of interest at CAG29.

We hope you will join us for this exciting event! To register for the colloquium, please visit the website: <https://cag29gsaf.org/>.

We look forward to seeing you at the CAG29!

Mrs. Anna Nguno Anna.Nguno@mme.gov.na / cag29.whk@gmail.com



Bogenfels, a 55 m high rock arch situated on the coast between Lüderitz and Oranjemund, Karas Region, Namibia

BOOK OF ABSTRACTS

29th Colloquium of African Geology, 26 – 29 September 2023 | Windhoek, Namibia

29th COLLOQUIUM OF AFRICAN GEOLOGY



Honourable Kornelia Shilunga, Deputy Minister of Mines and Energy, Republic of Namibia

**Delivered at the opening of the 29th Colloquium of African Geology
Mercure Hotel, Windhoek
26 September 2023**



- Director of Ceremonies,
- Right Honourable Saara Kuugongelwa- Amadhila - Prime Minister of the Republic of Namibia
- Honourable Laura McLeod-Katjirua- Governor of Khomas Region
- His Worship Joseph Uapingene- The Mayor of Windhoek
- Your Excellencies
- Dr. Stanley C. Finney - General Secretary of the International Union of Geological Sciences

- Prof. Olugbenga Okunlola - President of the Geological Society of Africa
- Madam Anna Nguno- Chairperson of CAG29 Organizing Committee
- Professor. Ancia Peters – CEO of National Commission on Research, Science and Technology

- Mr Bryan Eiseb – The Acting Executive Director in the Minister of Mines and Energy
- Madam Gloria Simubali- Deputy Executive Director of the Geological Survey of Namibia
- Dr. Leake Hangala - Patron of CAG29
- Plenary Speakers of CAG29
- Distinguished Delegates and Participants
- Members of the media
- Ladies and Gentlemen

A very good morning to all of you

The Ministry of Mines and Energy of the Republic of Namibia is proud to be the host of CAG29 through our geoscience research Department, the Geological Survey. I hereby acknowledge the pivotal role that the geoscientific research contributes to Namibia's socio-economic development. A common benefit across the African continent. The development of Africa's fortune of minerals, petroleum and underground water resources all begins with research.

Dear delegates of the colloquium, I commend you for your dedication to the earth sciences of Africa. It is through geoscientific research findings, the Ministry of Mines and Energy houses an enriched geoscientific database, key to our active mineral exploration and insightful baseline necessary for informed decision-making in sustainable mineral resource management, and responsible mining practices.

Through our shared regulatory frameworks, the governance of Africa encourages sustainable development of natural resources. To enlighten us further, we are graced with one of the top representatives of the Government of the Republic of Namibia. This Honourable earned her first

BOOK OF ABSTRACTS

29th Colloquium of African Geology, 26 – 29 September 2023 | Windhoek, Namibia

degree, a **bachelor's degree in economics** from Lincoln University (USA) in 1994, She further earned a **master's degree in financial economics** from the London School of Economics in 1998. She was awarded with an **Honorary Doctorate in Public Finance** from the University of Namibia in **2015**, and she was further awarded an honorary doctorate degree '**Doctor of Laws**' from Lincoln University in **2016**. She is an expert of Economics and a pioneer politician. Affiliated with Africa's development through serving in various regional and international bodies as governor or council member, at: International Monetary Fund/World Bank, African Union, African Development Bank, Afrexim Bank, Commonwealth, Southern Africa Development Community (SADC) and Southern African Customs Union (SACU).

Her remarkably lifetime contribution towards shaping Namibia's investment and socio-economic development began at young age. Serving as the Director General of National Planning Commission (1995 to 2003). In 2003, she became Minister of Finance and served until 2015, attaining proficiency in our national fiscal regime. Her keen analytical skills and unwavering commitment and dedication earned her recognition to her current reputable position as the Right Honourable Prime Minister of the Republic of Namibia, entrusted with a substantial role as the Head of Government Administration.

Director of ceremonies, Speakers, Delegates, Ladies and Gentlemen. It is my privilege and honour to introduce a remarkable leader and the 29th Colloquium of African Geology Keynote speaker, **The Right Honourable Dr. Saara Kuugongelwa Amadhila**, Prime Minister of the Republic of Namibia.

Right Honourable Prime Minister, please take the floor.



KEYNOTE ADDRESS BY PRIME MINISTER

Right Honourable Saara Kuugongelwa-Amadhila Prime Minister, Republic of Namibia

**Delivered at the official opening of the 29th Colloquium of African Geology by
Tuesday, 26 September 2023
Mercure Hotel, Windhoek**



- Director of Ceremonies.
- Hon. Kornelia Shilunga, Deputy Minister of Mines and Energy;
- Hon. Laura McLeod-Katjirua, Governor of Khomas Region;
- His Worship Cllr Joseph Uapingenge, Mayor of Windhoek;
- Dr. Stanley C. Finney - General Secretary of the International Union of Geological Sciences;
- Prof. Olugbenga Okunlola -President of the Geological Society of Africa;
- Prof. Ancia Peters – Chief Executive Officer, National Commission on Research, Science and Technology;
- Mr Bryan Eiseb, Acting Executive Director, Ministry of Mines and Energy;
- Dr. Leake Hangala, Patron of 29th Colloquium of African Geology
- Plenary Speakers;
- Distinguished Delegates;
- Members of the Media;
- Dr. Ladies and Gentlemen.

A very good morning!

It is my distinguished honor to join you today at this occasion of the 29th Colloquium of African Geology, under the theme “The earth sciences and Africa’s development: current realities, future projections”. I wish to thank the Ministry of Mines and Energy for organizing this Colloquium.

I am very confident that the objectives set for the Colloquium will be met, noting a very elaborate and engaging programme, ranging from pre & post courses and workshops, experts panel discussions and insightful presentations. The Continent of Africa aspires to transform itself into a strong global powerhouse of the future as contained in the AU Agenda 2063. It is, therefore, reassuring to see a large gathering of African geoscientist experts under one roof striving for a harmonious continental sustainable resource development.

I am informed that this gathering brings together all expertise relevant to elevate geoscientific research and generate solutions for Africa: Geoscience experts, experts of the regulatory frameworks guiding our extractive sector, law and policy makers, as well as Industry stakeholders. It is my expectation that the participants and experts will own the stewardship to steer the African continent towards the realization of its visions. These are the vital steps towards African geoscientific solutions, mineral and petroleum discoveries, unmasking of green energy production, underground water optimization, geohazard mitigation, as well as leveraging our geological wealth for the benefit of all Africans.

The geology, while it is a field of the earth and earth materials, is also crucial to assist us to identify and mitigate hazards caused by things such as earthquakes, coastal erosion, flooding, and landslides.

It is also through geology that we are able to identify renewable energy projects, which have massive potential for economic development and employment creation.

Therefore, this Colloquium is a platform which is supportive of the efforts to make our economy competitive.

The Government appreciates the crucial role that geoscience plays in our national upliftment, especially during this time that the country has discovered oil. We are dedicated to nurturing a national research spectrum, as well as contribute to a cross border conducive environment of geoscience research, innovation, and investment, for the benefit of our country and the entire continent and globe. Noting the global developments, this colloquium affirms its timely relevance. There continues to be unprecedented challenges stemming from the effects of lack of minerals beneficiation especially in Africa, the shift in technological era towards the 4th industrial revolution and the green energy production.

Africa's minerals resources offer an opportunity for employment creation, industrialization, and economic growth on the continent. There is a lot of employment benefits in the mineral's beneficiation, adding to benefits created by value addition. I, therefore, urge this Colloquium to consider workable proposals for the local beneficiation of our natural resources and the technological advancement of our economies. Collaborative efforts are critical for unlocking the potential of these resources to bring prosperity to the continent. It begins with addressing our common challenges, learning from each other, promotion of science and geology within academia and businesses, and fostering awareness by experts at conferences like these.

The Government of the Republic of Namibia has committed itself to support the extractive industry in order to improve it for the better. This is supportive of our Vision 2030 and a contribution towards African Agenda 2063. We shall leverage on the set of established favourable policies and regulatory frameworks, that not only encourage, but actively support geological research, exploration, mining, and sustainable resource management.

As I draw to a close, I wish to encourage different experts present here to explore the limitless opportunities this platform presents, through sharing of intensive geoscientific research and case studies, and unlock the geological treasures of Africa to contribute to a brighter, more sustainable future for all. Geology and the study of minerals must become entrenched in our day-to-day lives at schools, workplaces and within the academia.

The Government of Namibia remains committed to the promotion of science and support to the field. I then extend my best wishes for a productive and enlightening conference, filled with meaningful discussions, innovative ideas and fruitful partnerships.

Let us work hand in hand to unearth the geological potential of Africa and contribute to the success of Africa Agenda 2063.

I thank you.

WELCOME ADDRESS BY GOVERNOR OF KHOMAS REGION

Honourable Laura McLeod-Katjirua - Governor of Khomas Region

Delivered at the opening of 29th Colloquium of African Geology

Mercure hotel, Windhoek

26 September 2023

- Director of Ceremonies
- Honourable Saara Kuugongelwa- Amadhila - Prime Minister of Namibia
- Deputy Minister of Mines and Energy - Honourable Kornelia Shilunga
- His Worship the Mayor of Windhoek – Councillor Joseph Uapingene
- Dr. Stanley C. Finney - General Secretary of the International Union of Geological Sciences
- Prof. Olugbenga Okunlola - President of the Geological Society of Africa
- Chairperson of CAG29 Organizing Committee - Mrs Anna Nguno
- Prof. Anca Peters – CEO of National Commission on Research, Science and Technology
- Acting Executive Director in the Minister of Mines and Energy - Mr Bryan Eiseb
- Deputy Executive Director of the Geological Survey of Namibia – Ms Gloria Simubali
- Patron of CAG29 - Dr. Leake Hangala
- Excellencies, Plenary Speakers of CAG29, Distinguished Delegates, Members of the media
- Ladies and Gentlemen



Your Excellencies, Esteemed Delegates, and Industry Stakeholders

On behalf of the people and the governance of the Khomas Region, I am truly delighted to welcome you all to the beautiful city of Windhoek, in the heart of Khomas region, for the 29th Colloquium of African Geology. It is a privilege and honour to host such an esteemed gathering of enthusiasts from across the African continent and beyond. I am particularly pleased to welcome the General Secretary of the International Union of Geological Sciences, the President of the Geological Society of Africa, and all the international delegates of the colloquium. our Prime Minister, Minister and Deputy Minister of Mines and Energy of Namibia, and all local delegates you are evenly welcome. Special appreciation to the Geological Survey of Namibia for organizing the CAG29 and bringing this event to Namibia.

Geoscientific research, while often hidden from the public eye, is undeniably central to our existence. It is the foundation upon which we build and sustain our societies and economies. Research conferences are not held frequent enough with regard to their significance. Therefore, we need to capitalise on the few opportunities we get. Collectively exchanging ideas, collaborating on cutting-edge research, and fostering partnerships that transcend borders and cultures in order to unleash the full potential of geology for the benefit of all Africans. The theme of this year's colloquium is "**The Earth Sciences and Africa's Development: Current Realities, Future Projections.**" This is a very important topic, and I am confident that the discussions and debates at this colloquium will help us to better understand the role of the earth sciences in Africa's development.

I trust that your time here in Khomas region and Namibia at large will be both professionally rewarding and personally enriching. Once again, my warmest welcome to each one of you. May this conference be a resounding success and may our shared commitment to a harmonious continental geoscientific research be a source of inspiration for generations to come.

Thank you.

REMARKS BY MAYOR OF WINDHOEK

His Worship, Councillor Joseph Uapingene, Mayor of Windhoek, Namibia
Delivered at the opening of 29th Colloquium of African Geology
Mercure hotel, Windhoek
26 September 2023

Director of Ceremonies, Mr. Bryan Eiseb, Acting Executive Director in the Minister of Mines and Energy

- Right Honourable Saara Kuugongelwa-Amadhila, Prime Minister, MP
- Honourable Kornelia Shilunga, Deputy Minister of Mines and Energy, MP
- Honourable Laura McLeod-Katjirua, Governor of Khomas Region
- Dr. Stanley C. Finney - General Secretary of the International Union of Geological Sciences
- Prof. Olugbenga Okunlola - President of the Geological Society of Africa
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- Mrs. Anna Nguno, Chairperson of CAG29 Organising Committee
- Prof. Anca Peters – CEO of National Commission on
- Research, Science & Technology,
- Excellencies,
- Plenary Speakers of CAG29
- Distinguished Delegates, Members of the Media, Ladies and Gentlemen



It is an honour for me to deliver a few remarks at this very important occasion, of the 29th Colloquium of African Geology. The event brings together brilliant minds in geo-scientific research, from across the globe in recognition of the value that is linked to the advancement of livelihoods.

The Colloquium of African Geology is a biennial meeting organised under the auspices of the Geological Society of Africa where earth scientists globally have the opportunity to present their research results on topics related to African geology and their surroundings. This year's theme: *"The earth sciences and Africa's development: current realities and future projections"*, promises exciting discussion topics ranging the spectrum of disciplines such as:

- basic essential underground water,
- city planning away from hazardous zones, and
- technology manufacturing, to mention but a few.

Windhoek is as much affected by globalisation and the effects of climate change and their impact on our geological footprint. Therefore, engagements like this are crucial in preparing us to safe-guard our environment, protect our current and future resources and optimise value-driven projects. That said, we must also embrace the reality that the Fourth Industrial Revolution is upon us and that, the City of Windhoek's vision is to be *Sustainable and Caring City by 2027*. Therefore, I look forward to the deliberations and outcomes over the next few days and encourage your active participation, networking, and action plans against which we can monitor progress at the next session.

Before I end my address, I'd like to quote from the Book of Job 28: 5-6: *"The earth, from it comes food and underneath, it is turned up as fire. Its rocks are the source of sapphires and its dust contains gold."*

Let us be mindful of our respective responsibilities and the natural resources we have been gifted. Ours is a mission to ensure that our collective knowledge and wealth of experience in the earth sciences, are harvested towards bringing about sustainable development to the African continent.

BOOK OF ABSTRACTS

29th Colloquium of African Geology, 26 – 29 September 2023 | Windhoek, Namibia

With these few words, I welcome you warmly and with the Almighty's presence, wish you fruitful deliberations, discoveries, and lasting friendships.

I thank you!



BOOK OF ABSTRACTS

29th Colloquium of African Geology, 26 – 29 September 2023 | Windhoek, Namibia

CAG29 SUBTHEMES AND SESSIONS

The CAG29 consisted of 13 Sub-themes and 27 sessions, in addition to the 10 plenary talks. Table 1 shows the Subthemes, sessions, and their codes. These sessions featured keynote talks, oral presentations, poster presentations, and panel discussions.



SUBTHEMES, SESSIONS AND THEIR CODES

Table 1: Sub-themes, sessions, and their codes

CODE	SUB-THEMES	SESSIONS
ST01	The African Geological Record, Palaeontology, ancient environments, and palaeoclimates	ST01_S01- Palaeontology, ancient environments, and palaeo-climate ST01_S02- Basin evolution and dynamics ST01_S03- Neoproterozoic glacial record of Africa
ST02	Geodynamic evolution of the African continent: geochronology, mobile belts, and intraplate magmatism.	ST02_S01- Orogenic cycles of the African Continent – Archaean to Phanerozoic ST02_S02- Geochronology- a window into the evolution of planet Earth ST02_S03- Structural geology and Tectonics ST02_S04- Intraplate magmatism ST02_S05- Southern Namibia Mapping Programme: new insights into the geology and mineral deposits of the Karas Region (<i>Special Session</i>)
ST03	Ore deposit geology of Africa (Mineral Resources and ore forming processes)	ST03_S01- Ore deposits and plate tectonics ST03_S02- Ore deposits, exploration and metallogeny ST03_S03- Critical raw materials-strategic minerals
ST04	Geophysics, Geochemistry and Remote Sensing– Peering into the subsurface and Integrated approaches in Geosciences	ST04_S01- Innovation and integrated approaches in geophysics ST04_S02- Advances in geochemical exploration techniques and data interpretation ST04_S03- Remote Sensing Studies
ST05	Hydrogeology and water sustainability under a changing climate	ST05_S01- Hydrogeology and water sustainability under a changing climate
ST06	Geology in the service of society: Applied Geosciences in Africa	ST06_S01- Engineering geology, geotechnics and geohazards ST06_S02- Agrogeology, Medical Geology
ST07	Geoparks, Geotourism and Geoeithics for Promoting Earth Heritage	ST07_S01- Geoheritage, Geotourism and Geoparks in Africa
ST08	The role of Minerals and Fossil Fuel Industries in Africa’s Energy Transition to Carbon Neutral and Green Hydrogen Energy Economies	ST08_S01- The role of Minerals and Fossil Fuel industries in Africa’s Energy Transition to Carbon Neutral and Green Hydrogen Energy Economies
ST09	Africa’s Nuclear Fuel Resources	ST09_S01- Africa's Nuclear Fuel Resources
ST10	Hydrocarbon Potential in Africa	ST10_S01- Hydrocarbon Potential in Africa
ST11	Investment in the Mineral Industry: policy issues, legislations, challenges, governance, and best practices	ST11_S01- Implementation of a continental system for management of Africa’s mineral and energy resources: the African Mineral and Energy Resources Classification and Management System (AMREC) and Pan-African Resource Reporting Code (PARC), (<i>Special Session</i>) ST11_S02- Mining taxation, fiscal policies, and fiscal instruments
ST12	Geoscience Education for Sustainable Development	ST12_S01- Geoscience and public awareness
ST13	The fourth Industrial revolution, Artificial intelligence, and Information management	ST13_S01-The fourth Industrial revolution and its impact on mineral resource countries ST13_S02- Information management systems and value added products ST13_S03- Artificial intelligence, big data, and mineral system approach in mineral predictive mapping: Background and applications

PLENARY ABSTRACTS**The Nama Group: A unique palaeo-environmental archive at the dawn of animal biomineralization****Fred T. Bowyer**

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Abstract

Complex pre-Cambrian macrofossils were first described from marine sedimentary rocks of the Nama Group in southern Namibia almost 100 years ago. Since then, fossils of diverse pre-Cambrian organisms have been discovered in sedimentary successions on almost every continent. However, no other succession known globally has as rich and informative a record of Ediacaran palaeo-environmental conditions as the Nama Group, for several reasons. First, the Nama Group is comprised of both siliciclastic and carbonate marine sedimentary rocks that preserve both soft-bodied fossils and fossils of the first skeletal animals. Second, this mixture of lithologies provides the perfect archive for high resolution geochemical studies. Third, the succession is preserved subhorizontally across an area of tens of thousands of kilometres, providing unparalleled exposure of fossiliferous bedding planes that continue to yield new fossils, and the opportunity for accurate regional correlation and sequence stratigraphic analyses. Lastly, radiometric dating of numerous volcanic ash interbeds throughout the succession has resulted in exceptional calibration of the Nama Group record in absolute time. In this presentation I will provide an overview of important historical studies that have constrained the regional stratigraphic and palaeontological framework of the Nama Group, and discuss recent advances that reveal the marine geochemical conditions and global temp context of the Nama Group palaeo-environment.

Keywords: Nama Group, Biomineralization, Macrofossils, Palaeo-environment, Namibia



Regional Syntheses of Miocene Successions in Africa: A synopsis from petroleum Geology Point of View

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Abstract

This presentation will highlight a detailed study of the Cyrenaica basin in NE Libya and will also shed light on Miocene petroleum systems through a comparison between some selected examples from Northern, Western & South Africa regions. The aims of this work will include the following actions: **1)** Studying the Miocene carbonate outcrops in the Cyrenaica Basin and its offshore extension as an analogue to understand the rock properties of the Miocene play for future exploration, **2)** Present the Miocene succession in different African countries (Morocco, Algeria, Egypt, and Lebanon) with examples from West and South Africa to see its distribution and characteristics. Integration of the data gained from the handheld Gamma ray logs, stable carbon isotopes, sequence stratigraphic approach, and diagenetic history of the Miocene sediments will help us understanding the porosity of the reservoir rock and envisage whether it is constructive or destructive. The preliminary results, according to the surface analogue study, the Miocene petroleum system parameters can be recognized:

- Three reservoir facies (Oolitic grainstone, Cline red algae, and Microbial facies).
- Potential good seal represented by the Miocene Evaporite Section.
- Potential source rock indicated by high positive Carbon excursions in the Middle Miocene section (organic matter maturity needs to be proved for production).

Based on the preliminary surface analogue work, Reservoir rocks, Seal, and Organic productivity are already confirmed in the Cyrenaican Miocene rocks.

Keywords: Cyrenaica, Mediterranean, Offshore, Petroleum

The International Union of Geological Sciences (IUGS) and Global Geoscience development: What options for African Geoscientists?

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Abstract

Extending from the Mediterranean to the Southern Ocean, Africa contains vast deserts, tropical rainforests and savannahs, enormous mineral and energy resources, remarkable geological features and settings; it also faces the global challenges of today: exploitation of mineral resources and the environmental degradation and social impact that exploitation often entails, climate change with life-threatening droughts, and sustainability of growing populations. Geology plays the underlying role in all these challenges and in addressing them, IUGS must become more involved in Africa and worldwide. IUGS - a non-political, non-governmental, and non-profit organization - is one of the world's largest scientific bodies with a global membership of a million earth scientists from 123 countries/regions. The activities, projects, products, and endeavours of IUGS are generated by several hundred voluntary and unpaid members and officers, whose dedicated service is the heart of IUGS; most of the work is carried out in commissions, task groups, initiatives and joint programmes. Almost all benefit from the contributions made by members and officers from African countries, but nevertheless increased participation in IUGS activities is encouraged considering the importance of Africa as a continent. The Commission on Geoheritage (ICG) included 15 African locations in the "First 100" IUGS Geological Heritage Sites, and another 17 are being considered for the "Second 100". The Commission on Stratigraphy (ICS) approved the Global Stratotype Section and Point (GSSP) for the base of the Eocene Series/Epoch in Egypt, and the GSSP for the Cretaceous/ Palaeogene (Mesozoic/Cenozoic) boundary in Tunisia. Future efforts to refine the geologic time scale for the Archaean and Proterozoic will involve orogenic belts and the stratigraphic succession of southern Africa. Five African colleagues are regional representatives to the Commission on Global Geochemical Baseline (CGGB), which supports data collection for the Africa Geochemical Database programme, and the Commission on History of Geology (INHIGEO) includes 11 members and officers from 5 African countries. The Commission on Geoscience Education (COGE) with board members from Morocco and Egypt is training field officers who, in turn, will train earth science teachers. The Commission on Geoscience Information (CGI) collaborates with the Geoscience Information in Africa - Network (GIRAF) and includes members from 20 African countries. The IUGS Initiative in Forensic Geology, which provides training to law enforcement agencies worldwide with programmes on illegal mining and trafficking in metals and minerals such as a "Clean Gold Programme", still must develop its activities and membership in Africa. IUGS also supports early career geologists from Africa through its Hutchison Young Scientists Foundation travel awards and its financial support of projects in the IUGS-UNESCO International Geoscience Programme (IGCP). The Geological Society of Africa is an affiliated member of the IUGS. African countries are represented by members of the IUGS Executive Committee. The annual meeting of the IUGS Executive Committee will be held in Nairobi, Kenya, in February 2024, and will include a two-day event - "IUGS in Africa; Africa in the IUGS". It will be co-organized and co-sponsored by the Geological Society of Kenya, IUGS and the Geological Society of Africa. The Executive Committee will use the event to fully understand the global challenges facing Africa, to facilitate increased participation of African geoscience communities in IUGS activities, and to develop strategies to address global challenges with these communities.

Keywords: IUGS, Africa

UNESCO and Geosciences for 50 years for a sustainable future for our planet with a special focus in geosciences research and education in Africa

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Abstract

The United Nations Educational, Scientific and Cultural Organization (UNESCO) is an intergovernmental organization whose mandate includes contributing to peace and security by promoting scientific collaboration among nations. As such, UNESCO is the only United Nations (UN) body responsible for managing science matters. Since UNESCO's creation in 1945, its Natural Science sector has been involved in ambitious and successful projects in earth and environmental sciences, including its International Geoscience and Geoparks Programme (IGGP). Geoscientists are essential for ensuring appropriate delivery of Sustainable Development Goals (SDGs) in 2030, particularly due to the science intensive nature of the SDGs in emphasising research, innovation, capacity building, and technology transfer. This includes utilising earth sciences to better understand and manage the natural environment basis of many of the SDGs. Knowledge of the Earth's structure, its processes, and resources, will allow informed decision making to facilitate policy and practice for sustainable development. The International Geoscience Programme (IGCP) acknowledges the importance of addressing these challenges and support of the advancement of the 17 United Nations' Sustainable Development Goals (SDGs) is addressed through its projects. Through their flagship programme IGGP, UNESCO in partnership with the International Union of Geological Sciences (IUGS) and Global geoparks network (GGN) are committed to contributing to the implementation of UN SDGs with a special focus on empowering women and enabling international collaboration. Geoscientific expertise is critical in understanding the Earth's processes, identifying mineral resources, and managing natural hazards. However, geoscientists in developing countries face many challenges, including limited funding, training, and technology. The IGGP projects were always delivered through international collaboration and in 2023 IGGP launched a new survey aiming to assess the needs and priorities of African geoscientists, to better understand and address these challenges. The survey is part of a new project of the UNESCO IGGP, entitled Fostering Researchers in the Geosciences (FoRGe) under Geology for Sustainable Development project (IGCP 685). FoRGe aims to build research capacity in developing countries by responding to needs identified by researchers in those countries and by working in collaboration with educational institutions. The survey aims to identify the nature of work and challenges faced by African geoscientists, by gathering their views on the skills and knowledge required for effective practice. The survey will also provide insights into the state of geoscience professions in Africa, including the availability and use of technology and equipment, the impact of training and education quality on wider career, and the availability of funding for research and development.

The FoRGe survey is a critical step towards improving the status of geoscientists in Africa. By identifying the challenges and needs of the profession, the survey will enable FoRGe and UNESCO to develop tailored interventions to support the work of geoscientists. In addition to its Africa priority, which seeks to support sustainable development and preservation of natural and cultural heritage in Africa, UNESCO also promotes scientific cooperation and knowledge-sharing across borders. Through IGGP, UNESCO promotes and coordinates geoscientific research, and facilitates the exchange of knowledge across national boundaries.

Keywords: UNESCO, Sustainable development, Geoscience in Africa

Direction and Timing of Subduction and Continental Collision in the Pan-African Damara Belt of Namibia

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Abstract

D₁ and D₂ nappes, thrusts and stretching lineations in the Southern Margin Zone (SMZ) accretionary prism and D₂ sheath folds and stretching lineations in the southern Central Zone (sCZ) indicate NNW over SSW compression during NNE-directed transpressive subduction of the Southern Zone (SZ) and the Kalahari Craton below the leading, active margin (sCZ) of the overriding Congo Craton. The compression direction was simultaneously rotated or deflected to N-S towards the northern margin of the belt where massive north-directed overthrusting, nappe formation and sheath folding took place at the northern edge of the Northern Zone (NZ). D₁ is dated at 598-594 Ma in the NZ and is post-dated by 573-567 Ma gabbros and diorites in the sCZ. By this time, a fore-arc trench existed in the SZ in front of the active margin of the Congo Craton. This trench was the depository for syntectonic trench-fill greywackes derived from the sCZ and the South American active margin approaching from the west. The trench shallowed onto the downwarping, leading edge of the Kalahari Craton where Nama foreland deposition on the Southern Foreland (SF) had already started. The lower Nama siliciclastic Nama sediments contain detrital muscovites derived from South American and sCZ sources. The basal Nama limestones contain the 570-Ma Shuram carbon isotope anomaly. Syn- to post-D₂ granites in the sCZ have ages of 564-556 Ma. Orogen-parallel D₃ domes in the sCZ with a $s_{CZ}S_3$ foliation suggest a rotation of the subduction direction from transpressive NNE to orthogonal NW. Ages of syn- $s_{CZ}D_3$ granites containing the $s_{CZ}S_3$ foliation range from 556-542 Ma. A 539-Ma sCZ granite is unfoliated. The $s_{CZ}S_3$ foliation is continuous from the sCZ into the SZ. SZ orogen-parallel structures become SE vergent southwards, isoclinal and culminated during NW over SE transport in thrusting and sheath folding in the accretionary prism of the Us Pass Suture that marks the southern margin of the SZ. SZ and sCZ D₃ deformation episodes are considered to be coeval, i. e. 556-542 Ma. The fore-arc Donkerhuk Granite Batholith has structural and metamorphic aureoles that overprint SZ structures and the post-tectonic ± 535 -Ma M₂ assemblages. Ages of the oldest Donkerhuk granites lacking a regional foliation are 536-534 Ma. Volcanic ashes in the upper parts of the Nama foreland succession young upwards from 548.8 Ma to 543.3 Ma. These are coeval with the younger syn- $s_{CZ}D_3$ granites. An ash at the base of the overlying, red, Nomtsas Formation and Fish River Subgroup molasse has an age of 539.4 Ma. The 4 million year unconformity separating the foreland rocks from the overlying molasse succession is interpreted as marking the time of continental collision. Thus, the youngest sCZ granite with the $s_{CZ}S_3$ foliation (542 Ma), the oldest unfoliated sCZ granite (539 Ma), the peak of post-tectonic M₂ metamorphism (± 535 Ma), the post-tectonic structural and post-M₂ thermal overprint of the Donkerhuk Granite Batholith in the SZ (536 Ma and younger), and SF ashes all suggest that continental collision in the Damara Belt occurred between 542 and 539 Ma. Subduction lasted about 60 million years.

Keywords: Damara Belt, Subduction, Transport direction, Continental collision, Geochronology, Namibia

Medical Geology: what is it and how it can help to achieve the 2030 UN SDGs goals in Africa?

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Abstract

The world in general and Africa in particular, are facing serious interlinked health and geo-environmental challenges stemming from geological processes, materials, and factors, in addition to mining activities. From a geological point of view, the African continent where Medical Geology research is most required, is characterized by a very complex and dynamic geological history and evolution including frequent earthquakes and volcanic eruptions in tectonically active regions. This is in addition to water toxicity due to interaction with the geological environment including rocks and soil as well as air pollution due to dust storms especially in dry parts of the continent. Furthermore, the continent is known for its mining activities and petroleum exploration, which enhance the release of chemical elements and inhalable nanoparticles of minerals into the environment. These geo-environmental challenges require a holistic approach to mitigate their fatal consequences. From a health point of view, the African continent is known for high rates of non-communicable (NCDs) diseases such as cardiovascular and chronic respiratory tract diseases as well as cancer and diabetes. These diseases account for up to and over 40% of deaths in some African countries. In addition, globally, Africa still bears the highest neonatal mortality rate and the highest maternal mortality burden. However, the primary causes of such diseases and mortality remain unclear in many cases and attention is mostly given to risk factors and treatment rather than possible causes. Medical Geology, a fast growing multi/cross/inter-disciplinary field of science, focuses on these challenges and provides solutions and mitigation measures while addressing several SDGs through partnering (SDG 17) with experts from various fields of science. Identification of the geological sources of toxic and potentially harmful elements in the environment, which are transferred to human/animals body through food, water and air, as well as areas lacking essential elements for healthy living, is necessary to reduce the health impacts caused by such anomalies and ensure human and animal well-being in line with SDG 3, while the development and computing of predictive geospatial distribution modelling and techniques for their removal is required by SDG 9. Furthermore, in order to achieve SDG 6 and 7 and to prevent associated health risks, it is important to assess the nature and composition of water and energy sources for daily consumption. The continuous demand of safe and adequate water and energy grows continuously due to population increase, especially in Africa. Consequently, communities, especially in rural areas, often consider unsafe alternatives (uncontrolled water sources and burning of coal), which might contain harmful chemical elements with potentially serious short- and/or long-term health impacts. Therefore, their assessment is necessary in order to prevent health damage and to create a safer living environment. Training postgraduate students in medical geology, which aims to understand the geo-environment and its health impact on humans, animals and ecosystems in general, is necessary. Students should learn knowledge integration not only within geology but also with other disciplines. Furthermore, through community engagement, medical geology programmes can also contribute to the education of rural communities, who depend on their natural environment for a living, which is in line with SDG 4. The association of “geology” mainly with mining, a traditionally “male field”, might be a contributing factor in female under-representation in higher education and research sectors within geoscience globally and in Africa specifically. Therefore, incorporating “health” into the geoscientific disciplines might help to change this perception and achieve gender equality in line with SDG 5.

Keywords: Medical geology, 2030 UN SDGs goals, Africa, Diseases, Geo-environmental challenges

Artisanal and small-scale mining in Africa: Re-imagining the future with geology in mind

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Abstract

The artisanal and small-scale mining (ASM) sector in Africa is large, with estimates of about 9 million people directly involved. Globally ASM is a source of employment for more than 40 million people and contributes approximately 20% of the annual gold production, ca. 15-20% of cobalt, 20% of diamonds, as well as 80% of coloured gemstones and 25% of the tin production. The ASM sector is also key in the production of a variety of industrial minerals and construction materials, which are linked to local economies. There are opportunities for ASM in the future of the African mining sector driven by the African Union's (AU) developmental imperatives as reflected in the "African Mining Vision" (AMV) "Agenda 2063, the Africa we Want" and the "African Continental Free Trade Agreement", amongst others. However, it is disconcerting that in spite of the importance of the African ASM sector to global mineral supply chains, there is limited systematic approach to generation of geological knowledge and its strategic applications to support the development of the sector. For this to change specific interventions are needed which evaluate geological information to set aside opportunities for the ASM sector. Such information can be obtained from existing geological archives such as are maintained by national geological surveys or similar entities. The geological data may also come from exploration programmes, specifically targeting ASM, or as a result of industrial-scale exploration campaigns, in the form of reporting required by mining law. A potential source of geological data that is often overlooked is ASM activities, though ironically industrial-scale exploration reportedly uses ASM activities as indicators of mineralization. The major setback with ASM activities is that there is no systematic exploration of the ore deposits and the geological data gathered is inadequate and/or not stored to allow long-term planning and adequate mining development. This paper attempts to provide answers to some of the information required to formalize ASM activities that generate ecological data in elevating ASM activities. The Harare Greenstone Belt hosts substantial shear-hosted gold deposits, some of which are the basis of major gold production in Zimbabwe. A study of the historical exploitation of small deposits provides us with an opportunity to determine, if and how useable geological data was generated, stored, accessed and applied. The study makes a case for the importance of a strategic link between the generation of geological data and its provision to support ASM formalisation for desired developmental outcomes in the future.

Keywords: Artisanal and small-scale mining, African Mining Vision (AMV), African Continental Free Trade Agreement (AfCFTA) policy, Geological data, Harare Greenstone Belt

Africa's Critical / Strategic / Green Minerals, Distribution and Potentials: Imperatives for Value Chain Development

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Abstract

The world is about to witness a revolution in the digital, energy and transport system. For example, countries and developmental organisations (global and regional) ratify a raft of new laws and guidance on the adoption of the Electric Vehicle (EV) as an alternative to the Internal Combustion Engine (ICE) in a bid to cut down on the use of fossil fuel. Thus, the search for mineral raw materials that will be the main driver of these revolution is absolutely necessary.

The solution now and for the foreseeable future which will be low carbon emission driven critical components such as the Lithium Ion battery (LIB), which uses several mineral raw materials among them being Lithium and Cobalt (Li-Co), manganese, nickel, aluminium, graphite, REE, iron, Ta-Nb-Sn, W copper as well as phosphate and beryllium ore. These are german for the emergent digital revolution. These minerals, especially Li-Co metals and REEs, due to their relative scarcity / high supply risk have been classified as critical and are therefore regarded as the drivers of the emerging industrial trend. Their growing demand is driving these minerals and their processed products prices to astronomical levels, and this can be the game changer in economic development of countries endowed with deposits of these minerals.

In Africa, many countries are endowed with these minerals, which calls for their development in a bid to participate and benefit from this opportunity. In addition to export earnings, African countries aspire to derive greater economic value from their mineral resources and one of the assured ways is through linkage development (backward, forward and side-stream). Beside the resource endowments, other critical factors include international trade environments and their impact on the continent's/country's ability to successfully leverage its competitive advantage.

In view of this, a value chain analysis is a useful tool to avail options and permit assessment of policy trade-offs. Policy imperatives towards actualising the maximisation of the African potentials are highlighted in this presentation. These include promoting national and regional mineral exploration, developing smart partnerships with fully critical minerals integrated companies, development of strong financial institutions and funding imperatives. Establishment of Market Intelligent Unit (MIUs) for minerals at the continental level, strengthening of National Geological Surveys to establish Mineral Information Systems. Others include resourcing the African Minerals Development Centre (AMDC) to coordinate development of strategy for critical Minerals are options suggested. The regularisation and formalisation of artisanal and small-scale mining of these critical minerals especially are also considered.

Keywords: Value chain, Critical minerals, Lithium, Cobalt, Electric Vehicle

Crustal evolution and a tectonic framework for mineral deposits

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Abstract

It has long been recognized that mineral deposits are not randomly distributed, either in time or in space, and that broad patterns exist when relating deposit types to crustal evolution and global tectonic setting. Most of the world's great mineral districts and deposits are the products of a fortuitous, but focused, superposition of geological processes that resulted in anomalous concentration of metals, usually over a relatively short period of geological time. The understanding of crust-forming processes and the plate tectonic paradigm have become indispensable to the study of metallogeny, and this presentation summarizes ideas that relate the formation of ore deposits to global tectonics and continental evolution. Thus, ore deposits vary as a function of both their tectonic setting and the geologic time when they formed. As examples, “*orogenic*” ores (including orogenic gold ores, volcanogenic massive base metal sulphides (VMS), and the porphyry-epithermal family of base and precious metal deposits) were preferentially formed, or better preserved, either in the late stages of the Archaean Eon (between 3000 and 2500 Ma) or in the Phanerozoic Eon (between 541 Ma and the present day) (Figure 1). By contrast, the Proterozoic Eon, between 2500 and 541 Ma, preserves fewer of these types of deposits and so-called “*anorogenic*” magmatism (such as anorthosite hosted Ti deposits and the Olympic Dam and Kiruna type Fe oxide–Cu–Au, or IOCG, ores), as well as sediment hosted ores (such as SEDEX type Pb–Zn–Cu(-Ag–Au) deposits and stratiform “red-bed” type Cu deposits), are preferentially hosted in Proterozoic rocks (Figure 1).

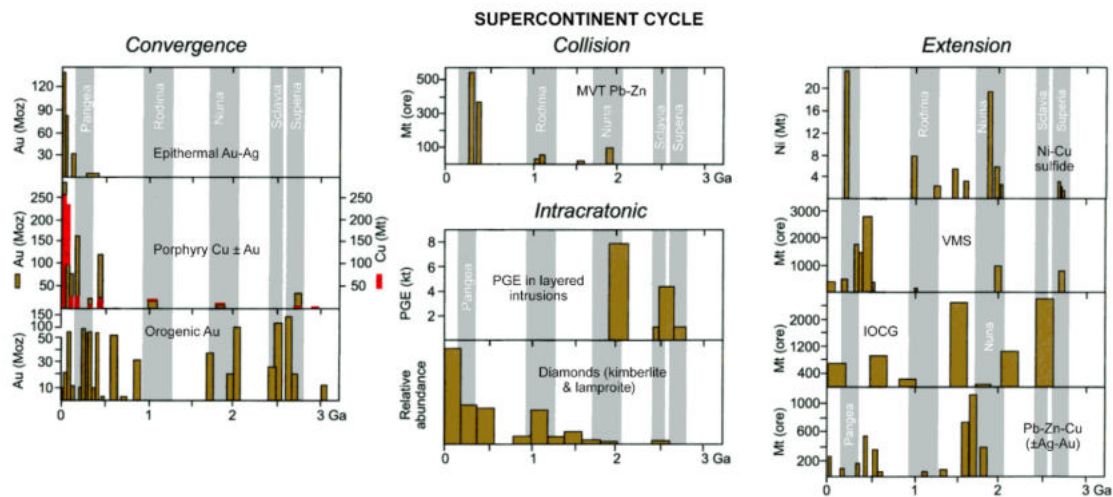


Figure 1: Temp distribution of ore deposit types as a function of the assembly and dispersal of supercontinents. Periods of supercontinent amalgamation are shown as grey bars (with increasing age Pangea – Rodinia – Nuna – Slavia – Superia).

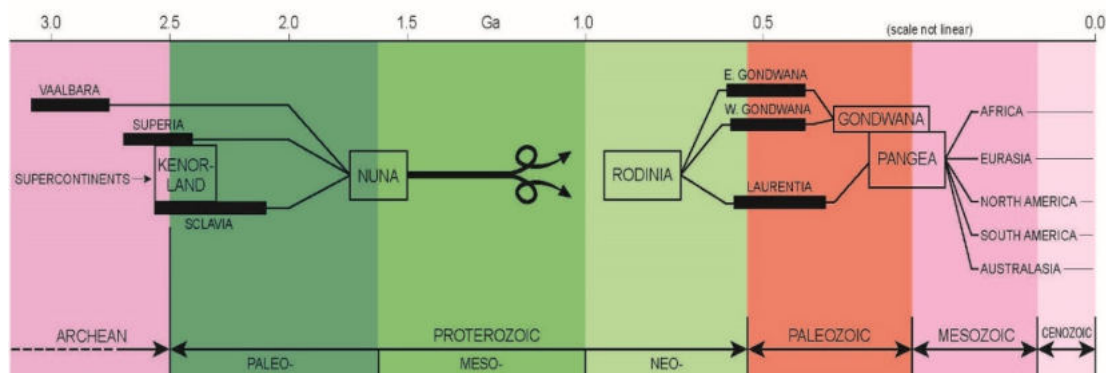


Figure 2: Scheme showing the timing of amalgamation and dispersal of supercontinents (boxed) as a function of geologic time. Note that for clarity the time scale is not linear.

The so-called “supercontinent cycle”, describing the broad scale amalgamation and dispersal of the major continental fragments with time, is shown in Figure 2. The periodic amalgamations of supercontinents - such as Nuna in the Mesoproterozoic, Rodinia in the Neoproterozoic, and Pangea in the early Mesozoic - coincided with times of relative continental stability and peaks in the production of anorogenic and continental sediment-hosted metal deposits. Periods of widespread continental fragmentation, by contrast, appear to be orogenically more active and gave rise to an entirely different suite of ore deposit types that include porphyry and epithermal base/precious metal deposits, as well as orogenic gold systems. The existence of supercontinents, and the cycles within which continental fragments coalesce and disperse, is fundamental to all Earth processes, including metallogeny. On a global scale, therefore, and across geologic time as a whole, crust formation has followed a linear evolution from Hadean to present that defines the current continental configuration. Ore deposit types on the other hand are best subdivided according to whether orogenic processes were predominantly convergent or divergent-and clearly reflect the cyclical pattern of supercontinent assembly and dispersal.

Keywords: Crustal evolution, Mineral deposits

Precambrian Geology of Central Africa: insights from past and recent geochronological data in various critical areas**S. Felix Toteu***Earth Science Specialist, Cameroon*sftoteu@yahoo.fr**Abstract**

The Central African Fold Belt (CAFB) is the least well-known of all major Pan-African belts. However, there have been important progresses during the last decades, mostly as the result of various geological mapping projects and geochronological dating. This presentation covers these progresses in various critical areas of western Central African Republic, the region standing between northern Cameroon and southwestern Chad, and southern Cameroon. We are able today to: (1) clarify the regional extension of the Congo Craton in SE Cameroon and in the SW Central African Republic; (2) demonstrate that the units thrust along the northern edge of the Congo Craton from Cameroon to the Central African Republic are comparable in nature and in age; (3) better constrain the limits and described better the role of the Adamawa-Yadé crustal block during the Pan-African pre-collisional and collisional events in relation to the Congo Craton and the Yaoundé-Yangana nappe units to the South, and to the Poli-Léré magmatic arc to the North and; (4) clarify some of the elements of correlation with NE Brazil. Overall, a model involving two subduction zones is proposed to explain the evolution of the Pan-African belt north of the Congo Craton. The main steps include; (1) break-up and basin development from the early Tonian to at least 620 Ma on the northern edge of the Congo Craton, and on both the southern and the northern edges of the Adamawa-Yadé Block, concomitantly with the development of the Poli-Léré arc in northern Cameroon and Chad; (2) pre-tectonic plutonism in all domains since c. 800 Ma with culmination between 650 and 620 Ma; (3) collisional events starting around 620 Ma with metamorphism reaching the granulite facies at c. 600 Ma in all the domains; (4) nappe tectonics with thrusting of the Yaoundé-Yangana units onto the Congo Craton, accretion of the Poli-Léré arc to Adamawa-Yadé Block, and widespread syntectonic magmatism (600–580 Ma) with emplacement partly controlled by transcurrent regional shear zones, and emplacement of post-tectonic granitoids (c. 550 Ma) in both Adamawa-Yadé block and Poli-Léré magmatic arc. Collisional and post-collisional (620–550 Ma) events were synchronous along the entire belt from Central Africa to Brazil.

Keywords: Central African Fold Belt, Pan-African belts, Geochronology

ST01: THE AFRICAN GEOLOGICAL RECORD, PALAEOLOGY, ANCIENT ENVIRONMENTS AND PALAEOCLIMATES

ST01_S01: Palaeontology, ancient environments, and palaeo-climate

Palaeoclimatic and geological evolution of the Quaternary sedimentary environments of the Ouémé delta in Benin (West Africa)

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Abstract

The main transgressive and progradative systems in which the marginal-litt environment evolve were mainly determined by glacio-eustatism during the Quaternary. This work aims to reconstruct the spatio-temp evolution of the climatic and geological palaeoenvironment of delta sediment deposits. Small cores of 3.4 to 10 m were carried out using a manual core drill from the Benin Office of Geological and Mining Research (OBRGM). To retrace the evolution of the palaeoclimate, a systematic sampling over a step of 15 cm was carried out from a core carried out using a corer. Granulometric analyzes were carried out by sieving on series of sieves of the AFNOR NFX 11504 module and by sedimentometry according to standard NF P 94-057. The heavy minerals are separated in the bromoform, mounted on a slide and identified by a polarizing microscope. The chronology of deposits is based on ¹⁴C dating. After identification of pollens and dinocysts from core sediments, relative frequencies and qualitative thermophilic indexes were determined. This work reveals that the palaeoenvironment of the Ouémé delta was quite dynamic during the Holocene. This dynamism initiated around 7200 years B.P. following the increase in the eustatic level was one of the factors favoring the accumulation of a thick layer of detrital sediments. At the expense of a lagoon basin, marine, fluvial, fluvio-marine environments have succeeded or even interconnected. These changes in the sedimentary environment are linked to alternations of cool climate and hot climate. Cool episodes are marked either by an improvement in productivity, or by a slowing of the eustatic rise with the spreading of fluvial sediments. The maturity of the deposits leading to the current morphology of the delta takes place during the Late Holocene regression. Lagoon and river environments now in place coexist until the present day in a generally dry and cold climate. Progressing towards the “Lake Nokoué-Porto-Novo lagoon” lagoon complex, fine deposits from the delta plain bury the mouth and channel bars. The importance of productivity during the Upper Holocene is linked to the nutrient inputs of the Ouémé River; which have no doubt been intensified by human activities.

Keywords: Palaeo-environment, Palaeoclimate, Sediment, Ouémé delta, Benin

An upper molar of *Namadapis* (Primates, Adapiformes, Middle Eocene, Namibia)

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Abstract

An upper molar found during acid treatment of blocks of Lutetian freshwater limestone from Black Crow (Sperrgebiet, Namibia) has dimensions and morphology that indicate that it likely represents the same species as the holotype mandible of *Namadapis interdictus* (Adapiformes). The cusps are tall and pointed with sharp crests emanating from their summits, all of which accord with the well-developed crests that occur in the lower molars of *Namadapis* (Godinot *et al.*, 2018). Whilst the lower molars of this species appear to be quite similar to those of *Adapoides troglodytes* from Shanghuang (Lutetian, China), the new upper molar is markedly different from those of the latter species. It possesses a large hypocone, two well-formed conules and its metaconule, which is voluminous, pointed and isolated by two grooves, differs radically from the curved and continuous postprotocrista of *Adapoides*. These two species thus belong to distinct groups of adapiformes. The large metaconule in the new tooth resembles that of *Notnamaia* from the same locality, which suggests that they are probably related forms. The cristodont features of the molar of *Namadapis* confirms the relationships of these two Namibian species to taxa (*Aframoni*, *Masradapis*, *Afradapis*) from somewhat younger deposits in the Fayum (Egypt) previously included in the Caenopithecinae. However, the new specimen indicates that appurtenance to this family is unlikely and that the African group had a separate origin at an earlier time than the previous discoveries suggested.

Keywords: Primates, Adapoid, Middle Eocene, Biogeography, Taxonomy

Reference:

Godinot, M., Senut, B. and Pickford, M. 2018. Primitive Adapidae from Namibia sheds light on the early primate radiation in Africa. *Comms. Geol. Surv. Nam.*, **20**, 140-162.

Deep Time Conservation Palaeobiology of the Angola-Benguela Frontal Zone

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Abstract

The cool Benguela Upwelling System is bounded to the north by the warm, nutrient poor, south flowing, Angola Current, the boundary forming the Angola-Benguela Frontal Zone (ABFZ). The ABFZ is dynamic, occasionally shifting southward by incursion of the Angola current along the shore, resulting interannually in a Benguela El Niño, which influences climate and productivity. A persistent Benguela El Niño has been proposed for the warm Late Pliocene, which is considered a likely analog for a future warming Earth. Furthermore, climate models predict poleward migration of atmospheric high-pressure Hadley cells and weakening of equatorward upwelling. Coastal outcrops between Piambo and Bentiaba, Angola, present an unparalleled stratigraphic record of the opening and growth of the central South Atlantic Ocean. Bentiaba, now located alongside the ABFZ at approximately 14° S latitude, has produced a rich and diverse marine reptile fauna (approximately 71.5 million-years-old, Early Maastrichtian, Late Cretaceous). Here we use published proxies of Hadley Cell palaeo-geographic extent through time with palaeo-latitude, palaeo-temperature, and other data derived from Bentiaba and elsewhere to discern probable upwelling along the southwest African coast since the Cretaceous in order to provide a conservation palaeobiology component to the consideration of its future. Fossil localities lie in predicted palaeo-latitudes of high-pressure cells, suggesting a variable but persistent component of wind-generated upwelling. A concern with regard to continued productivity of the Benguela Current is the possibility of longer and more frequent Benguela El Niños, with south-flowing warm water incursions of increasing magnitude, brought about by higher global temperatures, resulting in reduced productivity.

Keywords: Cretaceous, Benguela, Marine reptiles, Upwelling, Angola

What detailed sedimentology, mineralogy, geochemistry and innovative geochronology tell us about Kalahari sediment provenance and the Cenozoic palaeoclimate: the western Kalahari Basin of northern Namibia

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Abstract

A continuous 400 m core from the thick Kalahari Group sediments of northern Namibia was analysed in detail. Sedimentological, geochemical, mineralogical, granulometric and hydraulic data reveal the Cenozoic sedimentary history, palaeoclimate and palaeogeography of the region. U/Pb ages of uranium trapped in calcrete nodules in the sediments show that the core covers almost the entire Cenozoic. Two stacked megafans are distinguished. The older, red and clay-rich Olukonda Megafan sediments were sourced from mafic rocks, potentially the Kunene Anorthosite Complex, the end-Cretaceous African Surface regolith and pedogenic calcretes in the northwest, and was deposited by a palaeo-Kunene River flowing towards the southeast and east under semiarid climatic conditions. The capture of the Kunene towards the Atlantic during the Eocene resulted in a complete change in provenance. The overlying Cubango Megafan (Andoni Formation) was sourced from felsic metamorphic and granitoid rocks and transported from the north by the Palaeo-Cubango River. Detrital zircon U–Pb data confirm two distinct provenances, one with mainly Palaeoproterozoic and Mesoproterozoic rocks for the Olukonda Megafan and one with a wide range of Archaean to Neoproterozoic rocks of eastern Angola for the Cubango Megafan. Despite the distinct differences between the source regions of the megafans, the temporal hiatus between them must have been short. Long, contrasting climate intervals resulted in deposition of sediment packages with greater and lesser amounts of clays. These intervals form, respectively, the aquitards and the all-important fresh-water aquifers within the Kalahari succession.

Keywords: Sediment provenance, Cenozoic palaeoclimate, Kalahari Basin

Fossil Evidence of a Death Trap at Ozombindi, Northwestern Namibia

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Abstract

The Kaokoland is located in the Kunene Region of northwestern Namibia. The area preserves travertine and tufa deposits associated with springs. Small caves developed in some of these deposits in which skeletal remains accumulated (locally with stone tools) indicating that in the past environments and climates were cooler and more humid than they are today. Palaeontological expeditions to Kaokoland in the early 1990s reported Plio-Pleistocene fossils from several localities. In more recent years, plant impressions were discovered at Ongongo Springs near Sesfontein, while a diverse micromammal and invertebrate fauna has been described from sites such as Otjikondovirongo, Otjitaimé, Okongwe (previously called Okozonduno) and Omatapati. Preparation of a sample from the Okongwe cascade tufa yielded the extinct Pliocene rodent *Stenodontomys*, originally described from the Middle Pliocene of Makapansgat and subsequently reported from the Late Miocene - Early Pliocene of Langebaanweg (South Africa), which suggests that the deposit is likely to be Pliocene or older. In 2022 a cascade tufa complex named Ozombindi by the local Ovahimba people, and situated 80 km northwest of Opuwo, was discovered. The site preserves four areas of randomly orientated leg bones and jaws of large mammals in a breccia infilling a former cavity or fissure in cascade tufa. Provisional identifications based on visual observations of teeth suggest the presence of large reedbuck, wildebeest, eland, gemsbok, equids (possibly *Equus capensis*), rhino and hyaenid specimens. While the previously described sites in Kaokoland yielded mostly micromammal and invertebrate fossils and plants, the Ozombindi site preserves only large mammal remains, the taphonomy of which suggests that animals fell into a collapse hole and were unable to escape, resulting in death. Two specimens in the bone breccia, which belong to a hyaena, were found amongst the limb bones of the large bovids and zebras, indicating that the cavity may have served as a death trap also for carnivores, who fed on the trapped herbivores before joining their fate. The occurrence of a giant reedbuck, *Redunca darti* indicates an age range of late Pliocene to early Pleistocene for Ozombindi, as fossils of this extinct bovid have been reported from Makapansgat (South Africa) and Ekuma River (Etosha National Park, Namibia).

Keywords: Kaokoland, Ozombindi, Cascade tufa, Plio-Pleistocene, Namibia

Early Miocene Lovebird from Namibia

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Abstract

Lovebirds (*Agapornis*, Psittaculidae) currently occur in many parts of Namibia including Mopane Woodland and more humid environments (Miombo Woodlands, Savannah), but are rarely encountered in the Namib Desert or in winter rainfall regions. Fossils of this family of small parrot-like birds, also known as parakeets, have been described from the late Miocene of South Africa (Langebaanweg, ca 5-6 Ma) and the Pliocene of Morocco (Ahl-al-Oughlam, ca 3 Ma). In May, 2023, wet-screening of Early Miocene (ca 19-20 Ma) green silts was carried out at Grillental VI, northern Sperrgebiet, Namibia, in order to recover microfaunal remains (rodents, macroscelidids, reptiles, frogs). Several limb bones of small birds were recovered, belonging to passerine and non-passerine species. Close examination of the non-passerine remains indicates that they belong to the Psittaculidae, the humerus and carpometacarpus being close in morphology and dimensions to those of extant and fossil species of *Agapornis*. These fossils currently represent the earliest known remains of lovebirds from Africa. Interpretations of molecular data obtained from extant parrots suggest that *Agapornis* dispersed from Australia to Africa at the end of the Oligocene or the beginning of the Miocene (Manegold, 2013). If the timing of this trans-oceanic dispersal is correct, it would imply that the Grillental VI fossils were preserved relatively soon after the arrival of the genus in Africa. This dispersal took place a long time after a previous dispersal of parrots to Africa during the Palaeogene, represented by *Namapsitta praeruptorum* from the Late Eocene of Eocliff, also in the Sperrgebiet (Mourer-Chauviré *et al.* 2014, 2017). Lovebirds nest in tall trees or crevices in high cliffs, and most species feed on grass seeds while a few feed on figs (Manegold, 2013). The macrofaunal and microfaunal remains from Grillental VI include several lineages (crocodiles, large tortoises, anthracotheres, rhinocerotids, proboscideans, hyracoids, ruminants, suids, carnivorans, rodents, macroscelideans, erinaceids) (Pickford 2008) that indicate that, during the Early Miocene, the region was relatively humid and well vegetated, radically different from the treeless hyper-arid conditions that prevail there today. The presence of *Agapornis* in the Early Miocene sediments at Grillental reinforces these palaeoenvironmental and palaeoclimatic reconstructions. Thus, it is concluded that the Namib Desert originated after the deposition of the Grillental green silts, the onset of hyper-arid conditions probably starting about 17 Ma.

Keywords: Parakeets, Early Miocene, Biogeography

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Palaeontology of Mount Tsaus, Lower Nama Group, southern Namibia

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Abstract

One of the most diversified collections of metazoan soft-bodied, skeletal, and trace fossil records from the terminal Ediacaran Period are found in Namibia's Nama Group, which dates from around 550 to 538 million years ago (Ma). It has been hypothesized that the apparent decrease in global soft-bodied fossil diversity between the White Sea and Nama assemblage biozones is due to an extinction event, which may have occurred concurrently with the deposit of the lowest Kuibis Subgroup. This speculation and uncertainty brought about this research project. New trace fossils surfaced, and the objective is to describe and name them as well as estimate their age so as to find traces of the Cambrian Explosion. An important turning point in Earth's history occurred with the emergence of animal (metazoan) biomineralization, which allowed for the diversification of new animal body plans and biological regulation of the creation of skeletal carbonate sediments as well as a permanent reorganization of the world's carbon cycle. The terminal Ediacaran of the Nama Group, Namibia, is when the earliest known skeletal metazoans, the tubular 'cloudinids' like *Cloudina*, first emerged. However, it is unclear exactly when and why metazoans first developed the ability to biomineralize. Here, we offer palaeontological information from the Witputs Sub-basin, which is exposed in the Tsaus Mountains of the Tsau-//Khaeb (formerly Sperrgebiet) National Park and contains the earliest strata (Dabis Formation) of the Nama Group. The earliest occurrence of *Cloudina* is limited to limestones from the lower Kliphoek Member, which were deposited laterally comparable to the closer fossiliferous Kliphoek quartzite, around 551–550 Ma. These limestones were likely laid down in shallow waters following a change from semi-restricted, evaporative-dolomitic to open marine carbonate environments.

Keywords: Mount Tsaus, Palaeontology, Terminal Ediacaran, Nama assemblage, Namibia

Human Traces - Synthesizing Human Traces in the Stratigraphic record (HUMAN TRACES)

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Abstract

In 2019, the Subcommittee for Quaternary Stratigraphy voted that the Anthropocene should be treated as a formal chrono-stratigraphic unit defined by a GSSP, to be placed within the 20th century. This vote ended the “Anthropocene” debate, but left unchanged the long legacy of pre-Anthropocene human impacts. Although defining a global “golden spike” has chronostratigraphic value, it may lead to the assumption that all major impacts are recent. It does not represent the varied history of human activity with regionally asynchronous impacts that manifested differently in various parts of the world. Pre-Anthropocene impacts have been substantial, and their quantitative understanding is essential to managing the planet with the goal of moving towards sustainability. Lake sediments and other stratigraphic archives serve as long-term records of natural variability and human-induced changes, allowing us to assess responses to change on various timescales and to link them with either climatic or anthropic drivers. They also serve as a way of defining targets/reference conditions for ecosystem management and conservation providing a longer-term perspective for recent global changes in the context of the Anthropocene. There is still a paucity of long-term environmental regional data and a global synthesis of human impacts on lake ecosystems is lacking. The HUMAN TRACES working group under Past Global Changes (PAGES) has over the last two years assembled a research database of published lake geochemical records and aquatic bioindicators that contains sufficient information to establish temporal trends in nutrient and matter fluxes. Further the working group carried out a research community survey, to identify parameters considered essential to a flexible community data resource for sediment biogeochemical records and established a data structure and associated tools suitable for flexible and open access to the data. The Neotoma Paleoecology database was identified as the most appropriate open source resource that supports community curated data to support data management. This was selected as the most appropriate database to integrate the geochemical archives from lake sediments. Further for the pre-Anthropocene, the stable isotopes of lead (Pb) were identified as important sediment markers to track past human impact on geochemical cycles. Currently, there are regional working groups carrying out in depth review of South America and Africa to provide a synthesis of reservoirs and long-term development of anthropohydrocosms as agents of human traces in the environment. This work contributes to the debate on the setting of the stratigraphic division of the formal post-Holocene epoch.

Keywords: Anthropocene, Climate change, Environmental change, Human influence, Geologic time

The Dispersal of Marine Reptiles into the Middle South Atlantic as a Global Geobiological Event

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Abstract

The locality of Iembe, Angola, is important because it produces the oldest examples of mosasaurs and a eucryptodiran sea turtle from the South Atlantic. The locality also produced the first dinosaur remains from Angola. Long thought to be Late Turonian (~90 Ma) in age, discovery of the ammonite *Protexanites* sp. and the durophagous shark *Ptychodus latissimus* at the locality provide new biostratigraphic dating for the fossil-bearing horizon which is no older than middle Coniacian in age (~87 Ma). The mosasaurs from Iembe are most closely related to contemporaneous North American forms, while the eucryptodiran sister taxon is from the Aptian (~122 Ma) of the western Eurasian plate. Recent advances in our understanding the evolution of the Equatorial Atlantic Gateway provide context for understanding this dispersal event. By the close of the Albian (~100 Ma), the Equatorial Atlantic Gateway between the central and northern Atlantic Oceans was opening, and continued for some twenty million years to complete. Earlier stages were marked by poor circulation and inhospitable conditions including hypersalinity. The final stages were accompanied by the introduction of cooler bottom waters and changing oceanographic, and indeed, global climatic conditions. It was within these later stages the Iembe marine reptile fauna appears. Significantly, no mosasaurs or sea turtles are known from the central South Atlantic Ocean until near the completion of the Equatorial Atlantic Gateway.

Keywords: Marine reptiles, Geobiology, Angola

Grinding through the Ediacaran-Cambrian Transition

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Abstract

The Neoproterozoic Era (1000 - 541 Ma) is one of the most dramatic in Earth history: metazoans evolved, the supercontinent Rodinia formed and broke apart, the global carbon cycle underwent high-amplitude fluctuations, oxygen concentrations rose and climate experienced at least two episodes of worldwide glaciation. However, the discontinuous and fragmented nature of outcrop-based studies has hindered developing quantitative models of Earth system functioning during that Era. The *Geological Research through Integrated Neoproterozoic Drilling* (GRIND) project begins to rectify this scientific shortcoming by obtaining 13 cores through the archetype successions that record this environmental and biogeochemical change. The specific targets are the Ediacaran-Cambrian transition (ECT; c. 560-530 Ma) in southern Namibia (Nama Group), strata of west Brazil (Corumbá Group), and South China (Doushantuo, Dengying and equivalent formations). Drilling in Namibia and Brazil is complete, and drilling in China will commence in 2023. The work aims to 1) construct a highly resolved temp framework that will lead to the development of age models for the ECT; 2) refine the patterns of biotic evolution of organic-walled and mineralized microfossils, metazoans and trace fossils, and identify the links between and test hypotheses about biological evolution and environmental change, and 3) by using fresh, unweathered samples, determine the palaeo-environmental and biogeochemical conditions that led to the rise of oxygen and distinguish cause-and-effect relationships and basin-specific versus global-scale secular trends in geochemical and stable isotope patterns. We present sedimentological data from the characterised split cores from Namibia and Brazil, which are permanently archived at an in-country repository as well as the Federal Institute for Geosciences and Natural Resources in Germany. All cores will be available for future research, education and national capacity building activities and mark the first step towards creating an on-shore core archive that will match in stature that of the IODP.

Keywords: Brazil, China, Drilling, Ediacaran, Ediacaran-Cambrian Transition, Namibia

Bentiaba: an exceptional Late Cretaceous marine tetrapod fossil site in Southern Angola

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Abstract

The Upper Cretaceous exposures north of Bentiaba, Namibe Province, Southern Angola, have yielded numerous fossils of a wide variety of marine tetrapods. The excellent preservation of the fossil material makes the Bentiaba site rank amongst the best Mesozoic marine tetrapod sites of the Southern Hemisphere. Here we present an overview of this highlight of Angolan geoh heritage. The majority of the fossils recovered from Bentiaba comes from the lower Maastrichtian 'Bench 19', but other parts of the section also yielded numerous fossils. To date, ten mosasaur taxa were recognized, two species of plesiosaurs, and four clades of marine turtles. Also, pterosaur remains, and a rich shark and fish fauna have been recovered. The diverse fauna, the excellent state of preservation, the fact that a great number of fossils are preserved as associated or even articulated skeletons, the relative ease of excavation, and evidence of species interactions, has enabled numerous display and public engagement opportunities since the start of the excavations in 2005. Currently, a selection of fossils is on display at a special exhibition at the Smithsonian Institution in Washington DC, USA, and with the support of the Dutch Mondriaan Foundation, a composite skeleton of a large mosasaur is being reconstructed for display purposes in Angola and elsewhere.

Keywords: Late Cretaceous, Tetrapods, Mosasaurs, Angola

Taphonomy of Middle Triassic bone accumulations in the Ruhuhu Basin Manda Beds of Tanzania: evidence for pluvial episodes?

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Abstract

In the aftermath of the End-Permian mass extinction the speed of recovery of terrestrial ecosystems worldwide is hotly debated. In the main Karoo Basin of South Africa recent research has demonstrated that there was considerable climatic instability through the Induan and into the early Olenekian which affected the tetrapod populations and their ability to attain the diversity of pre-extinction ecosystems. We report new data on the climate, palaeoenvironments, and burial history of tetrapod fossils in the Middle Triassic Lifua Member of the Manda Beds (Songea Group) of southern Tanzania that reinforces the findings from South Africa. Two bone-bearing intervals have been identified, both hosted by rubified floodplain mudrocks deposited alongside rivers that flowed from the Ruhuhu rift scarps into a series of subsiding basins under a warm, seasonally wet climate. The lower occurrence is a bonebed containing fossils of a large dicynodont (*Dolichuranus*), large cynodonts (*Cynognathus*), temnospondyls, small reptiles, and at least two archosauromorph reptiles. A chaotic melange of semi-articulated, disarticulated, and reworked bones associated with pedogenically mottled sandy siltstone is interpreted as having accumulated in a distal crevasse splay complex. The bonebed is noteworthy for preserving *Dolichuranus* individuals spanning a range of sizes and ontogenetic stages; ongoing taphonomic and geochemical analyses will test whether the specimens accumulated during a single depositional event. The middle to upper Lifua bone accumulations are associated with floodplain pond and sheetwash deposits. Outcropping as isolated patches of strongly calcified rubified mudstones with lenses of reworked glaebule conglomerate, these accumulations contain partially articulated archosaur (*Asilisaurus*, *Nundasuchus*) and cynodont (*Scalenodon*) skeletons along with disassociated and fragmentary cynodont remains referable to *Luangwa*, *Aleodon*, *Cricodon*, and *Mandagomphodon*. Vertebrate coprolites and nonmarine bivalves ('Unio') are also found. Changes in floodplain facies, faunal assemblage, and taphonomic style between lower and middle to upper Lifua strata are similar to those recorded between the middle and upper Burgersdorp Formation (subzones B *Trirachodon-Kannemeyeria* to C *Cricodon-Ufudocyclops* of the *Cynognathus* Assemblage Zone) of the main Karoo Basin of South Africa. We propose that an increase in mean annual temperature and rainfall in southwestern Gondwana during Early to Middle Triassic times resulted in vegetated, semipermanent water bodies in the floodplain depressions that supported a relatively diverse assemblage of herbivorous dicynodont, cynodont, and early archosaur populations.

Keywords: Mid-Triassic, Bone accumulations, Floodplain environments, Pluvials, Tanzania

Recent drainage reversal in the highlands of Angola

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Abstract

The Bié Highlands of central Angola are the source region of several major rivers, including the Kwanza, Lungu-Bungo, Kwango, Cubango and Kunene. A puzzling feature of the highland is that a considerable portion is not underlain by basement, typical for an interior highland, but rather by younger sediments deposited since the breakup of Gondwana some 132 million years ago. The sediments would have been deposited in a topographic low and therefore the basin must have since been uplifted/inverted so that the original low is now a highland. One of the deepest sub-basins now sits in area of high topography which are now pervasively dissected by rivers which drain away from the central highlands. The amplitude of the topography is however low. Timing of this uplift is debated and will be discussed here. The highlands have the overall form of a half-dome rising some 500m above the plain to the east and south. The maximum width is some 650 km. Valleys are remarkably straight and incised by up to 400m, but within valleys the rivers meander and form broad floodplains. The catchment divide between the Cubango and Kwanza Rivers is unusual in that valleys run across the divide with rivers draining both north and south from the watershed. Small lakes are occasionally present on the divide with rivers draining from them in both directions. In the Cubango-Kwango-Lungu Bungu catchments the topography between the valleys is often flat and appears to resemble the remnants of a formerly more continuous plain. The headwaters of many tributaries are characterised by many amphitheatre shaped valleys. The location of the Bié Highland corresponds closely to a free air gravity high. Free air gravity anomalies indicate zones of uncompensated uplift so the high is interpreted here as having formed as a result of recent uplift. Drainage reversal has occurred in the valleys with aggressive headward erosion by the rivers that run north, resulting in their headwaters retreating southwards. This is an ongoing process with the implication that over time the southern catchments of the Cubango-Kwango-Lungu Bengu will become smaller. The migration of the catchments has significant implications for alluvial diamond exploration. The biogeography is also impacted by the dynamic changes that are occurring, in particular the distribution of fish species and ichthyological provinces of southern Angola

Keywords: Drainage reversal, Uplift, Biogeography, Bié, Angola

Nitrogen isotopes through the Lower Nama Group: Constraints on nitrogen cycling at the dawn of complex life and their palaeoenvironment

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Abstract

The Ediacaran Period (635 to 541 Ma) was a time of immense biological transformation and records the transition from a planet dominated by microscopic organisms to a Cambrian world teeming with complex animals. Nitrogen is needed by all living organisms for growth and development and there may be a direct link between the occurrence, past marine nitrogen concentrations, and the evolution of complex, multicellular organisms. In the past years, the fossil records and redox variations during the late Ediacaran in the Nama Basin have been extensively studied, but the nitrogen cycling and its potential relationships with carbon cycle have rarely been dealt with. The nitrogen cycle in the latest Ediacaran Ocean is not well constrained, though in south China similar work has been performed extensively in many sections of early Ediacaran and the Lower Cambrian, but not much is known on the terminal Ediacaran. Thus, this research gives an insight into the nitrogen cycling in the last stage of Precambrian Ocean To evaluate $\delta^{15}\text{N}$ pattern, timing and its implications for eukaryotes and palaeo-environment across the Lower Nama Group in southern Namibia, we used drilled cores from the international *Geological Research through Integrated Neoproterozoic Drilling* (GRIND) project. Thirty mudstone and shale samples were collected and systematically analyzed for $\delta^{15}\text{N}$, $\delta^{13}\text{C}_{\text{org}}$, total nitrogen (NT) and total organic carbon (TOC) contents (20 samples from the Nudaus Formation, 10 samples from the Nasep Member). These represent a range of tide- and delta influenced shoreface environments. The results show generally positive $\delta^{15}\text{N}$ values ranging from +1.4‰ to +3.9‰, but below the modern ocean value (+5‰). The values broadly increase from the lower to the upper Nudaus Formation and Nasep Member, possibly corresponding to decreasing water depth. $\delta^{13}\text{C}_{\text{org}}$ ranges from -24.6‰ to -19.1‰ with no clear stratigraphic trend. The positive $\delta^{15}\text{N}$ values, coupled with $\delta^{13}\text{C}_{\text{org}}$ results, suggest the existence of a stable nitrate pool and an active nitrogen cycling in the late Ediacaran Ocean, which may have provided with bio-available NO_3^- for the early skeletal metazoans. Palaeontological data show that metazoans were thriving in the middle Ediacaran and became even more complex and diverse towards the Cambrian. This suggests that co-existence of a constant nitrate reservoir and moderately oxygenated environment may have facilitated the evolution of large and skeletal metazoans and the initial establishment of a modern-like marine ecosystems in late Ediacaran.

Keywords: Ediacaran, Nitrogen, Nama Group, Evolution, Multicellular organisms

Transient shallow-ocean oxidation associated with the late Ediacaran Nama skeletal fauna: Evidence from iodine contents of the Lower Nama Group, southern Namibia

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Abstract

The terminal Ediacaran interval from ~ 550 Ma to 541 Ma witnessed the first appearance of skeletal metazoans and complex ecosystems in Earth history. This biotic innovation event is thought to be related to increase of oxygen in Earth's surface environments, but many studies suggested that pervasive oceanic anoxia continued through the late Ediacaran and early Cambrian. To further evaluate the redox conditions of the terminal Ediacaran interval and their potential relationship with biotic changes, we analyzed the iodine contents in the Lower Nama Group (~550–547 Ma) from the Driedoornvlagte and Zebra River sections, southern Namibia. The I/[Ca + Mg] values fluctuate from 0.08 to 6.20 $\mu\text{mol/mol}$, with an average of 0.94 $\mu\text{mol/mol}$ in the Driedoornvlagte section and 0.70 $\mu\text{mol/mol}$ in the Zebra River section. High I/[Ca + Mg] values ($> 2.6 \mu\text{mol/mol}$) occur immediately above the boundary between the lower and upper Omkyk Members, with a peak up to 6.20 $\mu\text{mol/mol}$ indicative of well-oxygenated surface waters comparable with those of the modern marine environments. Abundant skeletal fossils including *Cloudina*, *Namacalathus*, *Namapoikia* and trace fossils are observed only in the intervals after the high I/[Ca + Mg] peak. The results are consistent with the interpretation that the Nama skeletal communities grew in oxic ($\text{O}_2 > 20\text{--}70 \mu\text{M}$) and dysoxic ($\text{O}_2 \geq 10 \mu\text{M}$) waters above the chemocline. The I/[Ca + Mg] ratios show significant tempo-spatial variations, which is also consistent with previous studies that suggested redox-stratified terminal Ediacaran sedimentary basins and highly heterogeneous oceanic redox conditions.

Keywords: I/[Ca + Mg], Lower Nama Group, Redox conditions, Ocean oxygenation, Late Ediacaran, Namibia

Spatial Palaeoecological Study of New Bedding Plane Assemblages of the Ediacaran Biota in the Aar Member, Southern Namibia

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Abstract

Rocks deposited ca. 574–539 Ma in the late Ediacaran Period contain the oldest fossils of identifiable animals globally. Despite the description of many Ediacaran fossils in the Nama Group of Namibia over the previous 90 years, huge expanses of rock outcrop remain unexplored, resulting in many undocumented fossil taxa. An *in situ* Ediacaran macrofossil palaeo-community preserved on the underside of a fossil bed of planar laminated to massive sandstone was recently excavated in the fossil-rich Aar Member of the Dabis Formation (Kuibus Subgroup, Nama Group) on a previously unexplored farm near Aus, southern Namibia. This study is the first to investigate an *in situ*, matground community of Ediacaran macrofossils in Namibia, in contrast to previous studies on likely *ex situ* preserved fossils such as *Ernietta*, *Rangea* and *Pteridinium*. Palaeo-ecological examination of Ediacaran matground communities globally has produced important information on community interactions, feeding and reproduction of these organisms, but palaeo-ecological techniques remain largely untested on Ediacaran fossil sites of the Nama Group. This study intends to apply palaeo-ecological techniques to ~2 m² of the new bedding plane assemblages of Ediacaran biota to determine aspects of their mode of life and community interactions. Evidently preserved on the bedding surface in their original life position, these fossils permit collection of palaeo-ecological data that will allow an enhanced and more realistic understanding of the mode of life of Ediacaran taxa, including several new species, immediately prior to the Precambrian-Cambrian transition.

Keywords: Nama Group, Aar Member, Ediacaran Biota, Palaeo-ecology, Matground community, Namibia

Using faunal remains from Bolt's Farm Cave System (Cradle of Humankind) to understand the system's palaeo-environment

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Abstract

The Plio-Pleistocene sites of the Cradle of Humankind (UNESCO site), at Taung and Makapansgat Limeworks, all in South Africa, have yielded a rich collection of macrofauna and an abundance of microfauna. This has been validated by different publications on bovids, primates, carnivores, rodents, insectivores, elephant shrews and birds. The palaeokarst system of Bolt's Farm, Gauteng Province, South Africa, is no different from the above as it is endowed with numerous fossiliferous Plio-Pleistocene deposits. Macrofauna gives information about the past environment at the regional scale because of their high migration capacity. But ecosystems are often complex, mosaic, and to obtain a more precise reconstruction of the past environment, local indications must be considered. This information may concern the entire Cradle of Humankind, the nearby valley or only the site surroundings. Bovid faunal remains are useful in palaeo-ecological interpretations and elucidate contemporary regional environments. Carnivores on the other hand indicate prey size preferences and availability. Microfauna gives information about the local environmental conditions as they do not travel long distances. Fossils such as rodents, *Mylomygale*, *Agama* sp., *Hemachatus haemachatus*, and *Geronticus cf. calvus* have been yielded from Bolt's Farm Cave System and these have also been useful in the reconstruction of the palaeo-environment of the locality.

Keywords: Macrofauna, Microfauna, Bolt's Farm Cave System, Palaeo-environment

ST01_S02: Basin evolution and dynamics**The Geological Characterization of the Bamboesberg Member within the Molteno-Indwe Coalfield in the Eastern Cape Province, South Africa****M. Breakfast^{1*}, A Kenan¹, N. Lenardt², J. Hancox³**¹*Council for Geoscience, South Africa*²*University of Pretoria, South Africa*³*Evolutionary Studies Institute, University of the Witwatersrand***Corresponding author: umzolisto@yahoo.com***Abstract**

Sedimentary basins are not only known to host most of the energy resources such as oil, gas, coal, and geothermal hot water, but also significant mineral and water resources that are critical for human consumption. Therefore, it is vital to conduct technical and scientific research on the formation and evolution of the basins over geological time, including quantities, qualities, and spatial distributions of these energy, mineral, and water resources. The horseshoe-shaped Molteno-Indwe Coalfield is one of Southern Africa's sedimentary sub basins that is located in the north of the Eastern Cape Province and spans an area of around 4,400 Km². It covers the area from the towns of Maletswai to Burgersdorp, James Calata, Molteno, and Sterkstroom in the southwest; from east-west it covers Dordrecht, Indwe, Guba area, and Cala; and north-eastwards toward Elliot, Gubenxa, Engcobo, and Maclear. The Molteno-Indwe Coalfield is known for its long history of coal mining activity. Coal mining commenced in 1864 at Cyphergat near the town of Molteno, and by 1877, several mines were in operation near the town of Indwe. Coal from the Molteno-Indwe Basin was exploited to supply energy to the then-discovered Kimberley diamond fields. Thirteen vertical cores that were drilled within the Molteno-Indwe Coalfield were logged in detail and scanned by a hyperspectral scanner at the Council for Geoscience National Core Library located in Donkerhoek. All the cores were obtained from an intensive drilling program undertaken by CGS in the coalfield between 1984 and 1986. The main objective of this study is to characterize the Bamboesberg Member of the Molteno Formation in order to better understand its depositional conditions, sedimentary facies, and provenance. Consequently, preliminary results on geological data such as sedimentary facies, grain size, main contacts/boundaries, and types thereof (sharp, erosive, and gradational) from field core observations. In addition, the mineral dominant maps delineate the present of silicate and clay minerals, with the hydrocarbons in places.

Keywords: Molteno-Indwe coalfield, Geological characterization, Sedimentary facies, Hyperspectral scanner

Sedimentology and Geochemistry of Carbonate Bearing-Argillites on the Southeastern Flank of Mount Cameroon (Likomba)

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Abstract

Sedimentological, geochemical and petrographic studies were carried out on carbonate-bearing argillites outcropping at the southeastern flank of Mount Cameroon (Likomba) to determine the lithofacies and their associations, major element geochemistry and mineralogy. This was in an attempt to establish the relationship between the carbonate-argillites sequence and the Cameroon Volcanic Line (CVL), determine their provenance and predict a depositional model of the environment of deposition. Outcrops and rock samples were carefully observed and described in the field. Major elements of the rocks were analyzed using XRF technique. Thermal analysis and thin section studies were carried out accompanied with the determination of insoluble components of the carbonates. The carbonates are classed as biomicrites with siderite being the major carbonate mineral. Clay, quartz and pyrite constitute the major insoluble components of these rocks. Geochemical results depict a broad variation in their concentrations with silica and iron showing the highest concentrations and sodium and manganese with the least concentrations. In an attempt to account for the source of the iron, origin of siderite and the sediments, R-Mode analysis was used to discriminate the elemental associations, and two elemental associations were deduced: Fe₂O₃-MgO-Mn₂O₃ (72.56%) and TiO₂-SiO₂-Al₂O₃-K₂O (23.20%), indicating both Fe-enrichment event, the subsequent formation of the siderite and the contribution of the continental sediments to the formation of these rocks. The rocks consist of cyclic iron-rich carbonates alternating with sideritic-shales and might have been formed as a result of variations in the sea conditions as well as variation in sediment influx resulting from transgression and regression sequences occurring in a shallow to slightly deep marine environments. The rocks lie unconformably beneath the CVL and are highly fractured due to the overburden of the overlying igneous rocks.

Keywords: Sedimentology, Geochemistry, Petrography, Iron carbonates, Likomba, Cameroon

Utilising detailed carbonate mineralogy to derive a new chemostratigraphy for the Roan-Nguba Group Neoproterozoic succession in the Central African Copperbelt (Poster)

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Abstract

Continuous sections through the majority of the Neoproterozoic Katangan sedimentary Supergroup (Lower Roan to Kundulungu groups), the host rocks for the important copper-cobalt deposits in the Central African Copperbelt, are rarely intersected in individual drill cores. Recent drilling at the Lubambe Extension Project (247 Mt @ 3.64% TCu) by Lubambe Copper Mine has produced a +1.6 km core that intersects an apparently continuous sequence from the Mindola Clastics Formation of the Lower Roan Subgroup through the Upper Roan Subgroup and into the lower portion of the Nguba Group (including the Grand Conglomérat and overlying Kakontwe Limestone of the Nguba Group). Initial lithofacies studies of this drill core has revealed the presence of significant carbonates (primary and secondary) throughout the stratigraphy, with increasing abundance up sequence. However, the units are composed of multiple generations of carbonate minerals (calcite, dolomite, magnesite) indicating primary carbonates have been subjected to a number of post-deposition processes (e.g., diagenetic, hydrothermal, metamorphic). To best characterise the carbonate intervals representative carbonate samples have undergone geochemical characterisation through combined mineral chemistry (Raman, Tescan TIGER MIRA3 FEG-SEM, μ XRF, pXRF, QEM Scan) and isotopic (stable and radiogenic isotope analysis). Preliminary results indicate microscopic variations, not discernible from hand samples, such as discrete elemental variations within carbonate cements (Fe-Mg), with Fe often depleted in grains relative to the cement and variable degrees of magnesium alteration. Mineralogical characterisation is being used as a guide for ongoing isotopic work that is expected to reveal vertical trends reflecting environmental and sedimentary changes, as has been shown elsewhere. This work is allowing construction of a new chemostratigraphic “type section” in this important stratigraphic interval and interpretation of the complex effects of multiple alteration/mineralization events.

Keywords: Carbonates, Stable isotopes, Mineral chemistry, Neoproterozoic, Chemostratigraphy, Central African Copperbelt

Discovery of the Kavango Rift Basin, a Karoo-aged extensional basin in NE Namibia

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Abstract

Reflection seismic, exploratory drilling, and aerial full-tensor gradiometry surveys in NE Namibia by ReconAfrica have verified the existence of a Karoo-aged rift system under Kalahari cover. This rift was initially postulated by Granath and Dickson in 2016 and 2017 (HGS-PESGB Africa Conference; AAPG AETC & ICE available in Search & Discovery #30555). The form of the rift is a 110 km-long NW-SE trending graben with its southern side fading into the rollover of a half-graben at the extremities. Seismic coverage extends from Highway B8 southwest of Rundu to the boundary of Khaudum National Park. The northeastern side is a continuously linked normal fault system and exhibits the full suite of rift-related fault linkage structures. Internal horst blocks are characteristic. Drilling data show that the rift is filled with Karoo stratigraphy, beginning with the Dwyka Fm. as the basal unit, and continuing up through the Ecca Group and Omingonde Fm. The Etjo Sandstone caps the stratigraphic section with a sheet of Rooival basalt over much of the rift, particularly in the west. The major portion of the extensional history is Dwyka and Ecca in age, as reflected by considerable growth of those formations within the rift and often against internal horst blocks. Locally, extension continued up into Omingonde time as evidenced by fault-controlled thickening of this part of the section, and some inversion features are timed contemporaneously with that late extension. Ages of the stratigraphy are controlled by palynology, particularly in the lower Permian section, but the Omingonde and Etjo Formations (Triassic-Jurassic) are palaeontologically barren. The Omingonde and Etjo Formations dominate the extra-rift section which forms a uniform blanket outside the rift, usually some 600 m thick. Volcanic rocks occur in two positions: (1) the Rooival basalt and its associated dykes, which are equivalent to and part of the Botswana Karoo dyke swarm, have been age-dated at approximately 180 Ma. And (2) a series of basin floor mounds that are distinguishable in high pass filters of high-resolution aeromagnetic data may be volcanic in nature, consistent with bi-modal volcanism so common in extensional systems. The rift is centered under the East and West Kavango Regions, from which the names 'Kavango Basin,' 'Karoo Rift,' and 'Kavango Rift Basin' were adopted to distinguish this basin from the Owambo or Etosha Basin. Previous application of the name 'Kavango' referred to a sub-Basin of the Kalahari. Underlying the unconformity at the floor of the rift is a northward trending segment of the Damara frontal fold and thrust belt in the west and crystalline components of the Damara orogenic belt in the east. The identification of this previously unknown Damara trend is also a result of this exploration programme: the Damara makes a northward oroclinal bend (hidden under Kalahari cover) northeast of Grootfontein and thus isolates its foreland basin, the Owambo Basin, to areas west of the Kavango area. The Kavango rift sits between and presumably is kinematically linked to the Waterberg Basin to the SE, and to the rest of the transcontinental trend of Karoo extensional features to the east.

Keyword: Karoo rifts, Extensional basins, Karoo stratigraphy, Namibia

Sedimentology, Stratigraphy and Petrography of the oldest Nama Group: Tsaus Mountains, Southern Namibia

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Abstract

The Tsaus Mountains in southern Namibia, record the oldest known sedimentary successions of the late Ediacaran Nama Group investigated to date. Here, the sequence of sedimentary rocks document initial transgressive deposition atop the Proterozoic metamorphic basement (composed of granite/granodiorite with cross-cutting pegmatite veins). Recent fieldwork to the Tsaus Mountains has revealed numerous soft-bodied, skeletal and potential trace fossils, some of which likely represent the oldest representatives in the Nama Group recorded to date. This research aims to establish the stratigraphy, sedimentology and petrography of the Tsaus Mountains, to evaluate the regional palaeoenvironmental and facies evolution in this part of the Nama Basin. A field trip was conducted to the Tsaus Mountains, samples were systematically collected, and thin sections are to be prepared. Sedimentary structures were identified and photographed in the field, and height measurements were taken to establish a composite stratigraphic column. Here, the late Ediacaran portion of the lowermost Nama Group (Kuibus Subgroup), consists of the Kanies, Mara and Kliphoek Members of the Dabis Formation. Sedimentary rocks of the Kanies and lower Mara Members represent minor fluvial to marginal marine siliciclastics and carbonates. Only the Kanies Member is clastic, the lower Mara Member consists of carbonates (dolomite) which are followed by dominantly shallow marine carbonates and minor siliciclastics of the upper Mara and Kliphoek Members. In the Tsaus Mountains, carbonates of the lower Kliphoek Member preserve the oldest calcified metazoans. The maximum age for this succession is poorly constrained, but likely ≤ 551 Ma, corresponding with a marked decline in soft-bodied fossil diversity between the White Sea (>551 Ma) and Nama assemblage biozones. The minimum age (ca. 547.36 Ma) is based on regional correlation to a dated volcanic ash interbed.

Keywords: Tsaus Mountains, Nama Group, Sedimentology, Stratigraphy, Kuibus Subgroup, Namibia

Geology and Geochemistry of the Endorouique Basin (N'goussa Sabkha, Southern Algeria)

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Abstract

Saline lakes located in the rain shadow of alluvial fans or highland areas provide catchments for precipitation, while at the same time the arid basin floors are exposed to substantial evaporation. This study of ephemeral saline lake geochemistry uses multi-system data, including rainfall, weathering, groundwater, evaporation and precipitation - dissolution reactions, as well as reviews the threat of pollution to the N'goussa Sabkha, which is located in the south of the Safioune Sabkha, an inland saline lake in North Africa. The N'goussa Sabkha covers some 110 km² in south-eastern Algeria, containing a unique broad range of salt crust types. This study examines wet land area evaporation as it relates to land surface energy fluxes, salt crust characteristics, groundwater and climate in this closed playa. During two yearly cycles, physicochemical measurements of surface and subsurface water samples were taken at sixteen representative sites on this sabkha.

Keywords: Saline lakes, N'goussa Sabkha, Hydrogeochemistry, Subsurface water, Algeria



A sedimentology and sequence stratigraphy study of the Nama Group: Refining facies and chronostratigraphic boundaries throughout the Ediacaran-Cambrian Transition (ECT)

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Abstract

The Nama Group in southern Namibia represents one of most important geological records in Earth History – the Ediacaran-Cambrian Transition (ECT; 550 to 539 million years ago). It was a time that comprises Earth's first major biotic crisis of macroscopic eukaryotic life (the disappearance of the enigmatic 'Ediacaran biota') and immediately precedes the Cambrian explosion of complex life. Therefore, the Nama Group is an exciting target for palaeontological and palaeoenvironmental research. Yet, these rocks have a remarkable record of stratigraphic misunderstandings the correlation of the erosional surface from basin to basin and differentiation of the role of eustasy and local tectonics as controlling factors on associated relative sea-level fall is challenging. The base level fluctuation and the change in accommodation of the shoreline in the Witputs Subbasin have not been well understood, hence this work aims to solve the stratigraphic sequence problems in refining the chronostratigraphic using six drill cores obtained by the international *Geological Research through Integrated Neoproterozoic Drilling* (GRIND) project that target Kuibis and Schwarzrand Subgroups. Using detailed facies analyses and abundant volcanic ash beds, this work will correlate these cores with the surrounding outcrops, as well within and between the Witputs Subbasin and Neint Nababeep Plateau, South Africa. The study highlights the evidence of diagenesis and confirms the transgressive depositional system of the Witputs Subbasin.

Keywords: Nama Group, Ediacaran-Cambrian transition, Ediacaran biota, Sedimentology, Sequence stratigraphy, Namibia

Offshore nano-stratigraphy of the Cretaceous/Palaeogene Sedimentary Basin Formations of Côte d'Ivoire: Evolution of Sedimentary Environments

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Abstract

Analyses carried out in this study relate to sedimentology, biostratigraphy, geochemistry and the palaeoenvironment of the offshore geological formations of the Côte d'Ivoire sedimentary basin. They are based on the study of 272 spoil samples from seven (7) wells, and resulted in a better understanding of the depositional environment. The sedimentary material studied consists of ferruginous sand, clay sand, clay and sandy clay. The main nannofossil markers allow cutting of the upper part of the Campanian and the terminal Maastrichtian-Danian interval. Recognized biozones are analyzed and discussed. This study highlights the Cretaceous-Palaeogene (K/Pg) transition with four stages, i. e. Selandian (Middle Palaeocene), Danian (Lower Palaeocene), Maastrichtian and Campanian. In the various wells, the qualitative and quantitative analyses show that at the Cretaceous / Palaeogene boundary, the populations of nannofossils lose almost 100% of their diversity and overall numbers. The reappearance of nannofossils does not begin until after the mass extinction, which resulted from the K/Pg crisis. In the wells, the sudden extinction (accompanied by a fall in CaCO₃) and the mode of reappearance of the nannofossils indicate a catastrophic event at the end of the Cretaceous. The biozonation of nannofossils, supported by lithological, calcimetric and geochemical data, suggests a palaeoenvironment of internal continental shelf deposition.

Key words: Nannofossil biozonation, K/Pg Boundary, Palaeocene, Maastrichtian, Selandian, Danian, Offshore basin, Côte d'Ivoire

ST01_S03: Neoproterozoic glacial record of Africa**Ecosystem relocation on snowball Earth: polar-alpine ancestry of the modern surface biosphere****Paul F. Hoffman****School of Earth & Ocean Sciences, University of Victoria, 1216 Montrose Ave., Victoria, British Columbia, Canada V8T2K4***Corresponding author: paulhoffman@gmail.com***Abstract**

There is compelling palaeomagnetic, geochronologic, geochemical and sedimentological evidence for two long-lived pan-glacial ('snowball Earth') episodes during the Cryogenian Period, namely Sturtian (717 to 661 Ma) and Marinoan (646±5 to 635 Ma). Given current understanding of marine ice dynamics on snowball Earth, the world ocean would have been totally dark for ≥62 Myr in aggregate. Kilometre-thick floating ice shelves spread gravitationally from the poles and were hundreds of metres thick at their equatorial extremities due to back-pressure of ice from the opposite hemisphere. How then did phototrophic primary producers and their trophic dependents survive, given that fossils clearly show that eukaryotic algae, protists and fungi occupied marine environments in pre-Cryogenian time? The best climate model of snowball onset in Cryogenian palaeogeography implies that the time elapsed from 50% ocean ice cover to 100% darkness was less than 400 years. The deep crustal biosphere and submarine hydrothermal-vent biota would have survived, but extirpation would be the fate of marine primary producers—being a mixotroph won't save you if there is nothing to eat. Windblown inocula would have to contend with preestablished terrestrial biomes. How then did Tonian life survive in sufficient diversity to account for Ediacaran fossils and the deep pre-Cryogenian ancestry of modern marine plankton based on molecular phylogenetic clocks? One (perhaps only one) explanation is viable and is supported by a diversity of findings in the molecular phylogenomics of living taxa. It depends on an assumption that supra- and periglacial habitats have always existed in polar regions and/or mountain tops. Long before the Cryogenian, cyanobacteria, viruses, eukaryotic algae, fungi and protists would have occupied those (mainly freshwater) niches, just as they do in polar–alpine habitats today. At snowball onsets, those preestablished ecosystems simply migrated, along with the ice margins, to the equatorial zone of net sublimation. Their habitat area vastly expanded, and the cruelty of winter was greatly reduced. They thrived and evolved, given a steady nutrient supply in dust generated by glacial abrasion, strong surface winds and terrestrial ice margins. When each snowball episode ended, the ancestral polar–alpine survivors found themselves in the rapidly warming and nutrient-rich meltwater lid of a newly sunlit but vacant ocean. Some retreated with the ice margins while others adapted to new habitats. The torrid post-snowball greenhouse transients favoured bacteria in inland seas, but colder nutrient-rich coastal upwelling zones and higher latitudes favoured eukaryotes until atmospheric CO₂ readjusted to the low-albedo ocean. This ecosystem-relocation scenario is consistent with the freshwater ancestry and Ediacaran marine radiations of planktonic cyanobacteria and archaeplastid algae revealed by genetic ancestral state reconstruction. It is consistent with Cryogenian selection of two green algal lineages with contrasting salinity preferences and photorespiration mechanisms. Chlorophytes derive from saline bottom waters of ice-covered dry-valley lakes, where dim light dictated an energy-conserving mechanism. Streptophytes derive from brightly lit supraglacial meltwater habitats, where solar energy was available and a derived peroxisomal photorespiration mechanism capable of higher metabolic throughput was advantageous. The modern surface biosphere evolved from a polar–alpine subset of pre-Cryogenian life.

Keywords: Extremophiles, Evolution, Mass extinction, Phytoplankton, Global change

Footprints of the Cretaceous Continental Glacier in Sub-Saharan Africa: The Use of Converging Evidence

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Abstract

Landforms often intrigue and awe humanity and yet, from a geomorphological perspective, they present sterling evidence of past geomorphological and geological events that sculptured the surface of the land. This hypothetical paper presents the use of *Converging Evidence* to track the existence and the footprints of a vast Continental Glacier in Sub-Saharan Africa. It should be indicated that in most diagrams of Gondwanaland, the illustrations do not take into consideration the possibility of the presence of the glacier. About 600 Ma (during the Ediacaran Period), it is hypothesized that a large landmass in Sub-Saharan Africa was covered by a vast Continental Glacier, almost akin to that in present day Greenland. The relict geomorphological evidence presented in this article covers a vast area which stretches from Bujagali Falls in Uganda to the Cape Region in South Africa. It is theorized, that, as the Gondwana Continents drifted apart, the massive Continental Glacier in Sub-Saharan Africa started to retreat. It melted, twisted and turned, scoring and sculpturing the land surface, and releasing isostatic pressure, which resulted in uplift and formation of the Great Escarpment of Southern Africa. This vast region is dotted with glacial erratics, gigantic granitic tors with clear evidence of lee and stoss surfaces, cirques and pyramidal peaks (such as Signal Hill in Cape Town), as well as truncated dykes and kimberlitic pipes. A radar satellite mosaic of southern Africa shows a vast depressed area titled westward and converging at the mouth of the Orange River between Namibia and South Africa.

Keywords: Converging evidence, Continental glacier, Sub-Saharan Africa



Onset and Duration of the Marinoan Snowball Earth

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Abstract

Twice during the Neoproterozoic, Earth experienced runaway ice-albedo feedbacks that resulted in long lasting, global glaciations: the Cryogenian snowball Earth events. Radiometric ages have constrained the onset and termination of the first, the Sturtian, as well as the termination of the second, the Marinoan. Existing geochronology shows that the Marinoan was shorter, 4-15 My, than the Sturtian, 56 My. This range is wide, however, and the temp proximity between the two Snowball events (11-22 My) means that uncertainty in Marinoan onset also limits our knowledge of the chronology of the non-glacial interlude. Dating the onset of the Marinoan is critical for calibrating the timeline between the snowballs as well as constraining models that attempt to explain the difference in duration between the Sturtian and Marinoan. However, direct dating of glacial deposits is compromised by poor preservation potential of airfall tuffs in sub-ice environments. We present new CA-ID-TIMS U-Pb zircon dates from the Marinoan Ghaub Formation as well as the immediately underlying stratigraphy at Fransfontein Ridge, Namibia. These dates provide new constraints on the onset of the Marinoan glaciation and the tempo of snowball ice-grounding line migrations.

Keywords: Geochronology, Cryogenian, Snowball Earth



ST02: GEODYNAMIC EVOLUTION OF THE AFRICAN CONTINENT: GEOCHRONOLOGY, MOBILE BELTS, AND INTRAPLATE MAGMATISM**ST02_S01: Orogenic cycles of the African Continent - Archaean to Phanerozoic****Geochemical Signatures of Séguéla Peridotites in the West African Craton**

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Abstract

The present study deals with peridotites found in the Palaeoproterozoic domain of the Leo Man Shield, Séguéla region, west central of Côte d'Ivoire. Its main purpose is to show the importance of peridotites in the understanding of the lithospheric mantle. We present petrography and geochemical analyses of thirty (30) peridotites samples which show that the Séguéla peridotites are composed of lherzolite, dunite and harzburgite, with lherzolites the most abundant. Phenocrysts in the peridotites are serpentinised olivine, diopside and enstatite. Two types of Amphiboles are also present: primary magmatic and secondary (those derived from the alteration of clinopyroxene). Spinels presents have Cr₂O₃ content which varies between 28% and 37 wt%, Al₂O₃ (33% to 41 wt%) and MgO around 18 wt%. The spinels are TiO₂-poor with no ZnO. The Séguéla peridotites are characterised by Nb-Ta negative anomalies, enriched lithophile elements, light rare earth elements (La/Yb = 46 to 150) and heavy rare earth elements, along with depletion of high field strength elements. These features may suggest that the rocks were formed in an island-arc setting with mantle enrichment by fluids from a subduction zone or by mantle - magma interaction in a subduction zone context.

Keywords: Geochemistry, Peridotites, Lherzolites, Leo Shield, Côte d'Ivoire

Detrital zircon geochronology of quartzites from the Central Zone of the Limpopo Complex in southern Africa: Implications for different models and the timing of Zimbabwe Craton– Kaapvaal Craton amalgamation

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Abstract

U–Pb geochronological analyses have been conducted on 765 detrital zircon grains from 11 quartzite samples in the Central Zone of the Limpopo Complex, southern Africa, for constraining the depositional age and provenance of the protolith quartz-sandstone and evaluating the effect of high-grade metamorphism on zircon age data in polymetamorphic terranes. The age data have also been used to evaluate two contrasting tectonic models for the evolution of the complex, i. e. collision of the Zimbabwe and Kaapvaal Cratons and diapir-driven intracratonic orogeny, both during the Neoarchaeon. Magmatic cores of the zircons from the Beit Bridge, Phikwe, and Motloutse Complexes in the Central Zone show a wide age range from 3828 Ma to 1995 Ma. Ages from the Beit Bridge Complex in Zimbabwe (ca. 3.6–3.1 Ga) and South Africa (ca. 3.5–2.4 Ga) are dominantly Palaeoarchaeon to Neoarchaeon with minor Palaeoproterozoic ages. Similar Eoarchaeon to Neoarchaeon ages were also obtained from the Phikwe Complex (ca. 3.8–2.6 Ga), whereas ages from the Motloutse Complex are slightly younger (early Mesoarchaeon to Palaeoproterozoic; ca. 3.0–2.4 Ga). Although the age patterns from the three complexes are different, the distribution patterns of discordant and concordant data suggest Eoarchaeon to Mesoarchaeon (ca. 3.8–3.1 Ga) ages for magmatic cores of detrital zircon grains. Homogeneous zircon rims around magmatic cores gave metamorphic ages of ca. 2.61 Ga and ca. 2.27–2.02 Ga, probably formed by Neoarchaeon and Palaeoproterozoic high-grade metamorphisms. Similar Neoarchaeon (ca. 2.7–2.6 Ga) and Palaeoproterozoic concordant ages obtained from magmatic zircon cores are interpreted as reset ages due to Pb loss during the metamorphic events. The smaller peak of the Palaeoproterozoic age population compared to that of the Neoarchaeon age data suggests the dominant high-grade metamorphism of the Central Zone took place at ca. 2.7–2.6 Ga, either by collision of the Zimbabwe and Kaapvaal Cratons or by diapir-driven intracratonic orogeny. Therefore, cratonization of the Azanian (Kalahari) Craton probably occurred before ca. 2.6 Ga. Based on the age patterns, the depositional age of the protolith quartz-rich sandstone is constrained as 3.1–2.7 Ga. The provenance of the Palaeoarchaeon to Mesoarchaeon (3.6–3.1 Ga) detrital zircons has been inferred as orthogneisses and granitoids of the southern Zimbabwe Craton (e.g. Tokwe Segment). The oldest Eoarchaeon detrital zircon (3828 Ma) obtained from the Phikwe Complex suggests the presence of unknown older crust in this provenance.

Keywords: Limpopo Complex, U–Pb geochronology, Detrital zircons, Eo-archaeon to Neoarchaeon, Azanian (Kalahari) Craton

Palaeoproterozoic (2.01 Ga) high-pressure granulite facies metamorphism (14 kbar, >900°C) of garnet–orthopyroxene–cordierite–orthoamphibole gneisses from the Central Zone of the Limpopo Belt in eastern Botswana

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Abstract

The Central Zone (CZ) of the Limpopo Belt in southern Africa is a complex high-grade metamorphic zone. To better understand the poly-metamorphic history we present petrological and SHRIMP U-Pb zircon age data for garnet- and orthopyroxene-bearing cordierite-orthoamphibole (Grt-Opx-Crd-Oam) paragneiss and charnockite samples from the Baines Drift and Phikwe Complexes, respectively. The two complexes constitute the north-western segments of the CZ for which the metamorphic history is poorly understood. The high-pressure (HP) granulite facies metamorphism and clockwise *P-T* evolution for the feldspar-free Grt-Opx-Crd-Oam gneiss of the Baines Drift Complex are constrained by pseudosection modelling, Grt-Opx thermometry, and quartz in-garnet (QuiG) elastic barometry. The peak-metamorphic garnet-orthopyroxene-rutile-ilmenite-quartz assemblage formed at conditions of > 900°C and 14 kbar, followed by significant decompression still under granulite facies conditions as recorded by distinct orthopyroxene-cordierite coronas around garnet. The widespread formation of orthoamphibole documents subsequent near-isobaric cooling into the amphibolite facies. Metamorphic zircon in the Grt-Opx-Crd-Oam gneiss yielded a precise age of 2014 ± 8 Ma for the HP granulite facies metamorphism in the Baines Drift Complex. The clockwise *P-T* path of the Baines Drift Complex is comparable to the similarly aged 2.02 Ga metamorphism in the Beit Bridge Complex that forms the main segment of the CZ. The HP metamorphism is interpreted to reflect the intracontinental Palaeoproterozoic transpressional orogeny within the consolidated Kaapvaal-Zimbabwe Craton. The juxtapositioning of the lower-crustal HP granulite facies rocks of the Baines Drift Complex next to mid-crustal upper-amphibolite facies rocks of the Phikwe Complex is considered the result of nappe tectonics during the Palaeoproterozoic orogeny. SHRIMP U-Pb zircon data indicate that the granitic magma of the charnockite from the Phikwe Complex intruded at 2586 ± 27 Ma, broadly synchronous with major granitoid emplacement in the Beit Bridge Complex. The similar *P-T* evolution of ca. 2.02 Ga metamorphism and comparable voluminous granitoid emplacement at ca. 2.6 Ga indicate a common evolution of the Baines Drift, Phikwe and Beit Bridge Complexes in the CZ of the Limpopo Belt.

Keywords: High-pressure (HP) granulite facies metamorphism, Limpopo Belt, Phikwe Complex, Pseudosection, U-Pb zircon dating

Are the Ventersdorp Supergroup and Marydale Group coeval?

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Abstract

Microbeam zircon dating and geochemistry are used to investigate the volcanic and sedimentary packages of the Ventersdorp Supergroup and Marydale Group overlying Archaean granite basement at the southwestern margin of the Kaapvaal Craton. The Doornberg and Brakbosch Faults are major tectonostratigraphic boundaries, across which the stratigraphy, tectonic fabric and metamorphic imprint changes. Outcrops at T'kuip represent the last undisputable Ventersdorp Supergroup sequence in the area. The basal conglomerate and mafic tuff unit, locally called the Ongers River formation, unconformably overlies the 2905±7Ma Maritzdam Kaapvaal basement Granite. The tuffs conform geochemically to the basal Klipriviersberg Group of the Ventersdorp Supergroup. They contain xenocrystic zircons with a range of ages, grouped at 2921 ± 11 (n=38), and 2877 ± 5 Ma (n=13), all older than the <2799 ± 9 Ma base of the Ventersdorp Supergroup. However, three grains were dated at 2781 ± 19 (N=5), 2729 ± 13Ma (5) and 2733 ±16 Ma (1). They are probably xenocrysts, but represent maximum ages for the Ongers River formation. These data agree with the published ion probe data for Klipriviersberg zircons, which indicated an age younger than 2730 Ma. The local Kuip formation, comprising porphyritic rhyolites, disconformably overlies the Ongers River formation. Its U/Pb zircon date of 2716 ± 8 Ma confirms correlation with the 2720 ±2 Ma Makwassie Formation, which occurs at many localities across the craton. South of the Doornberg Fault, 2907 ± 4 Ma Welgevonden Granite predominates, showing the continuity of basement granites across the fault. However, small plutons of the 2721 ± 6 Ma Steenkop Granite Gneiss represent intrusive Makwassie Formation equivalents! Small exposures of quartz porphyries with blue quartz on farm Zoutpekel proved to have the same age (2718 ± 5 Ma) and geochemistry as the Makwassie (2720 ± 2 Ma). The Soetvlei Arkose, lowermost Marydale Group unit, overlies Welgevonden Granite with an undefined field relationship. Stratigraphic duplications and the relationship between stratigraphic dip and metamorphic gradient show that the Marydale Group is a thrust complex, possibly with inverted stratigraphy. Three Soetvlei arkose samples have disparate zircon Pb-Pb age histograms, with youngest major peaks at 2850 and 2910 and oldest grain at 3500 Ma! However, in one sample, two near-concordant grains give a Pb-Pb age of 2731 ± 14 Ma and together with five discordant points yield a discordia upper intercept age of 2733 ± 16 Ma! This shows that the Marydale Group was being deposited at the same time as the Ventersdorp Supergroup! Zircon Hf isotope data shows no difference between Ventersdorp Platberg (e. g. Makwassie rhyolite), Zoutpekel porphyry and the 2.7 Ga Marydale Soetvlei arkose detrital grain. The tectonically overlying pillow basalts of the Marydale Group Marydale also classify geochemically as Klipriviersberg Group! They are not yet precisely dated: Perdeput metabasites (2950 ± 180Ma Sm/Nd isochron) and Modderfontein BIF (2990 ± 120Ma Pb-Pb), but are probably coeval with parts of the Ventersdorp Supergroup. In conclusion, (1) The Klipriviersberg Group is younger than 2730 Ma. (2) The Marydale Group is probably a Ventersdorp correlate, formed in a continental margin environment.

Keywords: Marydale Group, Ventersdorp Supergroup, Zircon dating, Stratigraphy, South Africa

An African legacy to the Wilson Cycle concept: Tracing geological history of NW-Africa Variscan belts

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Abstract

From southern Senegal to northern Morocco, NW-Africa exhibits several poly-orogenic segments that register the successive opening and closure of the Iapetus and Rheic (Proto-Atlantic) palaeo-oceans prior to the break-up of Pangea and the formation of the Central Atlantic. Wilson (1966) chose this evolution to define his geodynamic cycle concept. At that time, the only Variscan orogen cited along the Atlantic coasts of Africa was the Mauritanides of Mauritania. Recent achievements in the entire Mauritanide belt from Senegal to southern Morocco, and on the Moroccan Meseta orogenic belt further north strongly increase the African legacy to this global concept. The Southern and Central Mauritanides are a poly-orogenic, Pan-African and Variscan fold belt characterized by a thin-skinned tectonic style that mirrors the final structure of the southern Appalachians whose evolution is distinct. The Oulad Dlim segment northwest of the Reguibat Rise, is the extension of the Mauritanides of Mauritania. It exhibits a Silurian-Devonian sector in the west that shows possible affinities with the Gondwana-derived Appalachian terranes. The Meseta orogen developed during the Palaeozoic onto a Cadomian basement. The western Meseta is only affected by Variscan events, mildly in the Coastal Block, while the eastern Meseta was also affected by Eo-Variscan (Neo-Adian) events. The along strike structural change from the Mauritanides to the Meseta is interpreted here by the transition from a head-on collision south of the South Meseta transform fault (SMF) to a dextral, transpressional collision north of the SMF. The Meseta Coastal Block was likely displaced from the south-westernmost Anti-Atlas during this process. The Wilson Cycle concept is applicable in the sense that the Atlantic Ocean opened where the former Rheic Ocean had closed. Local exceptions are: i) the Sehou Block of northern Meseta and ii) the Silurian-Devonian Sector of the Oulad Dlim Massif. They may have separated from Gondwana during opening of the Rheic and re-amalgamated during the Late Carboniferous and Pangea formation. Likewise, a NW- African fragment from the Anti-Atlas may have stranded offshore Massachusetts in eastern North-America. A Cryogenian to Cambrian Wilson cycle is nested in the major cycle, which separates the breakup of Rodinia from the breakup of Pangea. This minor nested cycle began when Cadomian terranes rifted off Africa; while some were transferred to Europe, others accreted back to NW Africa. This early cycle likely controlled the localization of the subsequent Rheic rift, and after the Variscan collision, that of the Atlantic rift along the Mauritanides.

Keywords: Mauritanides, Meseta, Anti-Atlas, Variscan, Rheic-Iapetus, Gondwana, Pangaea

Reference: Wilson, J. T. 1966. Did the Atlantic Close and then Re-Open? *Nature*, **211**, 676-681.

Multidisciplinary Reassessment of the Ediacaran Successions of the Anti-Atlas: New Perspective on the Geodynamic Evolution of the NW Margin of the West African Craton

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Abstract

The spatio-temp link between the Pan-African and the Cadomian Orogeny is still debated. Its understanding is crucial to the processes driving the amalgamation of Gondwana, as well as the increase in oxygen-concentration and nutrient transport in the oceans. The Anti-Atlas belt (Morocco) at the northern transition between the Gondwana continent and peripheral segments (Cadmia) records a tectono-magmatic assemblage from 880 to 650 Ma of the Pan-African Orogeny and from ca. 600 to 520 Ma of the Cadomian Orogeny. This contribution presents new lithostratigraphic, geochronological and geochemical data towards a regional stratigraphic correlation between the Anti-Atlas and adjacent terrains in order to verify the spatio-temp relationship between the end of the Pan-African Orogeny and the beginning of the Cadomian Orogeny at the northern margin of the West African Craton (WAC). Re-evaluation of these data allows us to distinguish four groups separated by three angular unconformities, linked to southward subduction beneath the WAC. (1) Following the accretion of the intra-oceanic terrain at 650 Ma, the Saghro Group consists of shallow to deep marine turbidites deposited between 640-604 Ma; they record geochemical signatures related to the stretching of continental crust (20 km) north of the Anti-Atlas major fault and establishment of a back-arc basin in the NW margin of the WAC including Anti-Atlas, Atlas-Meseta, Ougarta and the Ossa Morena Zone. The back-arc basin fill was deformed, exhumed and intruded by 610-600 Ma adakitic and high Sr/Y calc-alkaline granitoids in an over-thick continental crust (50 km). This is followed by a magmatic lull between 600-590 Ma. (2) The 590-580 Ma period records progressive crustal thinning and emplacement of a magma with evolved ϵNd (-12 to +4) and calc-alkaline signatures across the entire Anti-Atlas, Meseta and Ossa Morena Zones. In the Anti-Atlas and Atlas-Meseta this pulse was accompanied by a sedimentary gap between 600-580 Ma. (3) Calc-alkaline volcanics and siliciclastic sediments of the M'gouna Group were unconformably deposited between 580-570 Ma in fault-bounded basins formed on previously exhumed terrains. (4) The inversion of the M'gouna Group occurred at ~570 Ma. (5) A ~1000 m thick andesite-rhyolite volcanic series of the Lower Ouarzazate Group was deposited from 570-567 Ma, across the NW of the WAC. (6) The 567-550 Ma Upper Ouarzazate Group records a progressive shift to a mixture of alkaline, juvenile ($\epsilon\text{Nd} = -7$ to +7) volcano-plutonic and fluvio-lacustrine sediments. We suggest that the NW margin of the WAC records the formation and subsequent closing of a back-arc basin related to the south-dipping Cadomian subduction between 640-600 Ma and subsequent slab break-off. A slab break-off occurred following the back-arc closing at 600 Ma, which allowed asthenospheric doming and topographic elevation between 600 and 580 Ma, accompanied by intense erosion. Progressive crustal thinning caused the deposition of the M'gouna, Lower and Upper Ouarzazate Groups within transtensional and transpressional tectonic regimes. The maximum stretching of the NW margin of the WAC is recorded by the deposition of first marine sediments bearing Ediacaran biota in the Anti-Atlas and the establishment of a carbonate platform during the Lower Cambrian.

Keywords: Ediacaran, Subduction, Slab break-off, West African Craton

Revised geology of the Kamanjab Inlier, northern Namibia

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Abstract

The Kamanjab Inlier in northern Namibia exposes the southern margin of the Archaean to Palaeoproterozoic Angola Shield. It consists of Palaeoproterozoic low-grade volcanoclastic rocks of the Khoabendus Group, medium- to high grade gneisses, schist and quartzite of the Huab Metamorphic Complex, and the Fransfontein Granite Suite. Geological mapping in the Kamanjab area allowed subdivision of the Khoabendus Group into the lower Westend and upper Otjovazandu Formations dominated by metavolcanic and metasedimentary rocks, respectively. The volcanics and sediments were deposited mainly in local basins under shallow-marine conditions; however, in the upper part of the Otjovazandu Formation, regional transgression is recorded in the Arendsnes Shale Member. The base of the Khoabendus Group is obscured by massive, layer-parallel megasills of the Fransfontein Suite, digesting the basal rocks of the Westend Formation. The Fransfontein Suite is marked by great variation in composition and petrography. Geological mapping, combined with airborne geophysical data interpretation and petrography, reveals 10 different types which were emplaced into the Khoabendus Group as sheet-like intrusions and plutons. Geochemistry and geochronology of the Fransfontein Suite and the mostly felsic volcanic rocks of the Khoabendus Group show their coeval evolution between 1.88 and 1.82 Ga within an active continental margin related setting. Nd-isotope analysis yielded for Fransfontein Suite rocks T_{DM} model ages of 2.3-2.7 Ga and mostly negative $\epsilon Nd_{[1.85 Ga]}$ values (-6.2 to -2.2) indicating mixing of mantle derived magmas with crustal country rocks of predominantly Palaeoproterozoic provenance. Geological mapping of the Huab Complex shows its subdivision into a (i) southern migmatitic Rooikop/Lofdal Subdomain, (ii) a central non-migmatitic Suiderkruis-Aandgloed Subdomain and (iii) a north-eastern low-grade Ehobib Subdomain comprising Khoabendus rocks intruded by the Fransfontein Suite. This constrains a normal geothermal gradient from the bottom to the top of the structural pile and excludes nappe tectonics to explain the observed thrust contacts between the Suiderkruis-Aandgloed and Ehobib Subdomains. The Huab Metamorphic Complex is intruded by voluminous mafic magmas prior to a first phase of regional medium- to high-grade metamorphism and deformation (M_1). Their geochemical composition and geochronology indicate a continental arc/backarc system between 1.96 Ga (the youngest $Nd T_{DM}$ age) and 1.88 Ga (the oldest Fransfontein granite) and mixing of a juvenile mantle source with a crustal component of Archaean provenance. Metamorphic petrology yields inconclusive results for M_1 metamorphic conditions in the high-grade domains, where M_1 mineral paragenesis are reset during M_2 . In the northern, non-migmatitic part of the Huab Complex, M_1 metamorphic conditions are estimated at 10.5-11.3 kb and 650-700 °C.

The continuation of subduction after M_1 suggests that metamorphism and deformation were associated to magmatic underplating under extensional conditions and not to classical collision tectonics. Migmatitic paragneisses of the Huab Complex were intruded after M_1 by sheeted bodies of granitoids that subsequently were transformed into orthogneiss. The magmas coincide in age

(1.84-1.82 Ga), Nd-isotope and geochemical composition with those of the Fransfontein Suite, therefore representing their deeper-level equivalents.

The M_2 tectono-thermal event is characterised in the northern part of the study area (Khoabendus Group and Fransfontein Suite) by generally weak, mostly steep NE-SW trending foliations, down-dip stretching lineations with a small sinistral component and irregular-spaced, upright, tight folds that are often bound by normal faults. Outside these zones, the rocks are almost undeformed and foliations/lineations missing. Metamorphism reaches greenschist facies conditions. In the Huab Complex, M_2 deformation created non-cylindrical folds and dome and basin structures defining the present map-scale geometry. D_1 structures were generally transposed into the new penetrative D_2 foliation. In the Rooikop Subdomain, concentric sheath folds up to km-scale with steep axes attest to highly ductile conditions and predominantly vertical movements in the southern part of the Huab Complex. In the north and northeast, near the sheared contact with the overlying low-grade Khoabendus Group and Fransfontein granites, all rocks are transformed into mylonite. These features argue for the Huab Complex representing an M_2 mantled gneissic dome, or metamorphic core complex, which developed once more in an extensional setting either at ca. 1.8 Ga (the time of local granite emplaced into a syn- to post- D_2 fault) or at ca. 1.4-1.3 Ga during Mesoproterozoic rifting of the Kibaran event. Thermal overprint of the Huab Complex during this period is indicated by Ar-Ar and K-Ar hornblende and muscovite mineral ages dated at 1.45 to 1.32 Ga, which coincides with the emplacement age of the Kunene Igneous Complex.

Keywords: Kamanjab Inlier, Tectonics, Geochemistry, Geochronology, Namibia



Precambrian crustal architecture of Malawi

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Abstract

Malawi lies at an absolutely central and critical position at the complex junction of several very important Precambrian blocks and mobile belts. Superimposed upon this complex early to mid-Proterozoic crustal collage, the crust was variably (but locally intensely) re-worked during two phases of often cryptic Neoproterozoic tectonism and plutonism, the older N-S East African orogeny and the younger E-W Kuunga orogeny. GEMMAP revision mapping of the entire country, combined with data interpretation from newly-acquired airborne geophysics, classic and modern laboratory analytical methods (petrography, whole-rock geochemistry, isotope analysis, microprobe) and review of the crustal entities that surround Malawi now allow a definition of the principal crustal architecture of Malawi. In terms of nomenclature for the various lithostratigraphic and lithodemic units, the following scheme has been adopted. The highest-level term employed is Domain, which refers to the three main Precambrian crustal blocks making up the Malawi basement. These are the Palaeoproterozoic Ubendian Domain in the north, the Mesoproterozoic Irumide Domain in the central area and the Mesoproterozoic South Irumide Domain in the south. The term domain is preferred over others of similar rank, such as “Orogen” or “Province”, for example, whose definitions are either expressly genetic or are less clearly defined. Each domain is bounded by tectonic contacts and subdivided into two or more (also tectonically-bounded) subdomains, which share the main basic definition of the over-arching domain (age and origin), but show considerable lithological, compositional, structural and/or metamorphic differences, along with other variables, such as intrusive history. The term is considered to be more geologically neutral than other, more genetic, terms such as “Terrane”. The definition of lower-level lithostratigraphic terms of the constituent rock types are subdivided into lithodemic groups, formations and members which are mainly defined according to their geophysical characteristics.

The characteristics of the three main tectono-stratigraphic domains are:

- The Ubendian Domain underlies northern Malawi and is characterised by Palaeoproterozoic (Rhyacian-Orosirian) supercrustal and intrusive rocks that, between 2.2-1.8 Ga, were accreted between the SW edge of the Tanzania Craton and the NE margin of the Bangweulu Block, and subjected to several phases of deformation and metamorphism during the Ubendian Orogeny at ~1950 Ma. The domain has been subdivided into the northern Mbozi, central Ufipa and southern Nyika subdomains, recording amphibolite, eclogite and granulite facies metamorphic conditions, respectively. The continuation Nyika Subdomain into the Bangweulu Block of Zambia suggests the interpretation as internal zone of the Ubendian orogeny. In the new model, the Ubendian Belt s.s. represents the root zone for nappes that were transported to the north over the Tanzania Craton.
- The Irumide Domain is exposed in central Malawi and is characterised by Palaeoproterozoic (Ubendian) crust which, during late Mesoproterozoic times became an active continental margin south of the now-stabilised Bangweulu-Ubendian-Tanzania Craton block. The

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domain was extensively intruded by Mesoproterozoic magmatic rocks and underwent intense deformation and high-grade metamorphism during the Irumide Orogeny at ~1040 Ma. The domain has been subdivided into the northern Mzimba, central Kasungu and southern Mchinji subdomains

- The South Irumide Domain is exposed in southern Malawi and is made up of late Mesoproterozoic (Stenian) juvenile crust, which formed in an island arc setting and also underwent extensive magmatism and high-grade metamorphism during the Irumide Orogeny. The South Irumide Domain has been subdivided into the Lilongwe, Unango and Nampula subdomains.

After the establishment and stabilisation of this basic crustal architecture by ~1 Ga, subsequent Neoproterozoic rifting, and emplacement of alkaline plutons between ~900 and 650 Ma is recorded across the entire country and argues for the main tectonic blocks already being juxtaposed and in place by this time. The ~580 to 470 Ma Pan-African orogeny shows variable tectonic and thermal impact in Malawi and did not result in the formation of new crust, apart from voluminous plutonism (Blantyre Suite). A pervasive Pan-African overprint is recorded in the South Irumide Domain in southern Malawi, whereas in central and northern Malawi the deformation and metamorphism appear limited to discrete regional shear systems.

Keywords: Precambrian architecture, Malawi



The Eastern Extension of the Damara Orogenic Frontal Fold and Thrust Belt in northeast Namibia

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Abstract

Reflection seismic and exploratory drilling in the Kavango region of NE Namibia by ReconAfrica has discovered the existence of a well-preserved eastward extension of the Damara frontal fold and thrust belt, a structural system previously only delineated in the surface geology in the Otavi Mountainland and further west. This fold belt fronts the Damara orogenic wedge and is truncated above by a major unconformity over which lie some thin remnants of a presumed lower Palaeozoic section, an overlying region-wide Karoo section, and Kalahari sands. Three main aspects of the fold belt are particularly interesting: 1) it consists of a train of upright detachment and fault propagation folds similar in style to those exhibited in the Otavi Mountainland; 2) It is developed in presumed Mulden and Otavi Group rocks above a network of detachments that run at several horizons, 3) A tip line is formed at the frontal edge with a horizontal detachment within the Otavi rocks that extends backward under the thrust wedge. The detachment ramps to several horizons up into the Mulden and downward into and below what we pick as a reflection from within the Abenab Sub-group. Otherwise, the detachments are remarkably flat over distances as large as 20 km. Folds with low amplitude at the front grow to as much as 1000 m in amplitude away from the front. Eighty km east of the tip of the wedge, the detachment brings the Abenab up into an arch that appears to be the passive roof of a duplex of older rocks; imaging is poor below the Abenab level. The NNW-trend of the folds was a surprise: the thrust front makes a 100° northward (anticlockwise) oroclinal bend near Mangetti National Park. In eastern Kavango a major thrust brings Otavi Group rocks to the top of the thrust wedge at the overlying Pre-Karoo unconformity. Three wells were drilled into the thrust wedge in this area below the floor of the Kavango Rift. Otavi Group carbonates were identified on the basis of C and Sr isotope ratios and from diamicrites (presumed to be Ghaub Formation) that place the carbonates stratigraphically in the section near the Cryogenian/Ediacran boundary. Downhole data from all three wells indicate the structures plunge gently to the SE in agreement with the map pattern deduced from seismic mapping. A composite cross-section constructed in LithoTect™ software for the subsurface fold belt in the Kavango region compares favorably in style to one constructed across the Otavi Mountainland. The section intersected in the wells is similar to that exposed in the Mountainland.

Keywords: Precambrian tectonics, Damara Belt, Reflection seismic, Exploration, Namibia

Interaction of Birimian magmatism (2.1 Ga) and Archaean greyness in southwest Côte d'Ivoire (West African Craton): geodynamic implications

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Abstract

The geological area of southwest Côte d'Ivoire is still known as the SASCA domain, after the Sassandra and Cavally rivers that cross it. It is characterized by the presence of a segment of Archaean crust composed mainly of grey gneiss. This segment of Archaean crust, measuring around 10 km square, is considered to be a relic within the juvenile Birimian (Palaeoproterozoic) formations made up mainly of micaschists. The Archaean rocks consist mainly of grey gneisses up to 3.3 Ga in age (U-Pb on zircon). They also contain monazites with U-Pb ages averaging 2 Ga Ma, with Archaean inheritance up to 2650 Ma, indicating that they were more or less severely affected by the Eburnean (Palaeoproterozoic) orogeny. The foliation of the grey gneisses is generally oriented EW with a subvertical dip. Numerous mm to dm quartz and feldspar leucosomes occur in the foliation of the grey gneisses. The Birimian micaschists that surround the grey gneisses may or may not contain garnet and have a sub-vertical schistosity oriented generally NE. In the Balmer zone, the foliation of the grey gneisses is oriented NE. A multi-decameter potassic granite is emplaced by dextrally shearing the grey gneisses in an EW direction. The age of this granite is 2100 Ma (U-Pb on zircon). Its Nd model age at 3 Ga indicates contamination of Birimian magmatism by Archaean crust. In the Monogaga sector, the interaction between Birimian magmatism and Archaean grey gneisses is even more obvious. A Birimian zircon (age 207Pb/206Pb at 2100 Ma) was found in the grey gneisses, corroborating their remobilization during the Eburnean. Segments of Archaean crust ranging in size from cm to dm are frequently found in enclaves in Birimian granites. Basic to ultrabasic magmatism is also present in the foliation of grey gneisses in the form of cm to m veins that are sometimes boudiné. An intrusive basic rock in the grey gneisses has given a Nd model age of 2.5 Ga. Finally, there are cm to dm enclaves of boudiné pyroxenites in the foliation of the grey gneisses. The interaction between Birimian magmas and the Archaean crust takes place in a tectonic environment dominated by vertical and transcurrent movements, all in a global context of lithospheric compression. Structural elements seem to rule out the existence of tangential tectonics, i.e. a subduction zone of a priori modern type.

Keywords: SASCA domain, Grey gneiss, Mica schist, Zircon and monazite U-Pb, Nd model age, Côte d'Ivoire

Petrographic and geochemical characteristics of the Akaba igneous massif from the Pan-African orogen in Togo, West Africa

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Abstract

The Dahomeyide Orogen in Togo and adjoining parts of SE-Ghana and Benin records the West Africa Craton (WAC) suture into NW Gondwana. The suture zone is a narrow and lithologically diverse region with HP granulite complexes. In Togo the Akaba Massif, located in the central part of the country, belongs to this suture zone. Petrographical and whole rock geochemical analyses are used to evaluate the characteristics, petrogenesis and mode of emplacement of the Akaba Massif. The new data suggest that the massif consists of layered amphibolites, garnet-free granulites and metapyroxenites, which were equilibrated under granulite facies conditions and subsequently partially retrogressed to amphibolite facies. Geochemical data suggest that the granulites may have preserved the geochemical imprints of their igneous protoliths. They display tholeiitic affinity, slightly enriched LREE, no Eu anomaly and negative anomalies in Nb and Zr indicating subduction zone magma. These features are consistent with protoliths of N-MORB affinities. The Akaba Massif rocks originated in an oceanic arc environment and are thought to have been derived from a metasomatized mantle source.

Keywords: Granulites, Petrography, Geochemistry, Akaba Massif, Pan-African Orogeny, West Africa



Evolution of the External Nappes Zone of the Dahomeyide Belt: Implication for the pre-Gondwana position of the West African Craton during the Rodinia-Gondwana supercontinent cycle

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Abstract

The West African Craton (WAC) and Amazonia Craton are thought to have been connected from 2.0 Ga until their breakup during the Cretaceous. Nonetheless, this connection is poorly constrained in the Mesoproterozoic and early Neoproterozoic, although the Amazonian Craton is positioned close to the WAC in almost all the reconstructions of the supercontinent Rodinia (1200 – 1000 Ma). An Amazonian - WAC connection during the Mesoproterozoic is also supported by U-Pb baddeleyite ages from dolerite dyke swarms. Here, we present detrital U-Pb zircon ages from the external nappes of the Dahomeyide Belt and compare them with the Borborema Province to put positive constraints on the reconstruction of the pre-Gondwana position of the WAC with respect to the Amazonian Craton in the Rodinia-Gondwana supercontinent cycle. The Dahomeyide external nappes comprises siliciclastic units of the Voltaian Supergroup, the Buem structural unit and the Togo structural unit. Detrital zircon ages (3100 – 2500 Ma, 2400 – 2000 Ma, 1800 – 1000 Ma and 930 - 600 Ma) on the Buem structural unit, Togo structural unit and the Voltaian Supergroup, reveal two main sedimentary sequences in the Dahomeyide Belt, i. e., passive margin and foreland basin sequences with three potential provenances: Amazonian Craton, Benin-Nigerian Shield, ± West African Craton. The 3100 to 930 Ma zircon population corresponds to an Amazonian Craton provenance, with a minor contribution from the WAC, whereas the 900 – 600 Ma population belongs to the Benin-Nigerian Shield provenance. The evolution of the passive margin sequence of the Dahomeyide Belt started with the deposition of the Bombouaka Group of the Voltaian Supergroup (with a depositional age of 959 ± 65 Ma Rb–Sr isochron on clay), and was followed by the deposition of the Togo and Buem structural units, with depositional ages of 703 ± 8 Ma (zircon U-Pb on a metabasalt in the Togo structural unit) and of ca. 650 Ma (Rb/Sr in glauconite), respectively. This large variation in depositional ages reflects a long period of passive margin basin existence (from ~1000 to ~700 Ma), allowing zircons with 1000 – 930 Ma ages to be incorporated in the upper section of the passive margin units. Passive margin sedimentation was halted by the onset of the Neoproterozoic Pan-African orogeny, which resulted in subduction of the WAC and eventual collision with the Benin-Nigerian Shield between 780 and 570 Ma. Deposition of foreland basin sequences occurred during and after Pan-African continent-continent collision. This finding is reminiscent of the sedimentary rocks of the Borborema Province (NE Brazil), and implies similar evolution along the West Gondwana Orogen during the break-up of Rodinia and subsequent assembly of the Gondwana Supercontinent. As a greater portion of the detritus originates from the Amazonian Craton, the coexistence of the WAC and the Amazonian Craton with no major seas between is proposed to have lasted from the Palaeoproterozoic until the opening of the Atlantic Ocean in the Cretaceous.

Keywords: Gondwana, Rodinia, Dahomeyide Belt, Passive margin, West African Craton, Amazonian Craton

Cryogenian arc-continent collision in the Southern Brasilides and the origin of the Ugab and Swakop Zones, Namibia

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Abstract

The Neoproterozoic Adamastor and Khomas Oceans separated the Congo craton from South American cratonic blocks and the Kalahari craton, respectively. These palaeo-oceans are key features in plate reconstructions of the break-up of Rodinia, and their closures are associated with major Pan-African orogens and the assembly of Gondwana. Sedimentary records from the margins of these basins include the iconic Cryogenian Snowball Earth sequences of the Otavi/Swakop Group, which are preserved in the Kaoko and Damara Belts of Namibia. Despite the central role of these palaeo-oceans in Neoproterozoic tectonics and Earth history, disparate tectonic and palaeogeographic models persist for the tectonic setting of the Otavi/Swakop Group. The classic model for deposition of Cryogenian glacial deposits of the Otavi/Swakop Group is along rifted passive margins; however, recent models propose Cryogenian subduction under the Kaoko margin of Congo. Here we use new geological mapping, stratigraphy, Nd-, Hf-, and C-isotope geochemistry, and U-Pb zircon geochronology from the distal margins of the Congo and Kalahari cratons and allochthonous terranes in the Damara and Kaoko belts in Namibia as input to a new continuous palaeogeographic model for the opening and closure of these former ocean basins. Detrital zircon age spectra from Cryogenian strata in the Ugab (Southern Kaoko) and Swakop Zones of Namibia are similar to those from the upper Andrelândia and Araxá nappes in Brazil that formed with the collision of the Paranapanema block and Socorro-Guaxupé arc with the São Francisco craton above SW dipping subduction. This arc-continent collision in the southern Brasilides fed thick fans to the SE that are dominated by Cryogenian zircon, consistent with palaeocurrent and provenance data from the Zerissene turbidite system of the Ugab Zone. This ca. 650-630 Ma collision also initiated closure of the northern Adamastor Ocean between São Francisco and Congo, which is recorded on the western Congo margin by the influx of detritus from the DRC and Angola to the north. New mapping west of the Sesfontein thrust in the Kaoko Belt of Namibia suggests that exotic detritus from the Brasilia belt did not arrive on the Congo margin until the Ediacaran. The Ugab and Swakop Zones arrived with the Coast Terrane on the Congo margin above a SW-dipping subduction zone at ~600-590 Ma and collided with the SW Congo margin creating the orocline from the Kaoko Belt through the Outjo Zone, which resulted in the deposition of the Mulden foredeep and development of the Huab cusp ridge. Collision was followed by ca. 580 slab-breakoff, subduction reversal, and closure of the Khomas Ocean, culminating in the Damara orogen between Congo and Kalahari. Importantly, Cryogenian detrital zircon ages and geochemistry from Kalahari and Congo are distinct from those of the Ugab and Swakop Zones, which argues against a Congo or Kalahari origin for either terrane. Our new palaeogeographic reconstruction suggests that low-latitude arc-continent collisions associated with the earliest phases of the Pan-African orogens increased global weatherability that contributed to cooling and the initiation of Snowball Earth.

Keywords: U-Pb detrital zircon geochronology, Cryogenian arc-continent collision, Snowball Earth, Ugab Zone, Swakop Zone

Key findings of the multidisciplinary and integrated geoscientific mapping in the Giyani Greenstone Belt and surrounds, South Africa

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Abstract

The Council for Geoscience has embarked on an integrated and multidisciplinary geoscientific research in the Giyani Greenstone Belt (GGB) and surrounds. The objective of the project is to support economic growth, address water security and promote environmental stewardship through an integrated approach that covers multi-discipline tasks (i.e. detail geological mapping, soil geochemical mapping, geophysical investigations, geotechnical, groundwater and environmental studies). This data is also targeted toward understanding the geodynamic evolution of Archaean environments and how these affected various mineralizing systems. The GGB is situated along the boundary between the Kaapvaal Craton and the Southern Marginal Zone of the Limpopo Metamorphic Belt. It comprises largely of tonalite-trondhjemite-granodiorite rocks, metavolcanic and metasedimentary rocks and various Archaean-Palaeoproterozoic age granites. Six 1:50 000 geological maps covering the entire GGB and the surroundings were produced. A magnetotelluric (MT) survey focusing on deep crustal features (>15km) was conducted in the central part of the GGB along a profile of about 30 km, oriented NW-SE. This included the delineation of deep crustal shear zones and subsidiary structural zones. Integration of MT and historical geological datasets on deep geological structures confirmed that these subsurface structures hold potential for structurally controlled gold mineralization in the area. This is corroborated by the results of the Induced Polarization Survey in one of the generated mineral targets. Integration of the geological, regional soil geochemical datasets and radiometric data delineated previously unmapped sequences in the region. Geotechnical, groundwater and environmental studies were conducted to address socio-economic challenges in the area. Geotechnical studies led to a production of a geotechnical map, which delineated areas suitable for development. Hydrogeological results revealed that high-yielding groundwater occurrences are located on geological structures, which control water flow. Groundwater analyses revealed high concentrations of arsenic close to historical mining areas.

Keywords: Mapping, Archaean, Magnetotelluric survey, Geotechnical studies, Groundwater, Environmental studies, Giyani Greenstone Belt, South Africa

Geological evolution of northern Malawi: the final piece of the Ubendian jigsaw

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Abstract

The Palaeoproterozoic Ubendian Domain in Malawi comprises the SE segments of three distinct crustal blocks, namely (from north to south) the Mbozi, Ufipa and Nyika subdomains. Together, they represent about 30% of the surface area of the entire belt. A number of U-Pb zircon and Sm-Nd whole-rock isotope data are presented. The Mbozi Subdomain (SD) is predominantly comprised of mafic gneisses (Mbozi Group) with no Palaeoproterozoic granitoids. The Ufipa SD comprises several units of high grade supracrustal gneisses (Ufipa Group), with a maximum depositional age of ~2040 Ma, deposited upon a “cryptic” tonalite-granodiorite orthogneiss basement dated at ~2150 Ma, occurring as scattered bodies within the paragneisses. Small volumes of post-Ufipa Group granitoid were emplaced at ~1975 Ma followed by the emplacement of a series of Mesoproterozoic A-Type granites (Mwenga Suite) at ~1150 Ma. The Nyika SD also contains cryptic gneissic basement remnants (~2125 Ma), overlain by sequences of supracrustal gneiss (Nyika Group) deposited at ~2000 to 1980 Ma. These rocks were intruded by a number of granite plutons of varying age up to ~1946, with the emplacement of the porphyritic granites of the post-tectonic Nyika Suite. Three Nd-T_{DM} ages of mafic rocks from the Nyika SD between 2.4-2.8 Ga illustrate the influence of a source of Archaean inheritance, most likely from the Tanzania Craton. High grade regional metamorphism, migmatitisation and ductile deformation marked by vertical stretching took place soon after deposition of the supracrustal groups. The U-Pb data show only very limited evidence of ~1.1 Ma (Irumide) disturbance, but extensive effects of ~550 Ma (Pan-African) metamorphism. The current geometry of the northern part of the Ubendian Domain is largely controlled by Pan-African structures, dominated by the NNW-striking low- to medium grade Mugesse shear zones and in the south by the conjugate WSW-striking Mwembeshi shear zones. The bulk of the intervening Nyika SD is less affected, apart from the weaker N-S striking Nthalire shear zones. The historic three-fold crustal subdivision of the Ubendian Domain in Malawi is thus confirmed. Remnants of a cryptic but widespread ~2.1 Ga older basement have been identified, upon which supracrustal rocks were deposited around 2.0 Ga, followed by high grade metamorphism, accompanied and outlasted by a protracted and complex magmatic history in the Nyika SD. The data presented here show that the Ubendian rocks of Malawi are both coeval and contiguous with the Palaeoproterozoic “Bangweulu Block” of Zambia to the west, probably without a tectonic break. Thus, the whole concept of a separate, cratonic, Bangweulu Block is called into question. Rather it is proposed that the combined Bangweulu-Ubendian-Usagaran “belts” represent a contiguous Palaeoproterozoic orogenic system surrounding the southern part of the Archaean Tanzania Craton.

Keywords: Ubendian, Palaeoproterozoic, Bangweulu Block, Malawi

New geological mapping and reconstruction of geological evolution of southern Ethiopia

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Abstract

New geological mapping of the rock units of southern Ethiopia enables a comprehensive assessment of the geological patterns and the overall geodynamic evolution of the region. Southern Ethiopia provides unique records of geological evolution of the Earth's crust from Precambrian to Recent. Among the significant events studied are the East-African orogeny (ca. 770 to 550 Ma) and the evolution of the Main Ethiopian Rift (from ca. 42 Ma to recent). The Precambrian basement rocks in Ethiopia differ in deformation style, degree of metamorphism (low- to high-grade units), and lithological patterns. The tectono-metamorphic evolution could be summarized in four phases: (a) the late Tonian to late Cryogenian formation of volcanic arc(s) dated at ca. 770 Ma; (b) the crustal accretion related to intense migmatization and HT-MP metamorphism (T: 700–850 °C and P: 0.7–0.9 GPa) at depths of ~25–35 km dated at ca. 720 and 715 Ma; (c) the late Cryogenian to early Ediacaran episode (ca. 650 to 620 Ma) of continental collision associated with the main collisional episode between East Gondwana and the consolidated Congo–Tanzanian–Saharan craton of West Gondwana; (d) the Ediacaran–Cambrian Pan-African episode (ca. 630–500 Ma) linked with the late-orogenic exhumation, post-orogenic magmatism and localized activity along regional strike-slip shear zones.

The Main Ethiopian Rift is an active intra-continental rift bearing magma-dominated extension between the African (Nubian), Somalian, and Arabian lithospheric plates. The current extension rate between the African and Somalian Plates in the southern Main Ethiopian Rift is 5.2 ± 0.9 mm/yr in ~E–W direction. The Main Ethiopian Rift (MER) reflects a characteristic evolution of continental rifting from early plateau basalt lava flows (pre-rift stage), followed by forming of fault-dominated rift morphology in the early stages of continental extension (early-rift stage) toward magma-dominated extension (late rift stage). The formation of rift-related faults and escarpments commenced during the Miocene, accompanied by the extrusion of basalts, felsic volcanics, and volcanoclastics varying from intermediate to alkaline composition. These volcanic eruptions were followed by a period of drastically low volcanism. Subsequently, Pleistocene to Holocene late rift bimodal volcanic activity (from ca. 7 Ma to Recent) ensued along with volcanoclastic rocks and rhyolites and strongly welded rhyolitic ignimbrites and other pyroclastic deposits. The late rift volcanic activity is dominated by a sequence of felsic volcanoclastic deposits, alkali basalt to trachyte lava flows and pyroclastic cones.

Keywords: Geological mapping, Tectonics, Petrology, Geochemistry, Ethiopia

ST02_S02: Geochronology of the African continent and applications of new techniques- a window into the evolution of planet Earth

Precise Geochronology Aids Stratigraphy of the Sinclair Supergroup

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Abstract

U-Pb geochronology enabled was used to investigate the stratigraphy and crustal development of the Mesoproterozoic Sinclair Supergroup in the Konkiep Terrane (Namibia). This was mapped during the 1970-1990s, when three magmatic cycles were identified, but few reliable dates were established. We collected and dated 46 samples using ion probe and laser ablation ICP-MS U/Pb zircon methods, with 2 σ errors usually <10 Ma, complimented by Lu/Hf, Sm/Nd and geochemical analyses. Major advances include - Basement: We dated the oldest magmatic cycle at 1374 - 1300 Ma, but could not identify older basement. Regional metamorphism is absent, minor contact metamorphism and greenschist grade shear zones were found. Chronostratigraphy: Some units had been wrongly placed in the stratigraphic column, as volcanic and intrusive rocks may lack unique field characteristics. Rocks mapped as part of the 1108 Ma Guperas Formation north of the Wêeldsend Fault were reassigned to the 1344 Ma Welverdiend Formation, previously correlated with the 1214 Ma Barby Formation. We confirmed that the felsic Haiber Flats Formation and andesitic Barby Formation are coeval. We produced a simplified geological map uniting the Sinclair Mine and Awasib Mountains areas and signaling the way for future work. Tectonic setting: The Rehoboth Magmatic Arc, long established in the literature, comprised a north-trending leg in the Konkiep Terrane and an east-northeast trending leg following the Damara Front, including all three magmatic cycles. However, the significant gaps of 80 and 90 m. y., respectively, between the cycles make a continuous subduction history unlikely. The first magmatic cycle formed in a continental rift setting at the beginning of the Namaqua-Natal Wilson Cycle. Only the 1217-1205 Ma second magmatic cycle in the Konkiep Terrane is subduction-related, with calc-alkaline affinity and shoshonite lavas. Subduction of a Namaqua Ocean, culminated in the ~1200 Ma collision of the now highly metamorphosed Grunau Terrane and the Konkiep Terrane. The east-northeast trending leg of the Rehoboth Magmatic Arc does not exist as it only contains third cycle ~1100 Ma volcanic rocks belonging to the subcontinent wide Umkondo Large Igneous Province, uplifted along the Damara Front. Tectonostratigraphy: The Konkiep Terrane, which was previously regarded as part of the Namaqua-Natal Metamorphic Province to the southwest, has more in common with the Rehoboth Province to the northeast; similarities include comparable detrital zircon age spectra with rare Archaean grains, similar Lu-Hf evolution trends and evidence of a Palaeoproterozoic basement as shown by xenocryst data. The Konkiep Terrane's underwhelming tectonometamorphic response to collision with the Grunau Terrane (no regional metamorphism), shows that it already had a strong crustal structure before 1200 Ma. The corrugated regional magnetic texture, which distinguishes the Konkiep Terrane from the inland Rehoboth Province, developed during of the three Mesoproterozoic magmatic cycles.

Keywords: Konkiep Terrane, Rodinia, Rehoboth Province, Wilson Cycle, Namaqua-Natal Metamorphic Province

Detrital Zircon Geochronology of the Aubures, Guperas and Kunjas Formations: Constraints on Depositional Ages, Sediment Sources and Crustal Evolution

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Abstract

The Konkiep Terrane occurs along the western margin of Kalahari Craton in southern Namibia. The stratigraphy, geochronology and crustal evolution of the Konkiep Terrane are addressed using U-Pb ages and Lu-Hf isotope data from detrital zircons. The Kunjas, Guperas, Barby and Aubures Formations provide new constraints on sediment sources and crustal evolution. Our results show three episodes of crustal generation in the Archaean, Palaeoproterozoic and Mesoproterozoic eras. Archaean zircons as old as 3400 Ma were probably derived from the now unexposed basement of the Rehoboth Province, Palaeoproterozoic events between 2100 Ma and 1800 Ma have possible sources in the Rehoboth or Namaqua-Natal Province, while the youngest episode at 1400 Ma - 1100 Ma encompasses the whole Namaqua - Natal Mobile Belt. This age group corresponds to dated igneous rocks in the Konkiep Terrane and might have been locally derived. ϵ_{Hf} values for Archaean and Palaeoproterozoic zircons are subchondritic indicating derivation from old, reworked crust. Mesoproterozoic zircons show ϵ_{Hf} values which are similar to those obtained for magmatic rocks in the Konkiep Terrane, suggesting local derivation and involvement of both juvenile and old continental crust. U-Pb dating of detrital zircon grains produced maximum depositional ages of 1105 ± 12 Ma, ca. 1107 and 1305 ± 17 Ma for the Aubures, Guperas and Kunjas Formations respectively. The age spectra of the Aubures Formation, resemble those found in the sedimentary units of the Koras Group (South Africa) and the Langberg Formation in the Rehoboth Province, which supports the correlation of these units as suggested by previous researchers. The Guperas Formation records an age spectrum comparable to those obtained for the Billstein quartzite of the Rehoboth Group, suggesting a potential link. ϵ_{Hf} values and crustal residence ages (2873 Ma – 1547 Ma) correspond to those determined for rocks in the Rehoboth Province supporting earlier suggestions that the Konkiep Terrane might have originated as part of the Rehoboth Province.

Keywords: Konkiep Terrane, Sinclair Supergroup, Detrital zircon, U-Pb dating, Lu-Hf isotopes, Namibia

The geochronology and formation of granodiorites and granites within the Gawib Pluton and the Kubas Complex in the Damara Orogeny, Namibia (Poster)

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Abstract

The Gawib Pluton in the Damara Belt, Namibia, consists of two main intrusive rock types; magnesian, calc-alkaline, mostly metaluminous hornblende and titanite-bearing granodiorites and magnesian to ferroan, metaluminous to slightly peraluminous calc-alkaline granites. Uranium–Pb zircon data obtained on the granodiorites gave concordant ages of 548.5 ± 5.6 Ma indicating that the pluton belongs to the early syn-orogenic magmatism in the Damara orogeny. Major element variations indicated that fractional crystallization was the major rock forming mechanism for these granodiorites. Interpretations of geochemical and isotopic data from the complex suggest that the early syn-orogenic Pan-African igneous activity in this part of the Damara Belt was a high-temperature intra-crustal event. In contrast to igneous processes along active continental margins that also produce intermediate plutons with calc-alkaline affinities, this igneous event was not a major crust-forming episode, and the granodiorites represent mostly reprocessed crustal material. Interpretation of geochemical and isotope data from the complex suggests that the early syn-orogenic Pan-African igneous activity in this part of the Damara Belt was a high-temperature intra-crustal event. In contrast to the Kubas Complex, major and trace element data from c. 550 Ma-old grey granites and c. 510 Ma-old red leucogranites of the high-grade central part of the Damara orogen (Namibia) indicate that they are of dominantly deep crustal origin. In comparison with experimental results, the granites were derived by partial melting of granodioritic biotite gneiss at 900–950 °C and less than 10 kbar. Slightly peraluminous red leucogranites are also considered to be isotopically evolved (initial ϵNd : –15 to –18) but have undergone extensive crystal fractionation coupled with minor contamination of mid crustal meta-pelitic material. The consistency of the chemical data with a crustal anatectic origin and the observation that the grey granites intruded before the first peak of high-grade regional metamorphism suggests that they intruded simultaneously with the crustal thickening event. The red leucogranites are interpreted to be a result of crustal melting during the main peak of regional metamorphism. The heating events that promoted melting of fertile deep-crustal rocks might have been caused by the inferred high heat productivity of heat-producing radioactive elements (Th, U, K) together with crustal thickening during the main periods of the orogeny.

Keywords: Damara Orogeny, Geochronology, Trace elements, Granodiorite, Granites, Namibia

Geochronology and isotope geochemistry of the Cryogenian Abenab Subgroup on the western margin of the Congo Craton, Namibia

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Abstract

The Kaoko Belt along the Western margin of the Angola/Congo Craton records a collision with Rio de la Plata Craton during the amalgamation of Gondwana. Previous authors have suggested that the Coastal Terrane formed as an arc/back arc on the Congo margin by 650 Ma and collided ca. 590-570 Ma in an upper plate position with the arrival of Rio de la Plata. Others proposed that the South and West Congo margins were passive from Cryogenian through Ediacaran and that the Coastal Terrane did not arrive until ca. 590 Ma. Previous studies on the Kaoko margin in the Sesfontein area have suggested exotic sources appeared in Cryogenian strata, but these data are from units with poor stratigraphic control. This research targets the Abenab Subgroup in the Steilrandberg area, north of Opuwo to provide maximum deposition ages and to assess provenance using U-Pb detrital zircon from autochthonous late Cryogenian strata, as well as present new $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ record to establish an age model for these strata. Our data do not record large ca. 1.05 and 0.65 Ga peaks in Cryogenian successions that are seen in the Central and Ugab zones, thus discrediting models of proximal exotic source on the Congo margin at this time. The minor Cryogenian ages suggest reactivation and magmatism somewhere on the Congo margin, possibly to the north. This data suggests that the Coastal Terrane, and perhaps the Central and Ugab zones, were separated from the western Congo margin until the Ediacaran.

Keywords: Kaoko Belt, Abenab Subgroup, Coastal terrane, Neoproterozoic, Cryogenian, Angola (Congo) Craton, Namibia

Spatio-temp patterns of sediment provenance in the Dahomey Basin (SW Nigeria) investigated by means of U-Pb zircon geochronology

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Abstract

The Dahomey Basin of SW Nigeria is an arcuate depression connected with the opening of the Gulf of Guinea and rifting between Africa and South America. The basin infill consists of Cretaceous to recent deposits and preserves the first cycle of Phanerozoic sedimentation in the region. It was established on crystalline bedrock of the Nigerian Basement Complex (NBC), a crustal domain strongly overprinted by the Pan-African orogeny and intruded by Neoproterozoic granitoids. Flanking of the NBC by older Archaean to early Palaeoproterozoic cratonic blocks makes U-Pb geochronology of detrital zircons a promising tool to evaluate sediment dispersal and characterization of the main phases of crustal accretion and reworking during continental assembly. We present novel U-Pb analyses of zircons from two bedrock units (migmatitic gneiss and meta-sedimentary schist) at the margin of the Dahomey Basin, and on detrital zircons from separate units of the sedimentary infill (two samples from the Cretaceous Abeokuta Formation, one from the Eocene Ilaro Formation, and one from modern sands of the Osun River). Zircons extracted from the migmatitic gneiss consistently yielded Ediacaran ages ($n=43$), documenting pervasive resetting of coeval or inherited zircons during the Pan-African orogeny. All zircon grains from the metasedimentary schist show clear core-rim structures in cathodoluminescence (CL) images, with well-developed homogeneous rims. Rims consistently yielded Neoproterozoic (mostly Ediacaran) ages, but cores exhibited a broader age range, from Neoproterozoic to Mesoproterozoic (1-1.4 Ga) and Palaeoproterozoic (1.6-1.7 and 1.9 Ga). Therefore, metasedimentary units in the NBC preserve an indirect record of crustal events pre-dating the Pan-African orogeny. Erosion and transport of these grains account for distinctive pre-Neoproterozoic age populations in detrital zircons of Dahomey Basin sediments. Their provenance from metasedimentary source rocks should be identifiable in CL-images by the distinctive core-rim internal structure of the grains. From the four detrital zircon samples, a total of 1015 accepted ages (~250 per sample) were obtained. Of these, only six were Phanerozoic (one Silurian and five Cambrian), while the predominant age population in all samples was Neoproterozoic (58% to 87%). Archaean grains were absent in one sample and represented a minimal fraction (one, five and seven grains, respectively) in the other three. These results point to the NBC as the primary sediment source for the investigated units. Significant differences in presence/absence and relative abundance of Mesoproterozoic and Palaeoproterozoic age peaks were observed between the four samples. These dissimilarities could reflect variable source rocks, sediment transport processes or complexities of U-Pb geochronometry, and are to be explored further by correlating age and other grain attributes such as size, shape, internal structure, U content, and Th/U ratio. This study provides an initial framework for provenance analysis in the Dahomey Basin and contributes to the reconstruction of crustal history in Western Africa.

Keywords: Dahomey Basin, Detrital zircon, U-Pb geochronology, Provenance, Nigerian Basement Complex (NBC)

Provenance of the Anyaboni Formation of the Voltaian Supergroup, Ghana (Poster)

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Abstract

Petrographic and whole-rock geochemical studies were carried out on 20 sandstone samples collected from the Anyaboni Formation (Asesewa area) of the Voltaian Supergroup, to determine its provenance. A detailed petrographic study of thin sections was carried out using Leica DM 750 microscope. Modal mineralogy was determined by the Gazzi-Dickinson point-counting method with a Pelcon automatic point counter. At least 500 points were counted per slide. The samples were also analyzed for their major, trace and rare earth element concentrations. The major elements were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES) and trace element and rare earth element (REE) concentrations were determined by inductively coupled plasma mass spectrometry (ICP-MS). Loss-on-ignition (LOI) for the samples was determined by gravimetric method. Petrographically, the Anyaboni sandstones can be classified as quartz arenite and subarkose. The dominant framework grain is quartz; monocrystalline quartz dominates over polycrystalline quartz and mostly show undulose extinction with mineral inclusions of white mica. Lithic fragments constitute up to 8% of the rock volume and are mostly sedimentary and metamorphic in origin. These suggest derivation from granitic and recycled sedimentary rocks. Geochemically, the sandstones show high SiO₂ content (~ 90 wt%). The Th/U values are mostly higher than 4.0 and high field strength elements, (Zr, Hf), show enrichment over the ferromagnesian elements (Cr, V) on Neoproterozoic Upper Crust normalized trace element plot. On chondrite-normalized REE diagram, the sandstones show fractionated LREE patterns (average La_N/Sm_N = 3.55), negative Eu-anomalies (average Eu/Eu* = 0.62), and a fairly flat but slightly depleted HREE patterns (average Gd_N/Yb_N = 1.59). These favor a dominantly felsic source. The most likely source lithology, compatible with the observed petrographic and geochemical features, is metasedimentary and associated granitic rocks of the Palaeoproterozoic Biriman sedimentary basins. Quartz dominance in mineralogy, quartz feldspar lithics (QFL) and major element discrimination diagrams, suggest the tectonic setting of the depositional basin was a passive margin. Pre-metasomatized high chemical index weathering (CIW) values (75 to 99) and high plagioclase index of alteration (PIA) values (71 to 98) suggest intense chemical weathering at the sediment source area, which further suggests a warm, moist climate prevalent during the deposition of the Formation.

Keywords: Neoproterozoic, Petrography, Geochemistry, Provenance, Voltaian Supergroup, Ghana

Detrital Zircon Morphology and U-Pb Geochronology of Late Ordovician-Early Cretaceous Sandstones from the Coastal Sedimentary Deposits of Ghana: Implications for Provenance (Poster)

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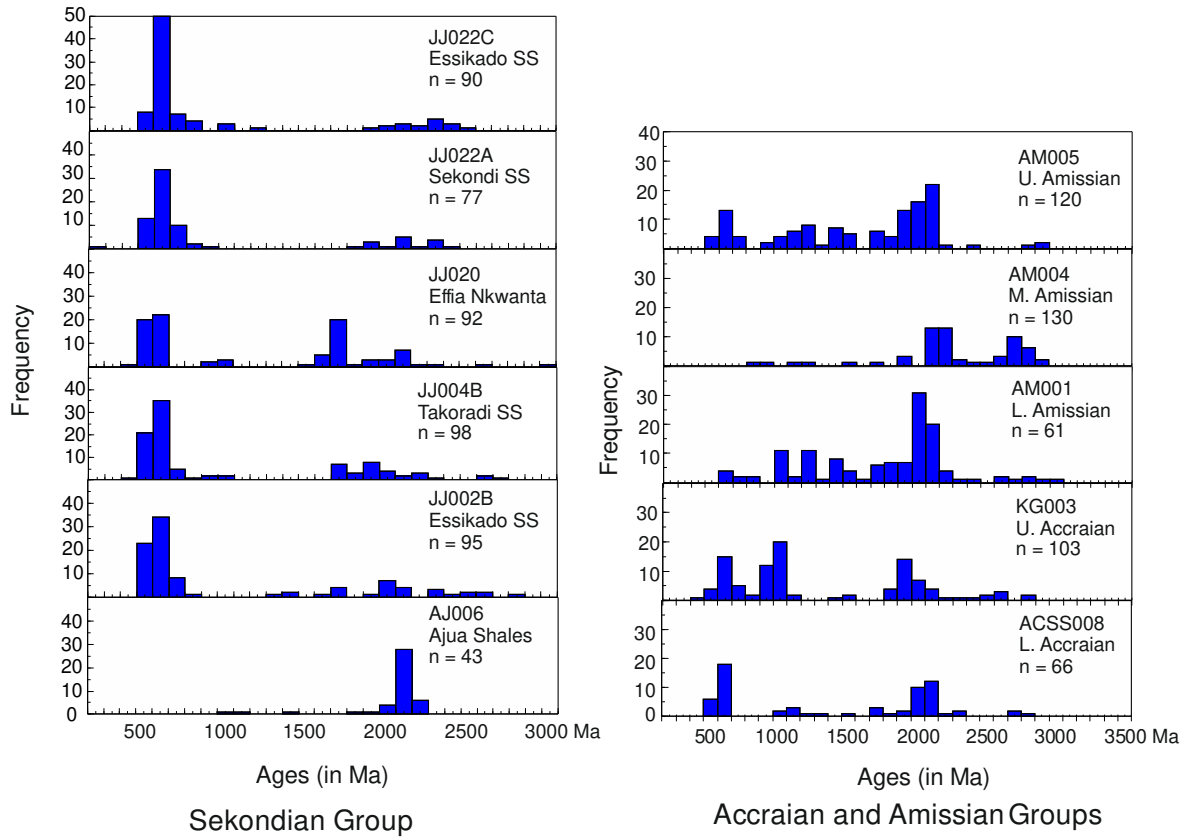
Abstract

Ordovician to Mesozoic sedimentary rocks are distributed along the coastal region of Ghana. They include the Sekondian Group, the Accraian Group and the Amissian Group. The provenance of these sedimentary deposits has been previously studied by their petrography and whole rock geochemistry. However, one of the limitations of the petrographic and geochemical approaches to provenance studies is that they are unable to deal effectively with mixed provenance. The application of radiogenic isotope techniques, particularly U-Pb dating of detrital zircons, to sedimentary provenance studies is especially appealing, because it eliminates any ambiguity of mixed populations from different sources. In this paper, we report the U-Pb dating of detrital zircons from these Phanerozoic deposits and discuss their provenance. Eleven (11) samples, comprising six (6) from the Sekondian Group, two (2) from the Accraian Group and three (3) from the Amissian Group were analyzed for their morphology and U-Pb geochronology using Scanning Electron Microscopy coupled with Cathodoluminescence Imaging (SEM-CL) as well as U-Pb measurements. A total of 1011 well-shaped detrital zircon grains were studied for their morphological characteristics, i. e. elongation (length-width ratio) and roundness; not less than fifty (50) grains were studied for each sample. A total of 890 zircon grains were analysed for their U-Th-Pb compositions resulting in about 1479 laser spots of which 975 concordant ages were used in data interpretation. The lowest formation of the Sekondian Group, i. e. the Ajua Shale, is represented by angular and stubby zircon grains of Birimian ages (2.3-1.9 Ga), implying a primary (non-recycled) parent source. This age range is characteristic of the Palaeoproterozoic Birimian Supergroup, which form the underlying rocks of the Sekondian Group. It is most likely therefore that these zircons were derived from the granitoids of the Birimian Supergroup. The zircons of the upper formations of the Sekondian Group and those of the Amissian and Accraian Groups, have a mix of angular, sub-angular and non-angular grains of Birimian ages (2.4-1.9 Ga), Mesoproterozoic to early Neoproterozoic (1.8-0.8 Ga) and Pan-African (0.8-0.5 Ga), suggesting their derivation from the Pan-African orogenic belt, with contributions from the Voltaian Supergroup and Birimian granitoids.

Keywords: Detrital zircon, Provenance, Phanerozoic, Sekondian Group, Ghana

BOOK OF ABSTRACTS

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Histogram of detrital zircon ages for the studied samples

ST02_S03: Structural geology and Tectonics**An integrated approach to Quaternary palaeo-shoreline correlation along the Southwest Coast of South Africa – Implications for neotectonics****Debbie Claassen*, Ponani Mthembi, Dawn Black***Council for Geoscience, Pretoria, South Africa***Corresponding author: dkilian@geoscience.org.za***Abstract**

Authors present contrasting views on possible neotectonic activity along the West Cape Coast of South Africa. In this study, correlation in the altimetry and chronology of onshore marine terraces and associated marine-related sediments, which preserve the combined effects of long-term eustatic fluctuations and regional crustal movements, is employed to establish Quaternary uplift rates and tectonic warping or displacement, particularly in proximity to known fault zones. To assess the tectonic stability, a two-phase data collection process was undertaken between Velddrif and Pringle Bay in the Western Cape Province. Phase one involved the comprehensive sourcing of existing data to create three geospatial databases that capture palaeo-shoreline indicators, Cenozoic geochronology, and subsurface borehole lithostratigraphy. Phase two involved the acquisition and development of a variety of new datasets derived from both field and desktop activities. Additional palaeo-shoreline indicators were identified through high-resolution survey mapping, LiDAR data, topographic profiles, interpolated palaeo-bedrock topography surfaces, palaeo-bedrock profiles, geological cross-sections, and new drillings. The holistic integration and interpretation of datasets revealed that wave-cut platforms and marine deposits associated with the Middle Holocene highstand ($\sim 3.5 \pm 0.5$ m asl) and the Late Pleistocene last major interglacial (MIS 5e) ($\sim 6 \pm 1$ m asl) are in agreement with known local eustatic manifestations. Surrounding undated palaeo-shorelines at similar elevations were consistently correlated across the coastal margin with no obvious tectonically related vertical displacement. Middle Pleistocene MIS 11 ($\sim 9/10 \pm 1$ m asl) terraces were challenging to identify due to Cenozoic cover and limited geochronology. Nonetheless, regional correlation suggests uniformity and absence of tectonic warping. Near Cape Columbine, the Colenso Fault is projected to extend beneath an extensive wave-cut notch capped by a calcrete. The shoreline tentatively correlated to MIS 11 remains continuous, suggesting a lack of vertical movement along the fault in the last ~ 400 ky. In addition, no fault scarp or displacement of the calcrete cap was found. Older Early Pleistocene to Pliocene terraces situated at ~ 15 , ~ 18 – 21 , and ~ 30 m asl, although identified, frequently lack geochronology and are often subject to re-occupation and/or dating uncertainties. However, their consistency in elevation inspires greater confidence in tectonic stability. The interpretation of borehole-interpolated palaeo-bedrock surfaces, in conjunction with palaeoclimate and eustatic reconstruction, revealed that Oligo-Miocene fluvial deposits of the Elandsfontyn Formation, extending far below present sea level at numerous localities along the coast, can be attributed to the presence of bedrock-incised palaeo-valleys subject to sea level changes without the need for major localized neotectonism of the type previously proposed. Similar palaeo-valleys were identified in the Cape Flats area where the credibility of the proposed >100 km Milnerton Fault is inconclusive. However, if present and in the proposed location, subsurface data across the False Bay area reveal a lack of offset in overburden marker beds. Ultimately, the data affirms the concept of a stable southern African passive continental margin with low regional isostatic rock uplift rates of <2 – 6 m/My since the Pliocene. No evidence of neotectonism or crustal warping along the proposed 'Cape Microplate' was found but can't be ruled out for much older Miocene to Mid-Pleistocene terraces where detailed geochronology is absent.

Keywords: Palaeo-shoreline, Terraces, Neotectonics, Tectonic uplift, South Africa

The Role of Segmentation, Reactivation & Dynamic Topography in the Evolution & Preservation of the Atlantic 1 Diamond Placer

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Abstract

It is almost 30 years since mining operations began in the Atlantic 1 Mining Licence on the southernmost shelf of Namibia. The marine diamond recovery fleet expanded rapidly, and through continuous improvement of mining rates and efficiencies for the different technologies used, annual production in excess of 1 million carats has been sustained since 2012.

During this time, the geological model for the placer continued to evolve as the diamond recovery activities opened up detailed windows into the orebody. Developing the Diamond Resources to allow the next 30 years of mining to be planned strategically has required the acquisition of new datasets, some of which extend into previously little-known areas.

Insights emerging provide hitherto unseen evidence of the spectacular geodynamics of this part of the Namibian margin during the Cenozoic. For the first time, the role that margin segmentation and reactivation tectonics have played in controlling the location, evolution, and preservation of the diamond placer on the Namibian continental shelf are becoming apparent.

Building upon the foundational lithostratigraphic framework that was produced using the detailed micropalaeontological studies of Ian McMillan, the geophysical evidence of extensive, large-scale Cenozoic tectonism means that much remains to be discovered about the dynamics of the economically significant fluvial-marine interface of Africa's iconic Orange River.

Keywords: Cenozoic, Reactivation tectonics, Dynamic topography, Diamond placer, Namibian shelf

Evolution of Phanerozoic tectonic stress on the western margin of the Congo Basin-Recording from the brittle fracturing of the Inkisi sandstones in Kinshasa and Brazzaville

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Abstract

The history of the brittle fracturing and related tectonic palaeostress have been analysed in the rapids of the Congo River at the outlet of the Pool Malebo between Kinshasa (Democratic Republic of the Congo) and Brazzaville (Republic of the Congo). A polyphase brittle deformation, mainly strike-slip, have been recorded in the lower Palaeozoic Inkisi sandstones. Those are surmounted by upper Jurassic shales and Cretaceous mostly aeolian sandstones. The upper part of the latter which has been partly silicified during the Palaeogene, is also affected by some brittle fracturing. The outcrops of in the river bed, studied in periods of low water over a period of seven years provided an important data bank of structural data on fractures and faults which have been used in a kinematic analysis and palaeostress inversion using the Win_tensor programme. An iterative procedure allowed to separate the total fault population into subsets, each characterized by a reduced stress tensor. Those represent four distinct brittle tectonic phases, all under a strike-slip tectonic regime, with the maximum principal stress axis (σ_1) horizontal. They all represent manifestations of far-field stresses originating from the interactions at the plate boundary, first of Gondwana, then of Africa, after its separation from South America. No extensional tectonic stress has been recorded.

Keywords: Evolution, Phanerozoic tectonics, Congo Basin, Polyphase brittle deformation

Contribution of geochemical and morpho-structural data to the geodynamic interpretation of Hoggar volcanism (Algerian Sahara): a new model of its origin

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Abstract

Large volumes of tholeiitic, alkaline and peralkaline, saturated and undersaturated lavas occurred in the Hoggar from the Eocene to the Quaternary. Numerous necks, domes, veins, plateaus, basaltic scarps, and various pyroclastic materials are the manifestations and products of this volcanism. They are distributed alongside the principal lithospheric faults that frequently separate the main blocs of the Hoggar. The current study focuses on several provinces of this volcanism in the LATEA, which roughly corresponds to an Archaeo-Palaeoproterozoic micro-continent fragmented by major faults during the Pan-African orogenic events. Following the methodology proposed by Nkono *et al.* (2009), the study consists of mapping volcanic structures, faults and associated lineaments using mid-resolution satellite imagery, such as Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) and Digital Elevation Models (SRTM: Shuttle Radar Topography Mission). This enables us to constrain the stress field and fault sets during volcanism. We thoroughly mapped the volcanic structures and applied a digital model that made it possible to determine the preferred distribution directions for each structure. Lineaments were processed similarly. In addition, we have incorporated recent results from processing geophysical data (magnetic and gravimetric), satellite imaging, and a geochemical synthesis to offer additional constraints that we think are crucial to the data processing. We highlight the importance of the NE-SW lineament of the Oued Amded, along which most of the various Cenozoic Hoggar volcanic provinces are situated, as well as its dextral movement (which most likely occurred primarily during the late Pan-African phases). We demonstrate that the study area has been subjected to significant Pan-African or Mesozoic lithospheric delamination. The volcanic activity is located at the intersection of this delaminated lithosphere and the lineament of the Oued Amded, or some of its satellites. The results obtained concur and suggest a direct relationship between the distribution of the volcanic structures and the lineament directions. These lineaments are disposed in accordance with a Riedel model. The volcanic structures are preferentially disposed in the transtensive T direction defined by the model. We propose a model where the origin of this volcanism is related to the activity along the Oued Amded lineament, and the presence of a lithosphere of widely variable thickness, re-fertilised by previous events. We will discuss its relationship with Cretaceous rifts, the presence of ancient cratons surrounding the Hoggar, and the counter-clockwise rotation of Africa towards Europe.

Keywords: Riedel Model, Peralkaline lavas, Cenozoic, Hoggar, Volcanism

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Multi-scale and multidisciplinary study of marbles above the Beni Bousera peridotite-granulite unit (Rif Belt, Morocco): Implications for the western Tethys opening

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Abstract

The Gibraltar Arc represents the western termination of the peri-Mediterranean Alpine orogenic systems. This orogen formed during the Alpine Mesozoic-Cenozoic convergence between Africa and Eurasia, which is associated with subduction of the westernmost Tethys lithosphere of the northwestern African plate. The timing and process of exhumation of the subcontinental peridotites of the Gibraltar Arc (Ronda, Beni Bousera (BB)) have been discussed extensively over the last decades. In this contribution, we present the results of our recent study carried out on high-grade marbles outcropping around the Beni Bousera antiform (northern Rif). In the field, the Beni Bousera marbles (BBMs) form lenticular outcrops, ~30 to 300 m thick, sandwiched between the granulites (kinzigites) of the Beni Bousera Unit (BBU) and the gneisses of the overlying Filali Unit (FU). These calcite-dolomite marbles present silicate-rich levels with conglomeratic layers that may contain reworked peridotites and kinzigites elements from BBU (work in progress). The structural analysis shows that the BBMs punctuate a major ductile shear zone: the Filali-Beni Bousera Shear Zone (FBBSZ), marked by intense mylonitization. The FBBSZ is accompanied by nested thrusts that place the kinzigites on the marbles with NW kinematics characterized by NNE-trending fold axes. Late normal faults cut the ductile structures of the FBBSZ. The petrological investigations show that the BBMs did not experience the HT-HP metamorphism of Variscan age recorded by the underlying granulites but rather a HT-LP metamorphism (~700-750°C, 4-8 kbar) comparable to that of the overlying Filali gneiss unit. U-Th-Pb geochronological results indicate that detrital zircon cores from the BBMs yield two age groups at ~270 Ma and ~340 Ma, suggesting a post-Permian depositional age. The zircon rims provide ages at ~21 Ma, corresponding to a thermal event associated with the back-arc opening of the Alboran Basin. Ar⁴⁰/Ar³⁹ phlogopite dating of the BBMs provided ages between 23 Ma and 24 Ma, close to U-Th-Pb ages of ~21 Ma obtained at the rims of zircons. These ages were attributed to the inversion of the major ductile shear zone (FBBSZ) under conditions of HT-LP metamorphism, related to the emplacement of gneisses of Filali Unit onto the kinzigites and peridotites of the BBU. The results reported here suggest that the Beni Bousera mantle rocks were exhumed at shallow depths as part of the southern magma-poor passive margin of the Alboran domain associated with a major detachment fault (subsequently inverted as the FBBSZ) during the Triassic-early Jurassic rifting responsible for the birth of the Maghrebian Tethys. During the Alpine orogeny, the lower Sebtides (BBU, BBMs, and FU) were affected during the (Upper Eocene)-Oligocene by tectonic burial, thrusting, and metamorphism before their final exhumation during the Miocene.

Keywords: HT-LP metamorphism, Triassic rifting, Mantle exhumation, Western Tethys, Gibraltar Arc

Structural Tectonic Evolution of the Buffels River shear zone, Namaqua Sector, Namaqualand-Natal Metamorphic Province, South Africa (Poster)

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Abstract

The Buffels River shear zone is an ENE-WSW oriented shear zone located within the Bushmanland Subprovince of the Namaqua Metamorphic Province, approximately 50 km south of the town of Springbok, north-western Namaqualand (South Africa). The shear zone has previously been described as the contact between the O'kiep and Garies Terranes in the north and south, respectively, while other authors disagree, stating that the contact between the two terranes is not the Buffels River shear zone but rather lies further to the south of it. Thus, the extent and relationship of the shear zone with the adjacent O'kiep and Garies terranes, have been poorly defined due to lack of structural and geochronological data. The methodologies applied in defining the tectonic evolution of the Buffels River shear zone include geological mapping, petrography, geochemistry, geochronology and isotope analysis. The rocks of the supracrustal belt occur as sheet-like bodies generally concordant to the regional gneissic foliation and are bordered on either side by a wall-rock of less deformed coarse-grained augen gneiss which has the same penetrative foliation trend as the supracrustal belt. The Buffels River shear zone is host to granitic orthogneisses of the ~1210 Ma Mesklip Gneiss, leucocratic gneisses of the 1204 ± 4 Ma Rooiplatklip Gneiss, as well as metamorphosed supracrustal rocks, i. e. garnet-biotite semi-pelitic gneiss (1222 ± 25 Ma to 1171 ± 21 Ma) and the grey biotite gneisses of the Kamiesberg Subgroup (1138 ± 22 Ma to 1113 ± 22 Ma), as well as 1168 ± 9 Ma amphibolite lenses of the Oorkraal Suite. The trace of the supracrustal belt is defined by a steep NNW-dipping, 4 km-wide zone consisting of mainly sheared supracrustal sequences and streaky augen gneiss which have a regionally consistent ENE-WSW trend of about 260° . Based on the findings of this study the Buffels River shear zone does not represent a terrane boundary as the Mesklip Gneiss outcrops on either side of the shear zone, with their geologic, geochemical and geochronological histories being identical. The Buffels River shear zone formed during D_3 deformation, and its age can be constrained between ~1138 Ma and ~1005 Ma, using the youngest detrital zircon age of the volcanoclastic rocks of the grey biotite gneiss and the end of the D_3 deformation, respectively. The shear zone developed preferentially along a supracrustal belt, during the D_3 deformational phase, forming a "steep structure" between megascale dome and basin structures situated north and south, respectively, and therefore does not represent a terrane boundary between the O'kiep and Garies Terranes.

Keywords: Namaqua-Natal Metamorphic Province, Bushmanland Subprovince, Buffels River shear zone, Structural geology, Steep structure, South Africa

Two Ediacaran collisions in the Damara Belt of Namibia: a northern margin perspective

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Abstract

The Damara Belt of Namibia has long been viewed as a late Ediacaran (~550 Ma) collision zone between the Kalahari and Congo cratons brought about by northward-dipping subduction of intervening oceanic lithosphere (Khomos Sea). However, it is wider than typical collision zones (e. g. Himalayas) and the syn-collisional foreland basin (Mulden Group) on the northern (Congo) margin lacks Ediacara-type fossils and is likely older than its tectonic equivalent (Nama Group) on the Kalahari margin where they abound (Germs, 1974). Geochronological evidence for a ~600 Ma collision in the Northern Zone was published by Lehmann *et al.* (2015). Since subduction is the main driver of plate convergence, two asynchronous collisions in the Damara Belt (excluding Kaoko-related events) imply two basins floored by subductible (quasi-oceanic) lithosphere. The rift–drift transition on the Congo margin is stratigraphically well-defined at ~655 Ma, implying that the northern basin (Outjo Sea) was open for ~55 Ma. I postulate southward-dipping subduction initiation along the southern margin of the Outjo Sea at ~625 Ma, when the plate was young enough (~30 Ma) to rupture but old enough to sink. Subduction initiation resulted in back-arc rifting and separation of a magmatic-arc bearing continental ribbon (Central Zone), which moved northward in response to Outjo Sea closure, allowing the back-arc basin (Khomos Sea) to open in its wake. Subduction polarity flip in response to arc-continent collision (between Central Zone and Congo margin) at ~600 Ma resulted in northward-directed subduction initiation along the northern margin of the Khomos Sea at ~590 Ma. Closure of the latter by northward subduction led to terminal collision at ~550 Ma of the Kalahari passive-margin with the Congo craton and its previously accreted Northern and Central Zones. In this interpretation, the Damara Belt records the asynchronous openings and closings of two seaways: the Outjo Sea (~655–600 Ma) and the Khomos Sea (~590–550 Ma). Although short-lived, both must have been floored by subductible lithosphere, if hypothetical forces external to the Damara Belt are disallowed (Occam's Razor). To the west, all three plates (Congo, Central Zone and Kalahari) were being subducted westward beneath the Ribeira–Dom Feliciano composite magmatic arc, which collided diachronously (southward younging) with the Congo–Damara–Kalahari system along the Kaoko and Gariiep Belts, which re-opened in the Early Cretaceous to form the South Atlantic Ocean. The proposed two-collision model for the Damara Belt makes testable predictions regarding the igneous chronology of the Central Zone and its margins. The Central Zone is modelled as a composite ensialic magmatic arc resulting from southward-directed Outjo Sea subduction (~625–600 Ma) followed by northward-directed Khomos Sea subduction (~590–550 Ma). A rift–drift transition at ~590 Ma is predicted for the Kalahari margin, which is ≥45 Ma younger than the age inferred from Witvlei Group stratigraphy. If the older age is correct, then the Khomos Sea opened before the Outjo Sea closed, and its opening was decoupled from subduction initiation in the Outjo Sea. The Damara Belt is a classic Pan-African collision zone needing accurate U–Pb geochronology of chemically-abraded igneous zircons.

Keywords: Pan-African orogeny, Damara Belt, Dom Feliciano magmatic arc, Neoproterozoic

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Exhumation of mantle peridotite in an embryonic oceanic basin at slow to ultraslow spreading ridge within the Dahomeyide belt in Ghana, West Africa (Poster)

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Abstract

The occurrence of exhumed mantle peridotite, gabbro, tectono-sedimentary breccias, volcanic rocks, marine and continental sedimentary units in the Buem structural unit (BSU) of the Pan-African Dahomeyide Belt in Ghana share similarities with typical ophiolite sequences. The BSU ophiolite complex, however, is incomplete (due to the absence of a sheeted dyke complex) compared to the classical Penrose ophiolite sequence, as displayed for instance by the Oman and Troodos ophiolites, and its lithological components are in both primary and tectonic contacts. Nonetheless, the BSU is characterized by features that are consistent with ocean-continent transition ophiolites similar to those of Iberia-Newfoundland and Alpine-Apennine. In the BSU, the serpentinitised peridotite dominates in terms of volume, and is either overlain by oceanic sediments, mafic volcanic or plutonic rocks, which are subordinate. The geochemical and isotopic characteristics of the mafic volcanic and plutonic rocks associated with the BSU serpentinitised peridotites are mostly similar to those of magmas formed by melting of depleted mantle. These MORB-type rocks have been interpreted as embryonic oceanic crust formed during the transition from rifting to seafloor spreading during the opening of the Pharusian Ocean. Slow and ultraslow spreading ridges are amagmatic with episodic magmatic activities resulting in thin oceanic crust (<7 km); thus the high effect of serpentinitisation is due to sufficient exposure of peridotites to the ocean floor. The significant effect of serpentinitisation of the BSU peridotite may indicate exhumation in a slow to ultraslow-spreading ridge. Geochemical and geochronological data for the clastic sedimentary rocks of the BSU associated with the mafic-ultramafic rocks suggest passive margin deposits, deposited during the opening of the Pharusian Ocean. Comparing the results from this study to data from the Novo Oriente Group indicate an evolution of the West Gondwana Orogen from initial mantle exhumation to syn-rift magmatism (Novo Oriente Group) and early stages of seafloor spreading (BSU mafic-ultramafic rocks) as has been proposed for the Alpine ophiolites. Therefore, ophiolites in the West Gondwana Orogen are of two main domains, i. e. proximal OCT of the Novo Oriente Group and distal embryonic oceanic crust of the BSU, formed during the break-up of the supercontinent Rodinia.

Keywords: Buem structural unit, Ophiolite, Peridotite, Exhumation, Sea floor spreading, Ghana

Ground-fissures origin as an interplay of active tectonics, lithological pattern and piping mechanism (Central Main Ethiopian Rift System)

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Abstract

The Main Ethiopian Rift (MER), where active continental rifting creates specific conditions for surface and sub-surface erosion, provides a prospective area to study the influence of tectonics, lithology, geomorphology, and climate on characteristic geomorphological and geological features. The formation and polyphase reactivation of faults in the changing regional stress-field significantly increase the rocks' tectonic anisotropy, the risks of slope instabilities and suffosis erosion. The suffosis erosion (also called tunnelling erosion, piping) is a serious risk for populated sites due to an unpredictable collapse and subsidence of the surface. The tunnelling erosion forms tunnels in the underground which further widens and finally the ceiling of the tunnels collapses forming a deep gully (ground fissures) and endanger population and infrastructure. Abundant ground-fissures in the southernmost Central Main Ethiopian Rift, are excellent natural laboratory to study their origin and formation. Specific conditions and factors influencing the origin and formation of ground fissures were discovered as follows: (a) The linkage between the ground-fissures and regional rift-related normal faults and associated extensional joints is an indisputable evidence that the active tectonic structures are key driving mechanism with a direct influence on the origin of ground-fissures. The slight a slight "clockwise" change of the direction of regional extension may have an influence on the overall ground-fissure geometry leading to the typical "*en-echelon*" patterns. (b) The presence of typical rock environment defined by "rigid" and "impermeable" layers (base), consisting mostly of ignimbrites which are overlain by several meters thick unconsolidated volcanoclastic deposits with low amount of clays. These essential conditions must be fulfilled to initiate "piping" as the control mechanisms for the subsurface erosion and tunnelling. Whereas the first condition could be researched using traditional geological techniques the latter one can be identified by means of seismic measurements as zones with a significant seismic anisotropy.

Keywords: Ground-fissures, Tunnelling erosion, Piping, Main Ethiopian Rift, Tectonics

Structural mapping of the ptygmatic folding of the cap carbonate layer in the Northern Naukluft Complex, Namibia

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Abstract

The Naukluft Nappe Complex is a fold and thrust belt formed during the last stage of the Damara Orogeny during the Cambrian between ~550 and 500 Ma. It consists of stacked nappes of Neoproterozoic strata, that were transported over a minimum distance of 78 km to the southeast from their origin in the Southern Margin Zone of the Damara Orogen onto the lower Nama Group of the Southern Foreland (Hartnady, 1978). The lithology of the northern part of the Naukluft Complex, in Blässkrans Formation consists mainly of limestone and dolostone, with layers of black limestone, interspersed with schists and phyllites. Amongst this package is a sequence of diamictite followed by a thick layer of cap carbonate, which forms part of one of the notable climate change episodes in Earth history, known as the Marinoan Snowball Earth event dated at ~635 Ma (Hoffmann *et al.*, 2004). These units, which are part of the Blässkrans Formation, are ptygmatically folded. We mapped the folded cap carbonates in the northern part of the Naukluft Nappe Complex to produce a detailed structural map of the area and identify the deformation episodes recorded by these folds. We present detailed descriptions of the lithologies and structures, as well as their spatial orientations. Stereonets are used to unravel the various stages of deformation, and tie them in with a broader regional tectonic interpretation.

Keywords: Cap carbonate, Naukluft Nappe Complex, Blässkrans Formation

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Structural framework and tectonic evolution of the offshore Namibe Basin, Angola

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Abstract

The Namibe Basin in southwest Angola formed during the rifting of the South Atlantic in the Lower Cretaceous and records a Valanginian to Quaternary succession both onshore and offshore. The offshore sector is an attractive exploration target due to similarities with proven hydrocarbon discoveries in the Kwanza Basin further north and the conjugate Santos Basin, as well as bitumen occurrences in the onshore sector. However, the offshore tectonostratigraphy is poorly constrained due to an absence of well data. The influence of magmatism on structure and sedimentation has not yet been addressed. High-resolution 3D seismic data (15,300km² area) provided by PSG was used to study the structural configuration of the Namibe Basin. The results were compared with potential field data (magnetics, gravimetry) provided for this study by PGS. Parallel to strike the offshore basin is segmented into three structural sectors: 1) a northern sector, which is dominated by a dual set of faults oriented NNW-SSE and N-S; 2) a central section comprised of N-S normal faults and accompanying en-echelon synthetic faults; and 3) a southern sector with N-S and NNW-SSE faults. The central sector has seen relatively higher subsidence compared to the northern and southern sectors and is the main salt depocenter. Two W-E trending structural arches of variable width (<500 m), but no obvious connection to onshore structural elements, separate the sectors. From east to west, three main crustal domains can be identified based on degree of faulting, reflection signature and magmatic budget. The continental domain reaches from the relatively unstretched hinterland in the east to the Atlantic hinge, which marks the landward termination of the purely continental basement. A hyper-extended domain forms part of the continental crust and is constrained between the Atlantic hinge and a marginal ridge further west. A sag basin is best developed above this hyper-extended domain and thins eastwards to the onshore sector. The marginal ridge coincides with an elevated basement feature and represents the necking zone corresponding to a positive anomaly on potential field maps. The transitional domain furthest to the west shows evidence of magmatism and Seaward Dipping Reflectors (SDRs), which are reminiscent of embryonic oceanic crust. This and several pulses of post-breakup volcanism suggest that the Namibe Basin is a volcanic-rifted margin, which based on seismic characterization is consistent with an upper plate setting. This may also explain the presence of a narrow sag basin. Several scenarios of possible uplift and dynamic support of the rift flanks due to post-rift convective systems may be responsible for the lack of salt beyond the limits of the hyper-extended domain. Our observations indicate the likelihood of dynamic support along salt-free rift shoulders as added component to lack of subsidence.

Keywords: Tectonic evolution, Namibe Basin, Reflector, Tectonostratigraphy, Angola

Polyphase deformation during prolonged HT metamorphism: constraints on dome formation in the Central Zone of the Damara Belt, Namibia (Poster)

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Abstract

The 590–470 Ma Pan-African Damara Belt formed near-synchronously with the Kaoko and Gariep belts in a rare trench-trench-trench triple junction setting during the Gondwana supercontinent assembly. While the Damara Belt has been the subject of numerous studies, the number, duration, and tectonic significance of metamorphic phases in the HTLP Central Zone (CZ) of the Damara Orogen are debated. Previous works proposed either short-lived but polyphase metamorphism or a prolonged, single-phase metamorphic evolution for the CZ. Furthermore, the relation between metamorphism and polyphase deformation in the CZ is still debated. To address these questions, we consider the Namibfontein-Vergenoeg (NV) domes, two adjacent, migmatite domes in the CZ. The NV domes formed by interference folding during three periods of crustal shortening. 1) An early phase of Kaokan E-W shortening produced upright folds with steep N-S striking S1 fabrics. 2) Subsequent Damaran, broadly N-S shortening resulted in dome-scale, moderately to steeply NNW-NNE-NE-plunging folds with moderately to steeply NNW-N-NNE-dipping S2 foliations. During progressive N-S shortening, low-angle W–NW-plunging F3 folds, and shallowly NW-dipping S3 fabrics overprinted S1 and S2 fabrics. The entire migmatitic edifice was affected by NE-plunging F4 folding with NE-dipping S4 fabrics, during 3) orogen-parallel, NE-SW shortening. All deformation fabrics grew at suprasolidus, amphibolite facies metamorphic conditions (as evidenced by structurally controlled leucosome in all deformation fabrics). Synkinematic assemblages are similar for all deformation fabrics (kfs-pl-qz-bt-sil ± grt-crd with accessory mon-zr-ilm-ap ± mag), except for garnet which is stable in D1 and D2 assemblages but is absent in D4 fabrics. Pseudosection modelling along with detailed petrography of migmatitic metapelite indicate peak temperature conditions of 3.5–4.6 kbar and 750–760°C. Based on a lack of medium–high-pressure inclusion mineral phases in early garnet (inclusion assemblage in garnet is the same as in the matrix except for cordierite), we envision a shallow, clockwise PT path with a temperature increase to ~750°C and subsequent anatexis during D1. Peak temperature conditions were likely reached during D2 and D3, after which the system cooled. D4 was active during the cooling phase, where garnet was no longer stable, but melt was still present (~740–690°C). U-Pb petrochronology of monazite from three structurally controlled leucosome and near-source S-type granite samples indicate that monazite continually grew and recrystallised from at least 540 Ma to 490 Ma. These data suggest that the rocks of the NV dome experienced one prolonged HTLP metamorphic event. During this time, the hot and partially molten rocks were progressively deformed by at least four phases of folding during three highly oblique tectonic switches resulting in fold interference structures. These results have implications for the tectonic evolution and long-lived heat flow (~50 m.y.) in the shallowly buried, hot orogen. Prolonged melt residence in the hot and weak migmatitic terrain may have contributed to the complex structural record of the CZ, with the Damara Belt deforming heterogeneously due to differing rheologies across the orogen.

Keywords: Pan-African orogeny, P-T-t-d, Monazite petrochronology

The role of crustal scale shear zones in Southwest Gondwana consolidation - Transatlantic correlation

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Abstract

We present the first correlation between South American and African shear zones based on a new reconstruction model of SW Gondwana continental crust, correlating 57 Brasiliano–Pan-African crustal-scale shear zones that sutured this palaeo-continent at c. a 500 Ma. The methodology included a compilation of shear zone data, along with geological database of the new Gondwana map (GIS), at 1:5M scale, all integrated with 17 platelets, that were reconstructed to 183 Ma using G-Plates software. This new kinematic model considers internal deformation on the South America continental crust corroborating the Gondwana fit and better linking the piercing points (subvertical shear zones) in line with the restoration of De Wit *et al.* (2008). The final amalgamation and consolidation of the SW Gondwana continental crust were attained by an anticlockwise rotation of three cratons (Kalahari, Angola and São Francisco) in relation to the clockwise rotation of the Río de la Plata Craton in the Early Palaeozoic Gondwana. These relative movements were accommodated by transcurrent shear zones active from 585 to 500 Ma within the Pan-African – Brasiliano belts that surround these cratons. This kinematic interaction resulted in the initiation of a long-term active margin starting with the Cambrian Pampean Orogeny and ending with the Permian–Triassic Gondwanides Orogeny.

Keywords: Continental reconstruction, Collision tectonics; Pan-African – Brasiliano belts, Piercing points

Reference:

De Wit, M.J., Stankiewicz, J. and Reeves, C. 2008. Restoring pan-African-Brasiliano connections: More Gondwana control, less Trans-Atlantic corruption. *Geol. Soc. Spec. Publ.*, **294**, 399–412, <https://doi.org/10.1144/SP294.20>.

Kenya Rift Valley Break-Up: Focus on Velocity, Trend and Vertical Displacement

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Abstract

The famous East African Rift System (EARS) is an intra-continental ridge system that comprises of two main branches; the Eastern and Western Branches. The Eastern Branch was of interest to this study because it hosts the study areas in the Northern Kenyan Rift (NKR) and the Central Kenyan Rift (CKR). The study sought to determine the difference in velocity break-up rates between the Victoria microplate and the Somalian plate with a focus on the Northern and the Central Kenyan Rifts, to determine the role of GPE in differentiating the break-up velocity rates between the NKR and the CKR, and finally to determine the effects of meteorological factor (in this case rainfall) on crustal subsidence due to continental water loading along the rift. The data was processed using GAMIT/GLOBK programmes, which use automated scripts to calculate the precise estimates of specific positions and velocities on Earth. Receiver independent exchange (RINEX) formatted files of Global Positioning System (GPS) data collected from the thirteen Global Navigation Satellite System (GNSS) stations were used, for the precise position estimates and velocities. For extension velocity rates along the rift and trends, a horizontal solution that was later converted to the Victoria microplate reference frame was found using the rot programme and plotted using Generic Mapping Tools (GMT). On the other hand, to determine whether the increasing lake levels directly affect subsidence along the rift, station position time series files from GAMIT/GLOBK for the stations close to major lakes along the Kenyan Rift Valley were used to visualize seasonality using tsview; a modular software used for image acquisition, processing, and analysis. To analyze the correlation with meteorological factors, rainfall data for the corresponding years from Kenyan Meteorological Department (KMD) were analyzed using Microsoft Excel to create a time series and used for comparison. The GNSS stations in the Northern Kenyan Rift (NKR) showed slower extension rates with XTBI and XTBT measuring 0.8mm/yr and 2.1mm/yr velocity break-up rates respectively. On the other hand, the Central Kenyan Rift (CKR) GNSS stations showed faster extension rates with KYN6, KYN4, KYN3, KYN2, and KYN7 measuring 1.7mm/yr, 1.5mm/yr, 3.0mm/yr, 2.0mm/yr, and 3.3mm/yr velocity break-up rates respectively. The GNSS stations in the NKR show slower geodetic rifting rates unlike the GNSS stations in the CKR. The difference in the break-up velocity rates could be possibly due to the influence of Gravitational Potential Energy (GPE) that is higher in the CKR due to high topography, unlike the NKR, which is generally a depression, thus having lower GPE. The position time series also recorded surface amplitude change that portray an inverse relationship with rainfall time series. Thus, this inverse relationship shows a systematic correlation between vertical displacements portrayed by crustal subsidence and continental water loading (CWL), where increase in rainfall leads to crustal subsidence, and little or no rainfall leads to crustal flexure.

Keywords: East African Rift System, Kenya Rift Extension Rates, Vertical displacement, Gravitational potential energy, Continental water loading

ST02_S04: Intraplate magmatism**Late-rift volcanic activity in geochemical, petrological and tectonic perspective (Tosa Sucha Volcanic Complex; Southern Main Ethiopian Rift)**

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Abstract

The studied area is situated in the southern part of ~NNE–SSW trending Main Ethiopian Rift (MER) belonging to the Cenozoic East African Rift System (EARS). The volcanic ridge Tosa Sucha Volcanic Complex separates Lake Chamo and Lake Abaya to the north. In total 17 samples of volcanic rocks were used for petrological investigation and/or whole-rock geochemical analysis. For the determination of the age of ignimbrites, the K–Ar method was applied. Our results indicate that volcanic activity commenced with eruptions of basaltic-to-basaltic trachyandesite (~0.8–1.9 Ma) lavas and pyroclastic deposits. In the later-stage (~0.7–0.5 Ma) the volcanic activity ensued with a heterogeneous composition of the magma ranging from basaltic to trachytic. The chemical variation in the volcanic sequences of the Tosa Sucha Volcanic Complex can be explained by fractional crystallization with very little crustal contamination. The mineral chemistry and geochemical modelling suggest that the first stage of the Tosa Sucha volcanic sequence evolved mainly under pressures of 3–4 kbar by fractional crystallization of clinopyroxene and olivine ± spinel and magnetite, in a moderately hydrous (H₂O = 2–3 wt %) conditions. The pressure estimates from these rocks imply that the magma impounded and crystallized at ~9–15 km depth. Our analytical data also shows that the subsequent stage of magmatism ensued under a significantly wider range of 1 to 6 kbar crystallization pressure conditions. Based on the inferred crystallization depth of 5–22 km of second magmatic stage, at least two magma reservoirs at different depths are supposed. The trachytic magmas are shown to be derived from a trachybasaltic melt via fractionation of the mineral assemblage clinopyroxene, olivine, and apatite. The Kaersutite phenocrysts yield temperatures of 988–1024 °C and 12–15 km depth of crystallisation. The Magnesio-fluorohastingsite in the crystalline groundmass on the other hand yielded the temperature of ~800 °C and the crystallisation depth of ~4 km. These changes in amphibole composition were associated with the opening of the system and loss of H₂O from 4 to 1 wt. %. The fabric pattern and palaeostress analysis tandem with the K–Ar ages of the volcanic complex reveals that the volcanism is closely associated with the regional extension that was active at the time in the ~SE(ESE)–NW(WNW) (azimuth 128°) direction along with evidence of local variation in the stress field.

Keywords: Mineral chemistry, Geochemistry, Geothermo-barometry, Tectonics, K–Ar dating, Southern Main Ethiopian Rift

The High Moulouya batholith in the upper crust: intrusion - host rock interaction and emplacement model

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Abstract

In the Moroccan Eastern Meseta, the Aouli-Mibladen and Boumia granitic massifs constitute a single batholith, covering an area of approximately 2400 km². This batholith, called the High Moulouya Batholith (HMB), is partially hidden under Meso-Cenozoic cover. The HMB was emplaced in Cambro-Ordovician metasedimentary rocks that had undergone greenschist facies metamorphism (Chl+Mus+Qtz+Pl+Kfs); subsequently they were affected by HT-BP superimposed contact metamorphism linked to HMB emplacement. Four metamorphic zones were evidenced defining four isograds corresponding to four main metamorphic reactions:

- The biotite zone is characterized by the overall mineral association Bt+Mus+Chl+FK+Qtz (\pm Pl \pm Grt) corresponding to the appearance of biotite and the discontinuous monovariant reaction: Chl+Qtz+FK+H₂O=Bt+Mus;
- The cordierite zone is composed of Bt+Mus+Crd+Chl+FK+Qtz (\pm Pl). Crd is formed by the reaction: Chl+Bt+Mus+Qtz = Crd+FK+H₂O;
- The formation of aluminium silicates defining successively the andalusite and sillimanite zones and their isograds corresponds to the following reactions: Mus+Crd=Bt+And (Sill)+Qtz+H₂O and/or Mus+Qtz=FK+And (Sill)+H₂O (4) and/or And=Sill (5).

The obtained results, using pseudosection modelling as well as petrogenetic grid calculations, allow to better define the P-T conditions of HMB emplacement. Biotite appears at a temperature of 400°C, cordierite at 500 to 520°C and andalusite at 580 to 600°C. The stability field of the andalusite-sillimanite paragenesis constrains the pressure at 2.6 to 2.9 Kb, which is considered constant for the entire metamorphic aureole. Therefore, the granitoids of the HMB were emplaced at a depth of 8.5 to 9.5 km, developing a contact aureole with temperatures ranging from 400 to 625°C. Moreover, 2D gravity modelling revealed that the HMB has a laccolithic shape with a thickness ranging from 3 to 5 km. The presence of numerous feeders suggests that the emplacement of the HMB occurred through a dyking process.

Keywords: Variscan, High Moulouya batholith, Pseudosections, 2D gravity modelling, Dyking, Morocco

Igneous dykes across the westernmost Orange River region

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Abstract

The semi-arid region around the westernmost Orange River exposes numerous cross-cutting mafic to felsic and more or less alkali dykes, some of which relate to nearby igneous central complexes. The objective was to unravel and group these into separate magmatic events, and even volcanic systems within these, based on the literature), field relationships, petrography and bulk rock geochemistry. Much field work was conducted in conjunction with joint venture mapping projects by the Geological Survey of Namibia and South Africa's Council for Geosciences. Results suggest the existences of at least seven dyke forming events which can be grouped in the following chronological order: (1) Mafic and felsic, subalkali, metamorphosed and deformed yet mostly E-W trending dykes within the Orange-Fish River confluence area, showing the strongest subduction zone signatures and likely feeders to de Hoop Subgroup lavas, within the Orange River Group of a Richtersveld Magmatic Arc. (2) Inside one remote Nama-window, SSW-NNE trending dykes appear as peripheral extensions of the Gannakouriep dyke swarm (GDS) but with high Mg & Si, low Ti and lithospheric signatures that differ too much from the GDS and bear a greater affinity to the ~1.1 Ga Umkondo large igneous province. (3) The Richtersveld Igneous Complex (RIC) includes SW-NE trending bostonite dykes that likely fed nearby felsic lavas and are best exposed at the Orange River's Sjambok section. Other, more N-S trending felsic dykes, outcropping across a wider area, may also relate to a mainly felsic RIC that may somehow be linked with an only up to 50 myr-younger mafic GDS. (4) The study area's most prominent N-S to SSW-NNE trending GDS, with up to 1 km-thick dykes, were emplaced during a ~795 Ma break-up of Rodinia. These dykes were deformed by sinistral transpression from the west, induced by the Gariep Orogen. Most of the swarm's dykes share remarkably restricted transitional basalt compositions and similar incompatible element signatures that are reconciled with a common, large and sub-crustal magma reservoir, which was in turn derived from a relatively enriched mantle (plume?) source. (5) The post-Gariep Kuboos-Bremen Line (KBL) includes several moderately alkali ring-complexes, where many dykes are tentatively linked to a north-easterly located Haruchas and a more centrally located Grootpenseiland-Marinkas Kwela complex, while other dykes are not as easily related to a specific complex. Apart from a few phonolites and carbonatites, most KBL-dykes are bimodally either trachy-basaltic or trachytic. (6) Both coast-parallel and -perpendicular dolerite dykes, related to the ~140-130 Ma opening of the South Atlantic, cut across the coastal Sperrgebiet area. Rather than representing circumferential dykes, significantly thinner coast-perpendicular dykes likely utilized transverse faults during proto-Atlantic rifting. (7) Numerous tephritic to phonolitic dykes that also cut across the Sperrgebiet area are more silica-undersaturated than KBL-dykes and belong to an Eocene Lüderitz Alkali Igneous Province, including inland Klinghardt lavas. Some dykes can tentatively be related to two exposed ring-complexes. Co-existing trachytes to alkali rhyolites likely formed through crustal assimilation during fractional crystallization of parental tephrites.

Keywords: Igneous dykes, Field relationships, Petrography, Geochemistry

Ouarkziz transitional crater (Algeria): morpho-metric parameters using remote sensing, field investigations and postimpact process (Poster)

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Abstract

The Ouarkziz structure is one of the four Algerian impact craters occurring on the EID (Earth Impact Database). It is well exposed, morphologically visible and partially covered. The structure is located in a vast, very arid Saharan geological domain, devoid of any vegetation cover. This makes it very easy to detect by TanDEM-X digital elevation model and Alsat-1B satellite images. The aim of this work is the analysis of the morphometric and structural parameters of the Ouarkziz crater on the basis of remote sensing and new field data, as well as the post-impact process affecting it. The Ouarkziz crater is a 3.5 km in diameter with a terrace width of 580 m. Based on its diameter alone it is classified as a complex crater; however, a central peak is not detected. On the TanDEM-X radar images, a small hill is observed to the SW of the central area, which field investigation has shown to correspond to vertical grey limestones constituting the base of the target rock on the North flank of the Tindouf basin with a thickness of 300 m. The stratigraphic peak SU allows an estimated depth of the formations implicated in uplifting of the central peak in a complex impact event; it has a depth of about 279 m at Ouarkziz. These deposits may then represent an “abortive” peak that has not undergone significant uplift to form a topographic, visible central peak. The elongated N-S diameter of the Ouarkziz is due to the thickness of the hard rocks forming the outer terrace towards the north; this terrace affects an easily eroded target towards the south. The Ouarkziz transitory crater was thus formed following the upraising of the dipped Lower limestones at the north, SE and SW sides, while the rim was formed on the marl with gypsum and the Upper limestones towards the south of the structure. This is confirmed by the TanDEM-X map which clearly shows that the Lower limestones have been uplifted from their original position at the SE and SW of the Ouarkziz structure. The height from the rim to the floor is more significant towards the north; this is due to the dipping of the north flank of Tindouf to the SW. The erosion of the Hamadian plateau seems to have contributed considerably to the burying of the structure. Ouarkziz has been considered for a long time as a “highly eroded structure” because of the absence of a central peak. In sedimentary rocks, at 3 km in diameter, some craters may develop a central peak and are therefore classified as complex (e. g. Goyder, Australia). In other craters of the same diameter, a central peak is not observed, which classifies them as simple (e. g. Gusev, Russia). Together with six other structures in the world, the Ouarkziz structure is classified as a transitional crater. The influence of the target rock characteristics (nature, lithology, rheology, thickness, pre-impact dipping) is discussed in this presentation.

Keywords: Ouarkziz structure, Transitional crater, Stratigraphic uplift, TanDEM-X, Algeria

Thickness estimates of the Etendeka volcanic province based on diagenesis of the Jurassic Etjo Formation, Namibia

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Abstract

The emplacement of the Paraná-Etendeka large igneous province in the Lower Cretaceous (~133 Ma; e.g. Renne *et al.*, 1996) marks one of the largest magmatic events in the history of Gondwana. On the African continent, present-day remnants of the lavas are largely restricted to the NW of Namibia where they attain a maximum preserved thickness of ~900 m (Milner *et al.*, 1992). Feeder dyke systems however indicate a much wider original extent of this volcanic province and, based on thermochronological analyses, several studies have indicated a much thicker original pile of volcanic rocks (up to 5 km; e.g. Raab *et al.*, 2005; Brown *et al.*, 2014). However, thickness values based on thermochronology rely on an estimated geothermal gradient and therefore vary significantly with the applied gradient. We present here an alternative approach to assess the Etendeka cover thickness by investigating the diagenesis of the aeolian upper unit of the Jurassic Etjo Formation. We have studied this sandstone at the localities of Waterberg, Mt. Etjo, and Gamsberg, that lie >100 km apart. At all locations, the sandstone is texturally mature and highly quartzose with very low quantities of feldspars and lithic grains. Significant differences are in average quartz cement values, which are 15.4 % at Mt. Etjo, 6.5 % at Waterberg, and 24.3 % at Gamsberg. The higher quartz cement volume as well as kaolinite-to-illite transformation at Mt. Etjo indicate a higher temperature there than at Waterberg. We attribute this difference to the proximity of Mt. Etjo near the presumed center of Etendeka volcanism and hence a thicker lava overburden than at Waterberg. Using Touchstone™ numerical modeling for sandstone diagenesis, supported by crustal heat flow modeling based on published crustal properties of the study localities, our preliminary results lean towards a Lower Cretaceous rock overburden of ~3.0 km at Mt. Etjo and ~2.2 km at Waterberg. The very high quartz cement volumes at Gamsberg are hard to interpret due to evidence for a first quartz cement generation prior to Etendeka burial. Nevertheless, our preliminary modeling results indicate an original Etendeka thickness above Gamsberg in a range similar to that at Mt. Etjo and Waterberg. Our study sheds light onto the extent and thickness of the Etendeka volcanic cover, which provides an important context for the understanding of the evolution of the African continental margin along the southern Atlantic. It improves our understanding to which extent flood volcanic rocks have modified the landscape and gives constraints on the amount of rock eroded since the Lower Cretaceous.

Keywords: Parana-Etendeka Large Igneous Province, Etjo Formation

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ST02_S05: Southern Namibia Mapping Programme: new insights into the geology and mineral deposits of the Karas Region (Special Session)**Geochemical and isotopic zonation of the Orange River Pegmatite Belt in Southwestern Africa – links to magmatic-hydrothermal events during the late Stenian-Tonian Rodinian assembly of the Namaqua Metamorphic Province****S. Doggart^a, C. Harris^b, P. Macey^c**^a*Council for Geoscience, South Africa*^b*Department of Geological Sciences, University of Cape Town, Rondebosch 7701, South Africa*^c*Department of Geological Sciences, University of Cape Town, Rondebosch 7701, South Africa***Corresponding author: sdoggart@geoscience.org.za***Abstract**

The Orange River Pegmatite Belt (ORPB) forms a continuous, ~450 km-long W-E trending belt intruding the Namaqua sector of the Proterozoic Namaqua-Natal Metamorphic Province (NNMP) in south-western Africa. The western section of the belt is predominantly composed of Li-Cs-Ta (LCT)-type pegmatites, whereas the eastern part is dominated by Nb-Y-F (NYF)-type pegmatites. Regional U-Pb geochronology suggests that the emplacement of the ORPB occurred over a period of approximately 75 million years (1040 to 965 Ma). This emplacement period coincided with, and surpassed, the strike-slip shear event at the conclusion of the Mesoproterozoic Namaqua orogeny. The pegmatites intruded along evolving NW-trending, subvertical shear zones, such as the Pofadder Shear Zone, as well as reactivated older Namaqua tectonic domain boundaries affected by transcurrent shearing. Sm-Nd isotope data for the pegmatites illustrate a correlation with respect to the ϵ_{Nd} values for the rocks from the hosting tectonic domains of the NNMP, implying a localized source for the pegmatites but a regional and contemporaneous melting process. The $\delta^{18}\text{O}$ values of quartz in the LCT pegmatites range from 6.9 to 9.4‰ (mean = 8.8‰) in the western section, whereas in the far eastern Kakamas Domain, they vary from 10.9‰ to 14.6‰ (mean = 12.5‰). Furthermore, quartz-feldspar mineral pairs range in $\Delta_{\text{qtz-fsp}}$ from -2.5‰ to 6.9‰. Only nine samples have $\Delta_{\text{qtz-fsp}}$ values between 0.3‰ and 1.53‰, consistent with equilibrium at magmatic temperatures. The remaining samples display evidence of fluid-rock interactions, either during high-temperature crystallization or low-temperature hydrothermal fluid activity post-emplacement. NYF pegmatites within the Kakamas domain exhibit a broader range of quartz $\delta^{18}\text{O}$ values (9.9‰ to 12.2‰; mean = 11.3‰), consistent with the mixed metamorphic rock assemblage in this area. $\Delta_{\text{qtz-fsp}}$ values for the NYF pegmatites range from 2.3‰ to 5.1‰, consistent with interaction with high-temperature hydrothermal fluids during crystallization and/or emplacement. These results further support the interpretations of the Sm-Nd isotope geochemistry, confirming a regional zonation of the ORPB in terms of both radiogenic and stable isotopic characteristics. The findings suggest a possible fluid source related to the melting of local host rocks, resulting in the widespread emplacement of pegmatites at approximately 1.0 billion years ago.

Keywords: Orange River pegmatite belt, LCT-type pegmatites, NYF-type pegmatites, Stable isotopes, Namaqua-Natal Metamorphic Province

How geoscience mapping and research in the Orange River Pegmatite Belt provide valuable insights into critical metal mineralization within the pegmatites of the Namaqua-Natal Metamorphic Province

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Abstract

The increasing demand for rare metals driven by the growth of the high-tech industry and the sustainable energy sector has renewed interest in the pegmatites of the ORPB. To address their strategic importance, we have initiated a comprehensive mapping and research programme in the Orange River Pegmatite Belt (ORPB), employing various techniques including regional and structural mapping, advanced remote sensing analysis, mineral geochemistry, and stable and radiogenic isotopic studies. The ORPB in southern Africa stretches approximately 450 km in an east-west direction, intruding the Namaqua sector of the Namaqua-Natal Metamorphic Province (NNMP). The ORPB exhibits variations in pegmatite characteristics along its strike, with the western part of the belt predominantly hosting Li-Cs-Ta (LCT)-type pegmatites, while the eastern section is dominated by Nb-Y-F (NYF)-type pegmatites. Our objectives encompass determining the spatial distribution, geometry, and structural hosts of the pegmatites, elucidating the nature and sources of the pegmatite melts and fluids, and gaining a deeper understanding of the processes that led to the enrichment of rare metals within the mineralized pegmatites. Extensive structural mapping, geochronological studies, and isotopic analyses have shed light on the tectonic processes and potential sources of these pegmatites. Initial findings from structural investigations suggest a relationship between host rock rheology variations, regional stress regimes related to D4 transcurrent shearing, and the creation of suitable structural sites for pegmatite emplacement. U-Pb geochronology has revealed that the emplacement of the ORPB occurred over a period of approximately 75 million years (1040 to 965 Ma). Sm-Nd isotope analyses have indicated that the source(s) of the pegmatite melts are influenced by the lithological composition (metasedimentary and/or meta-igneous rocks) of the hosting tectonic domains within the NNMP. A comprehensive review of the pegmatite mineral system within the Namaqua Metamorphic Province (NNMP) and incorporating ideas from global pegmatite studies has led to the development of a preliminary guide for investigating pegmatite fields in the context of frontier exploration for economically viable and strategic mineral deposits. The key findings suggest that the emplacement of pegmatites is influenced by several factors. (1) The presence of widespread lithospheric shearing and faulting at a regional scale. (2) The emplacement of pegmatites is favoured in an evolved collisional tectonic setting, which may involve orogenic collapse, slab delamination, and/or slab pull-back, resulting in lithospheric thinning. However, the source of pegmatite melts and fluids, as well as the concentration of critical metals, remains poorly understood and requires further investigation.

To advance this research, additional studies involving geochemical analysis, remote sensing, geophysics, and extensive field investigations are crucial. It is recommended to adopt a more targeted approach focusing on specific pegmatite clusters and regions to further investigate their potential and mineral fertility.

Keywords: Critical metals, Orange River pegmatite belt, LCT-type pegmatites, NYF-type pegmatites, Geological Mapping

The oldest rocks in Namibia: Archaean crustal fragments in the 1.9 Ga Richtersveld Magmatic Arc, NW Namaqua-Natal Metamorphic Province

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Abstract

Previous studies have suggested a juvenile island arc setting for the Richtersveld Magmatic Arc (RMA), the older Palaeoproterozoic block located in the westernmost Namaqua Sector of the Mesoproterozoic Namaqua-Natal Metamorphic Province. Recent geological mapping, U-Pb zircon geochronology and Sm-Nd isotopic studies carried out during the Southern Namibia Mapping Programme (SNMP) has, however, revealed the presence of older crustal “rafts” hosted within the RMA. Evidence includes the significant number of inherited zircons in RMA plutonic rocks (~1.9 Ga Vioolsdrif Suite) and detrital zircons in coeval RMA meta-sedimentary rocks (Orange River Group) with Neoproterozoic to Palaeoproterozoic age peaks (~3.3 to 2.0 Ga). Nd T_{DM} model ages of ~2.2-2.4 Ga also suggest older crust within the source region of the RMA magmas. Previous publications of the SNMP have demonstrated the ~2.02 Ga inheritance and detrital zircon peak in the RMA rocks is sourced from the Wasserkuppe Suite of the Sperrgebiet Domain, a pre-existing arc domain cannibalised by the RMA. The Bankwasser Migmatite (~2.9 – 2.5 Ga detrital ages) occurs as a mega-inclusion within the central RMA and is thought to be a fragment of the Kaapvaal Craton margin. Recent mapping and geochronology have revealed an even older Archaean crustal inclusion on the NW margin of the RMA, about 65km north of Lüderitz. The high-grade Blue Mountain Group metapelite contains detrital zircons between ~3.3 and 2.7 Ga and is surrounded by ~2.0 Ga Wasserkuppe Suite and ~1.9 Ga Vioolsdrif Suite rocks that have, together, been deformed, metamorphosed and intruded by granitoids during the polyphase Mesoproterozoic Namaqua Orogeny (~1.2-1.0 Ga). U-Pb analyses of detrital zircons obtained from the nearby Neoproterozoic low-grade diamictites (Halifax Formation) of the Gariep Supergroup yield a wide spread of ages from 3.3 to 1.0 Ga, with the older detritus confirming the presence of ancient crust in the vicinity. The SNMP has played a crucial role in revealing three distinct crustal mega xenoliths within the RMA and challenge previous assumptions about the homogeneity and origins of the RMA. These new findings emphasise the importance of continued mapping and accompanied geochronology in resolving the histories of complex geological terrains.

Keywords: Palaeoproterozoic, Archaean, Richtersveld Arc, Namaqua Metamorphic Province, Zircon

The long-lived ductile to brittle evolution of the Marshall Rocks-Pofadder Shear Zone during the final stages of the 1.2-0.96 Ma Namaqua Orogeny, Namaqua Metamorphic Province, Namibia and South Africa

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Abstract

The Marshall Rocks-Pofadder Shear Zone (MRPSZ) is a continental-scale transcurrent high strain zone extending from the Namibia coastline near Lüderitz to east of Pofadder in South Africa. With a length of over 500 km, it represents the largest of the set of NW-trending discrete dextral shear zones that crosscut the Palaeo- to Mesoproterozoic rocks of the Namaqua Metamorphic Province (NMP) and developed during the terminal D₄ phase of the Namaqua Orogeny at around 1.0 Ga. Recent geological mapping along the whole length of the MRPSZ by the Geological Survey of Namibia and the Council for Geoscience reveals a continuous belt of mylonitic rocks that preserve evidence of four sub-stages of D₄ deformation named in this study as D_{4a-d} and reflect the progressive evolution of the shear zone from deep to shallow crustal levels. Initial D_{4a} amphibolite-facies ductile shearing resulted in an up to 20 km wide zone of folding / reorientation of the earlier ductile Namaqua D₂ fabrics and D₃ mega-fold structures. Continued shearing under progressively lower temperatures / higher strain rates led to more localized shear deformation (D_{4b}) along a steep, ca. 1000 m wide zone of mylonite, phyllonite and cataclasite, and sub-horizontal lineations, that now forms the main core of the shear zone. Cross-cutting relationships indicate that phase D_{4b} showcase multiple stages of mylonitisation and coeval pegmatite magmatism. The mylonitic D_{4b} core has at least three major jogs along the length of the MRPSZ. In the southeast it was offset by discrete <30m wide ultramylonitic and ultracataclastic D_{4c} shears as the shear zone rocks moved into the ductile-brittle transition zone. Locally, the D_{4c} ultramylonite contains breccia textures (D_{4d}) that indicate even younger transient slip events and ductile creep. The MRPSZ and related coeval shear zones and reactivated thrust zones controlled the emplacement of ~1.01-0.96 Ga pegmatites and late-Namaqua granites in western NMP. Early pegmatites were deformed by the subsequent shearing and younger pegmatites crosscut the mylonite and early pegmatites. These observations indicate that the MRPSZ was active for at least 45 Ma probably during the final unroofing of the Namaqua-Natal Metamorphic Province. It also indicates the MRPSZ and other D₄ structures are critical to understanding the spatial and genetic controls on the important pegmatite-hosted mineral commodities in the western NMP.

Keywords: Marshall Rocks-Pofadder Shear Zone, Namaqua-Natal Metamorphic Province, Ductile-brittle transition, Pegmatite emplacement

The late-Namaqua Sperlingsputs Shear Zone System, Haib area, southern Namibia

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Abstract

The Richtersveld Magmatic Arc (RMA) forms a major ~200 km wide Palaeoproterozoic block within the Mesoproterozoic Namaqua Metamorphic Province (NMP). It consists of rafts of Orange River Group volcanic rocks intruded by voluminous coeval Vioolsdrif Suite granitoids (1905-1865 Ma; Macey *et al.*, 2015). The RMA is subdivided into two domains with equivalent stratigraphic units but different metamorphic grade and deformation. In the W are low-grade greenschist-facies rocks affected only by D₁ (Vioolsdrif Domain). They are separated by a ~2 km wide transition zone - termed the Namaqua Front by Blignault *et al.* (1983) - from the amphibolite-facies Pella Domain in the NE. The Pella Domain is strongly transposed by the main ductile D₂ phase of the Namaqua Orogeny at ~1215 Ma. Re-examination of the Namaqua Front found that it coincides with the northern margin of the ~15 km wide Sperlingsputs Shear Zone System (SPSZS), which consists of five main WNW-trending, steeply dipping shear zones cross-cutting the Vioolsdrif Domain and truncating the Haib porphyry Cu deposit. The SPSZS represents an anastomosing zone of deformation that mainly follows the less competent Orange River volcanics which are sheared into fissile cataclasites and mylonites, and wrap around largely unsheared blocks of bedded lava and, more often, Vioolsdrif granitoids. The northernmost shear zone reworks the southern boundary of the Namaqua Front and cross-cuts the penetrative Pella Domain fabrics and structures, thus post-dating D₂. The rocks north of the northernmost shear zone have a gneissic and schistose texture, with an overall mid- to upper amphibolite-facies mineral assemblage, while south of it they are weakly deformed with a lower greenschist-facies mineral assemblage. The dominant steeply south-plunging lineation, along with various shear sense indicators suggest a significant vertical component to the shear with an overall top to the north sense of movement. However, in some areas, the shear zones are accompanied by the development of a sub-horizontal lineation with a dextral sense of movement indicating a transpressional regime. The SPSZS is intruded by deformed and undeformed pegmatite dykes and plugs, which suggests intrusion during and soon after shearing - a relationship similar to that in other large shear zones in the area (Marshall Rocks-Pofadder Shear Zone (MRPSZ), Eureka shear Zone (ESZ)). Assuming that these pegmatites are equivalent to those in the, the SPSZS developed during the late-Namaqua D₄-dextral shearing event between ~1005 and 950 Ma, together with the also NW-trending MRPSZ and ESZ (Lambert, 2013).

Keywords: Sperlingsputs Shear Zone, Namaqua Orogeny, Namaqua Metamorphic Province

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A continental back-arc setting for the Namaqua Belt: Evidence from the Kakamas Domain

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Abstract

A study of the NW Kakamas Domain in South Africa/Namibia provides a new, unified lithostratigraphy and evolutionary history, applicable to the whole Namaqua Sector. The Mesoproterozoic history ranges from ~1350 to 960 Ma, but isotopic evidence suggests it was built upon pre-existing Palaeoproterozoic continental crust that extended west from the Archaean Craton. In eastern Namaqualand, early rift-related magmatism and sedimentation at ~1350 occurred in a confined ocean basin. Subsequent tectonic reversal and subduction at ~1290-1240 Ma led to establishment of the Areachap, Konkiep and Kaaie Domains. In the Kakamas Domain, widespread deposition of pelitic sediments occurred at ~1220 Ma (Narries Group). These contain detrital zircons derived from proximal crust with ages between ~2020 and 1800 Ma (western Palaeoproterozoic domains) and 1350-1240 Ma (eastern early Namaqua domains), suggesting pre-sedimentation juxtaposition. The pelites underwent granulite grade metamorphism at ~1210 Ma (peak conditions: 4.5–6 kbar and 770–850°C), associated with voluminous, predominantly S-type granitoid orthogneisses between ~1210 and 1190 Ma (Eendoorn and Ham River Suites) and low-angle ductile (D₂) deformation which continued until ~1110 Ma, interspersed with periods of sedimentation. This enduring P-T regime is inconsistent with the expected crustal over-thickening associated with the generally accepted collision-accretion Namaqualand model. Rather, we propose the Namaqua Sector is a 'hot orogen' developed in a wide continental back-arc with subduction west of the present-day outcrop. The observed high geotherm resulted from thinned back-arc lithosphere accompanied by an influx of mantle melts. Ductile D₂ deformation resulted from "bottom-driven" tectonics and viscous drag within the crust by convective flow in the underlying asthenospheric mantle. This extended tectonothermal regime ceased at ~1110 Ma when SW-directed thrusting stacked the Namaqua Domains into their current positions, constrained in the Kakamas Domain by late- to post-tectonic I-type granitoids intruded between ~1125-1100 Ma (Komsberg Suite). The thermal peak then shifted west to the Bushmanland and Aus Domains, where voluminous granites (1000-1025 Ma) were associated with high-T/low-P granulite facies thermal metamorphism and mega-scale open folding (D₃). Unroofing of the Namaqua Sector is marked by large-scale, NW-trending, sub-vertical transcurrent D₄ dextral shear zones and associated pegmatites and leucogranites at ~990 Ma.

Keywords: Kakamas Domain, Namaqua Metamorphic Province, Geochronology, Hot orogen

Multispectral and hyperspectral remote sensing for geology mapping: Namaqualand region, South Africa

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Abstract

The Council for Geoscience's onshore mapping programme includes the geological mapping of South Africa at 1:50 000 scale. Traditional mapping techniques involve extensive fieldwork and field sampling, which is not feasible in most cases due to time and financial constraints. If large parts of the country have to be covered, novel techniques such as Remote Sensing (RS) and Geographic Information Systems (GIS) must be applied used to facilitate the process. This study focuses on the 2817DD Nous and 2818CC Goodhouse 1:50 000 scale maps in the Northern Cape Province. RS datasets used include Sentinel 2, Landsat 9, ALOS PALSAR, ASTER, SPOT 6, ESRI base maps and aerial imagery. The challenge is that most of the multispectral datasets have low spectral and spatial resolution, and data with higher resolution, for example airborne hyperspectral data, are better suited. In 2018, airborne hyperspectral data were collected for the Council for Geoscience covering select areas in the Northern Cape Province. Although airborne hyperspectral datasets provide the best resolution, the cost of acquisition limit their use for regional scale applications. A range of image processing techniques were applied to the imagery to enable discrimination between lithological units, highlight and enhance structural features and show areas of hydrothermal alteration. The techniques applied include band ratios and maths, principal component analysis (PCA); and minimum noise transform (MNF) and directional filtering. For the hyperspectral data, mineral distribution maps were also created using absorption feature characteristics based on field spectral data. The processing was primary done using the in-house developed PyGMI open-source software package. ENVI, Erdas Imagine and ArcGIS were also used to integrate and analyse the data. The processing results were displayed as colour composites and used in conjunction with other datasets like the Shuttle Radar Topography (SRTM) elevation data and existing geological related data and knowledge to provide bases for the compilation of 1:50 000 scale geology maps through manual digitization. The advantages of remote sensing are that it allows coverage of large areas in a short time, inaccessible areas like private lands or mountains can be mapped adequately, areas with uncomplicated geology can be produced with little/no fieldwork, and it helps focus fieldwork thereby reducing the costs of these exercises. From our experiences, it is imperative to use the remote sensing data from all sensors because they all provide different types of information and highlight different features. In some areas however, due the low resolution of the MS data and the similarities in responses of the materials on the ground and the presence of vegetation, the results from RS alone should be used with caution because they are not conclusive. Geological knowledge and fieldwork is required to verify them before the final map is created.

Keywords: GIS, Remote Sensing, Airborne data, Hyperspectral data, Mineral distribution maps, Directional filtering

Geological mapping, petrological characterization and geochemistry of rocks in the Aus area, southern Namibia: Implications for potential copper mineralization (Poster)

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Abstract

The study area is located in the southern part of Namibia, within the Aus Domain of the Namaqua Sector of the Mesoproterozoic Namaqua-Natal Metamorphic Province. The sector hosts significant base metal sulfide deposits that have been mined intermittently for the past century. In this study, detailed field mapping, petrographical and geochemical analyses, and U-Pb zircon dating were conducted to evaluate the chemical characteristics and tectonic setting with the intent to assess the economic feasibility and potential of known copper occurrences in the Aus area. The geological setting of this area encompasses the Garub Group, which preserves the oldest rocks in the area and consists of marble, calc-silicates, metapelites, garnet-biotite-quartz gneisses, amphibolites, mafic granulites and serpentinites, intruded by several variably deformed granites. The main intrusive units are the Aus, Tsirub and Kubub orthogneisses. However, field mapping identified a highly fractured and metasomatized K-feldspar-plagioclase-epidote rock, which requires further investigation. Petrographic studies confirm the compositional and deformational variability observed in the field, while geochemical analysis reveals that all granitoids within the study area are acidic, strongly peraluminous and products of shoshonitic and high-K calc-alkaline magmas derived from an A-type source. The A-type granites formed as a result of crustal contamination during the continental extensional phase and have been subjected to compressional deformation. Chondrite-normalised spider diagrams show negative Ta, Nb, P and Ti anomalies, with enrichments in Th and LREE, which suggests that the rocks are derived from an arc environment. Three geotectonic settings were established, i. e. Syn-Collisional Granites (syn-COLG), Volcanic Arc Granites (VAG) and Within Plate Granites (WPG). These inconsistent plots of samples may be attributed to hydrothermal alteration and/or sharing of varying degrees of fractionation within multiple flows, and support a collision of crustal fragments. Granitoid plutonism (Tsirub augen gneiss, Aus granite gneiss) occurred at 1110 ± 7 Ma and 1085 ± 36 Ma, respectively. Several granites, which could be responsible for hydrothermal activity, quartz veins, fault structures and the occurrence of malachite may bear evidence for copper mineralization in the study area.

Keywords: Namaqua-Natal Metamorphic Province, Geological mapping, Tectonic setting, Granitoids, Copper, Namibia

Geology of the Aukam Valley, Namaqua Metamorphic Complex, Southwestern Namibia: Implications for Regional Tectonostratigraphy

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Abstract

Recent 1: 50 000 scale geological mapping conducted in the Namaqua-Natal Metamorphic Province in southern Namibia, has redefined and clarified most aspects of the regional tectonostratigraphy of the various domains. The mapping is part of a joint regional geological mapping programme between the Council for Geoscience (CGS, South Africa) and the Geological Survey of Namibia (GSN), which commenced in 2013. The Namaqua-Natal Metamorphic Province consists of the Palaeoproterozoic Sperrgebiet Domain (~2.02 Ga) and Richtersveld Magmatic Arc (~1.9 Ga), and the high-grade ~1.3 to 1.1 Ga Mesoproterozoic rocks of the Kakamas and Aus Domains. The Aukam Valley basement rocks crop out as an inlier within the Nama Group southeast of Aus. The area had not been mapped in detail in the past, with large parts shown as “Undifferentiated Namaqua” on the existing 1:250 000 Geological Survey maps. Our mapping reveals the Aukam Valley geology to consist of a variety of high-grade gneisses and granites. Cordierite-sillimanite-garnet-K-feldspar metapelite and associated garnet-quartz-feldspar leucosome bodies, which formed during granulite facies anatexis, are intruded by dykes of mafic granulite and voluminous sheets of coarse-grained and augen-textured leucogranite gneiss. The penetrative gneissic Namaqua foliation extends in WNW direction and dips to the northeast. The metapelites resemble the ~1.22 Ga Garub Group and the Narries Groups in the Aus and Kakamas Domains, respectively. Similarly, the leucogranite gneisses are comparable with the ~1.2 Ga Aus Gneiss and Ham Suites (South Africa) of the Aus and Kakamas Domains. The high-grade rocks are intruded by late-tectonic ~1.1 Ga porphyritic enderbite and granodiorite of the Komsberg Suite and ~1.0 Ga pegmatites related to the terminal Namaqua dextral shear event. The new mapping confirms that the Aukam Valley inlier forms part of the Aus-Kakamas granulite mega-thrust sheet. The area is of economic significance as it hosts graphite mineralization, which has been mined at the Aukam Graphite Mine.

Keywords: Namaqua-Natal Metamorphic Province, Aukam Valley, Aus Domain, Kakamas Domain, Namibia

Using major mapping programmes to develop capacity and drive research collaboration

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Abstract

Regional geological mapping at various scales has been carried out by the Geological Survey of Namibia (GSN) for more than a century, complemented by the work of local and international university research institutions and mining exploration companies. As a result, a highly heterogeneous geological map coverage and information base for the country was established, with very detailed data for some areas, and merely reconnaissance mapping elsewhere. Understaffing and a lack of experienced personnel has caused the geological coverage of the country to stagnate since the 1990s. To remedy this situation, a project combining contract mapping by experienced senior geologists and training of GSN staff in modern mapping and map production techniques was initiated in 2013. The first focal area for this new and revision mapping was the //Karas Region of southern Namibia, which was selected on geological and economic grounds. After ten years the “Southern Namibia Mapping Programme” (SNMP) has contributed significantly to the long-term national geoscience objective of acquiring detailed geological map coverage (1:50 000 scale) for the entire country. SNMP has produced a variety of deliverables / products including 90 full and partial 1:50 000 scale geological map sheets, reports, geochronological, geochemical and literature databases, as well as twelve peer-reviewed publications in international journals and twenty-three conference abstracts. On the capacity building side, sixteen post-graduate research projects were completed during SNMP, specifically five BSc (Hons) and four MSc degrees from the University of Stellenbosch (South Africa), one BSc (Hons) and one PhD from McGill University (Canada), one BSc (Hons) from the University of Cape Town (South Africa) and four BSc (Hons) from the University of Namibia. Major mapping programmes thus provide a common platform for government and research institutions to collaborate on joint projects, share data and exchange expertise, with enhanced capacity and know-how not the least of their many benefits. By leveraging the power of these programmes, research collaborations are strengthened, leading to a deeper understanding of geological processes, and contribute to the sustainable development of our natural resources and the environment.

Keywords: Capacity building, Research collaboration, Mapping project

The need of Guidelines and Standardization in New Mapping Projects

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Abstract

To enable the smooth integration of newly mapped areas into an existing geological map coverage and database, it is essential to adhere and refer to stipulated standards, especially with regard to naming, and – during the map compilation stage – colour coding of newly identified geological units. As database principles require that there must be no duplication or other ambiguities, failure to do so necessarily results in misperception as well as incongruous map products to the detriment of the user and necessitates considerable additional effort to remove unclarities thus created (e. g. renaming of units, changing of codes and colours, editing of reports, revision of map layouts). Accordingly, it is advisable, especially in contract work, to decide on a set of guidelines and standards to be adopted during the successive stages of a mapping project (i. e. field work, map compilation, reporting) and to stipulate procedures to be followed at each step before the start of the mapping campaign, especially before final map and report compilation. Examples shown in our presentation, derived from the 10-year Southern Namibian Mapping Project, serve to illustrate the pitfalls of an absence of specific guidelines, and the need of close communication at every stage of the project between mapping and GIS-geologists in charge of database maintenance and map compilation.

Keywords: Mapping, Database maintenance



The Lüderitz Domain of the Richtersveld Magmatic Arc, southern Namibia

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Abstract

The basement rocks of the Lüderitz area, SW Namibia, are dominated by migmatitic metavolcanic and intrusive gneisses that resemble those of the Palaeoproterozoic Richtersveld Magmatic Arc (RMA; ~1.89 Ga; Macey *et al.*, 2017) of the Namaqua-Natal Metamorphic Province (NNMP). Detailed geological mapping, geochemical, isotopic and geochronological analysis was carried out to establish a new, modern lithostratigraphy for the area and to determine whether the Lüderitz gneisses indeed form part of the RMA. The mafic, andesitic and dacitic metavolcanic gneisses (1876 ± 9 Ma) are grouped in the Albatross Formation and occur as rafts within the coeval orthogneisses (1918-1855 Ma). Six main types of orthogneiss were mapped, i. e. the Kolmanskop nigmatite, the Adventure Bay metagabbro-metadiorite, the Radford Bay, Kowisberg and Albatross Bay granodiorite-granite gneisses and the Elizabeth Point leucogranite gneiss. The volcanic and plutonic rocks are overlain by the Dagger Rocks Group that yielded a youngest detrital grain age of 1731 ± 46 Ma. The supracrustal and plutonic rocks were strongly deformed and metamorphosed during the polyphase Mesoproterozoic Namaqua Orogeny. Intense early Namaqua deformation and associated anatexis was accompanied by the intrusion of ~1.2 Ga leucogranite sheets (Griffith Bay and Klammerberg leucogranite gneisses) and the development of a penetrative, steeply NW-dipping, NE-striking gneissic foliation. Thrust tectonics during the final juxtapositioning of the NNMP tectonic domains (Macey *et al.*, 2022) was accompanied by the intrusion of the ~1.1 Ga Pyramid Granite. The NW-trending Marshall Rocks-Pofadder Shear Zone north of Lüderitz deforms the older basement gneisses and is associated with coeval voluminous pegmatite magmatism (~1.01-0.96 Ga). The metavolcanic and intrusive rocks of the Lüderitz area have geochemical characteristics indicative of rocks formed in a supra-subduction - arc environment. Furthermore, the Lüderitz gneisses have similar mineral compositions to those of the Pella Domain of the RMA, and their ages overlap with those of the Pella and Vioolsdrif Domains of the 1.91-1.86 Ga Richtersveld Magmatic Arc (Macey *et al.*, 2017). Based on these data, we propose that the Lüderitz Domain marks the north-western extension of the RMA and that the Albatross Formation and the orthogneisses form part of the Orange River Group and Vioolsdrif Suite, respectively.

Keywords: Richtersveld Arc, Geochemistry, Geochronology, Namaqua Metamorphic Province

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Mapping Neotectonic Fault Scarps in Southern Namibia

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Abstract

This study combines field work, high-resolution satellite-derived digital elevation models (DEMs) and aeromagnetic data to investigate neotectonic fault scarps in Southern Namibia. One such scarp, the Hebron Fault, is relatively well known, but the identification of the Anusi-Tafelberg scarp during geological mapping suggested that these features may be more prevalent than previously recognized. To identify and characterize such features global DEMs and freely available satellite imagery were used to identify several other possible scarps in SW Namibia and four of these were studied in more detail in the field, using Pleiades satellite imagery and field work. Others can be identified in the TanDEM-X DEMs. The scarps range up to 80 km in length and 10.2 m in height suggesting that they represent major earthquake events, some towards the upper end of continental normal faulting. Some segments show evidence of repeated rupture within the geomorphological residence time of the landscape which suggests that geomorphological information can usefully be used for prospective forecasting of hazard. Conversely, significant earthquakes appear to be able to occur on faults with limited post-Nama cumulative brittle offsets posing challenges for the identification of similar structures. Aeromagnetic data reveals a strong association with older ductile structures including the Marshall-Rocks-Pofadder Shear Zone. The apparent clustering of palaeoseismic events in a relatively small area poses interesting questions: Are such events more widely distributed but better preserved in this arid landscape with extensive calcrete cementation? Do these scarps represent a cluster of activity associated with inter-event stress interactions? Is this area a zone of particularly high stress or does it contain structures which are particularly susceptible to reactivation? Palaeoseismic trenching and the dating of Quaternary landforms to assess fault slip rate and the relative timing of past ruptures would help to resolve these questions and further constrain the seismic hazard within the region.

Keywords: Mapping, Fault scarp, Neotectonic, Palaeoseismic

The Aukam Valley - a window into far-field, Jurassic age (?) fluorite and Cambrian age graphite mineralization

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Abstract

The Aukam valley in southwestern Namibia exposes a number of high purity fluorite veins and a rare, vein hosted, amorphous graphite deposit. Mineralization is hosted within high grade metamorphic rocks of the Mesoproterozoic age Namaqua Metamorphic Province. These veins are situated at, or very close to the overlying late Neoproterozoic Nama Group sedimentary unconformity. At Aukam, graphite occurs as a massive zone of granite gneiss replacement and as disseminated grains along a shear zone of at least 5 km. The Namaqua gneisses show a regional peak metamorphic granulite facies event and a later ductile overprint with amphibolite facies temperatures of around 570 - 600 °C and 2.8 - 3.5 kbar. Between 530 and 546 Ma, and with the unconformity already in place, the graphite, which has been dated via intergrown monazite, was precipitated. Conditions were maximum greenschist facies, as shown by graphite crystallization temperatures of around 360 - 410 °C and with associated alteration assemblage of quartz and muscovite (sericite). The $\delta^{13}\text{C}$ isotopes values indicate at least a partly biogenic source for the graphite, however, the exact fluid origin remains unclear. The fluorite veins have features indicating a lower metamorphic-environment and with calcite $\delta^{13}\text{C}$ values in these veins similar to the regional Kuibis Subgroup graphitic limestones overlying the unconformity it is apparent that these represent the source rocks. Microthermometric data indicates precipitation from a mixed fluid with two chemically contrasting end-members. These end-members are (1) F-rich brines sourced from the Namaqua basement, and (2) Ca-rich, limestone derived formation fluids from the Nama Group. Observed fluorite overgrowths on earlier precipitated quartz is likely the effect of post-mixing fluid cooling. Locally, late-stage calcite is recognized with fluid inclusion compositions distinctly different from those observed in the fluorite and quartz. With significantly lower homogenization temperatures, these likely formed during the shutdown and collapse of the hydrothermal system. The fluorite veins are hosted in post-Cambrian brittle structures that probably formed during the opening of the South Atlantic in Jurassic times. Similar deposits of massive fluorite mineralization occur on both sides of the Atlantic Ocean, and is likely associated with this rifting. This study demonstrates the key source/s of solution for the formation of both the fluorite and graphite mineralization is most likely above the unconformity, and not the granulite facies host rocks below, and that mineralization occurred long after the development of the unconformity and may be expected in other parts still concealed by overlying Nama sediments.

Keywords: Aukam Valley, Graphite, Fluorite, Nama Group, Namaqua Metamorphic Province

ST03: ORE DEPOSIT GEOLOGY OF AFRICA (MINERAL RESOURCES AND ORE FORMING PROCESSES)**ST03_S01: Ore deposits and plate tectonics****Craton-scale distribution patterns of structural elements and gold mineralization in the Tanzania Craton, as revealed by remote sensing data****Gregor Borg^{a*}, Elisante Mshiu^b**^a*Economic Geology and Petrology Research Group, Martin Luther University Halle-Wittenberg, Germany,*^b*Department of Geosciences, School of Mines and Geosciences, University of Dar es Salaam*Corresponding author: gregor.borg@geo.uni-halle.de**Abstract**

The Tanzanian Craton extends from Kenya in the north, southwards almost towards the Mozambique border. The Tanzanian Craton is bounded by Proterozoic mobile belts in the west and south, as well as by younger extensional rift and graben systems both west and east.

Tanzania hosts numerous gold deposits in the famous Southern and Eastern Lake Victoria Goldfields, some being mined for decades. The majority are hypogene, shear-zone-hosted or BIF-replacement deposits, e.g. Bulyanhulu and Geita Mine. The gold deposits are hosted predominantly by Archaean greenstone belts, which have undergone greenschist to locally amphibolite facies grade metamorphism. These Archaean granite-greenstone terrains of northern Tanzania and south-eastern Kenya comprise metavolcanic and metasedimentary supra-crustals, which have been intruded by Archaean syn- and post-orogenic granitoids. In contrast, the central and southern part of the Tanzania Craton is markedly void of substantial gold deposits, although rich secondary, (palaeo-)placer gold deposits occur northwest of Mbeya towards Lake Rukwa, just off the southwestern margin of the Tanzanian Craton. The Luika gold deposit in SW Tanzania is a rare exception to this pattern, but the deposit is probably of post-Archaean age. The metamorphic grade of most of the southern part of the Tanzanian Craton is of granulite facies grade. Our recent processing and interpretation of remote sensing data has revealed three types of structural lineament patterns within and adjacent to the Tanzania Craton. i) The gold-bearing northern part of the Craton is characterised by intersecting, straight, brittle lineaments, reflecting conjugate sets of shear-zones and faults, orientated WNW-ESE and WSW-ENE. These gold-mineralized structures reflect a crustal level of the ductile-brittle transition zone, which has received gold-bearing fluids from deeper crustal levels, probably released by metamorphic dehydration reactions. ii) The largely barren central and southern part of the Tanzania Craton features curvilinear lineaments and structures, which show curved wrap-around patterns along the southern margin of the Tanzania Craton. These structures formed at much deeper crustal levels, where granulite facies grade metamorphism caused dehydration, expelling metal-bearing metamorphic fluids to higher crustal levels, which have become eroded by now. iii) Straight-lined extensional faults and graben systems flank the Tanzanian Craton both on its western and eastern sides. The gold of the (palaeo-)placer deposits off-craton between Mbeya and Lake Rukwa could possibly represent the eroded gold deposits of former granite-greenstone terrains of the southern Tanzania Craton.

Remote sensing data demonstrates that the Tanzania Craton has been tilted with uplift in the south, probably by the collisional event of the formation of the Mozambique Belt. The subsequent erosion has removed the potentially gold mineralized crustal levels of the southern Tanzanian Craton, whereas the highly gold-mineralized granite-greenstone terrains of the northern Tanzania Craton remained intact and are being mined today.

Keywords: Tanzanian Craton, Archaean, Gold deposits, Remote sensing

Crustal evolution and the Nigerian metallogenic framework

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Abstract

The integration of existing structural, isotopic, remotely sensed data allows for the characterization of distinct mineralizing epochs related to the tectonothermal evolution of Nigeria. The remotely sensed methods include satellite, aeromagnetic and enhanced techniques that facilitate qualitative geological interpretation of potential field anomalies. The results indicate that the earliest significant mineralization corresponds to iron deposits formed during early Palaeoproterozoic oxyatmo-inversion in greenstone belts that have been segmented into N-S rafts as schist belts during Neoproterozoic (Pan-African) tectono-thermal event. The latter reworking resulted in formation of recrystallized manganiferous iron ores, chromite and related PGM in serpentinized layered mafic and ultramafic bands as well as epigenetic auriferous quartz reefs and veins in NNE to SSW transcurrent shears. This was followed by the formation of Sn-Li-Be-Ta-bearing pegmatite dykes in ENE-WSW structures in late Pan-African as clearly demarcated by aeromagnetic and potential field anomalies. Then a prolonged Palaeozoic hiatus was broken by the predominantly Mesozoic uplift and anorogenic migratory magmatism with emplacement of per-alkaline Younger Granite ring dykes during which transition element deposits (Sn-Nb-W-Mo) of upper crustal origin were formed. The global tectonic structural adjustment which commenced in the Pan African and controlled the emplacement of the Younger Granites was followed by the opening of the Southern Atlantic in the Early Cretaceous. The resulting inland and coastal sedimentary basins in Nigeria and Brazil; which failed arm formed the Benue Trough platform accumulated hydrothermal base metals (Pb-Zn-Cu-Ba) in the Santonian mega-folds. The Tertiary accumulated both metallic as well as non-metallic energy mineral resources in form of uranium and hydrocarbon in the northern Benue Trough and coastal basins, especially the Niger Delta. Late Cretaceous (Campano-Maastrichtian) and Cenozoic aerobic settings at high altitudes accumulated sedimentary lateritic duricrust, oolitic and pisolitic ironstones on Agbaja and bauxite on Mambilla plateaux respectively; while phosphatic beds accumulated in Tertiary flat-lying beds of Sokoto and Dahomey basins. In conclusion, it is evident that metallogenic processes in the Nigerian Precambrian shield occurred in phases. While the precursor is generally disseminated and consanguineous with mineralization on the West African Craton, the minable ores derived from reworked Neoproterozoic crust as structurally controlled pegmatitic or hydrothermal epigenetic veins in shear zones, as shown in the suggested metallogenic domains map of Nigeria resulting from this study.

Keywords: Crustal evolution, Metallogenic processes, Nigeria

Gold mineralization related to the Kandi shear zone in the Sinende area, Dahomeyides orogen, Benin Republic, West Africa

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Abstract

The gold potential of the internal zone of the Dahomeyide Orogen remains little known in Benin Republic. Field observations and structural measurements, optical microscopy, major and trace elements Fusion ICPOES/ICPMS and Au-Fire Assay gravimetric analyses were carried out on samples from the Sinende area located in the northern part of the Kandi shear zone, to better constrain its gold potential. In the Sinende area, gold occurs as grains in microfractures within milky quartz veins, and is associated with sulphides and oxides. The quartz veins are oriented N-S to NNE-SSW, which is similar to the orientation of the mylonitic foliation of the gneissic host rocks of the Kandi shear zone. Geochemical analyses indicate that the gold concentration in some rocks and saprolite from Sinende varies between 4 and 385 ppb. Gold is more heavily concentrated in the quartz veins (124 to 385 ppb) than in the mylonites (71ppb) and the saprolite (4 to 69 ppb). The association of Au with Cu, As and Mo suggests that the latter can be used as pathfinder elements for Au prospecting in the Sinende area. A hydrothermal origin is proposed for the gold deposition, which suggests that within the Kandi shear zone gold mineralizing fluids were able to ascend and circulate. Therefore, the Kandi shear zone in Benin Republic is an important geological prospect for gold exploration that needs to be investigated further.

Keywords: Gold, Quartz vein, Kandi shear zone, Dahomeyide orogen, Benin

Late orogenic, competency-controlled copper sulfide mobilization at the Onganja Mining District, Namibia

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Abstract

The Onganja Mining District, ~60 km NE of Windhoek, is a structurally controlled copper deposit within the Southern Zone of the Damara Orogen. The district has produced copper concentrates between 1904 and the early 1970s. The recent discovery of two copper-rich orebodies has regenerated interest in its economic potential. This study moves towards providing a comprehensive genetic model by combining structural, petrographic, whole-rock chemical, mineral chemistry and geochronology datasets. Most of the mined-out orebodies at Onganja were chalcopyrite-chalcocite infill breccias and veins associated with a N-S trending quartz-albite vein system which crosscuts the metabasite-metapelite country rock lithologies, while the two recently discovered orebodies have a spatial association to amphibolite-bearing units and comprise massive to disseminated sulphides that are stratiform to the regional S₂ axial planar foliation. These orebodies consist of chalcopyrite and magnetite with minor pyrite and molybdenite. Furthermore, geochemical analysis (fire assay) of the ores indicates Au, U, and REE enrichment occurs with the copper mineralisation. Cream-white to pinkish-red albitisation of the schists occurs throughout the district as both foliation-bound bands and as haloes around quartz-albite veins. Locally, subhedral albite grains are observed in cavities adjacent to quartz veins. Likewise, mica growth is approximately foliation parallel to the S₂ or formed mica books within the same cavities as the albite crystals. Magnetite and hematite are closely associated with albitisation; the former is associated with amphibole-bearing units while the latter is associated with metapelites. Locally, hematite is potentially converted to mushketovite within the quartz-albite veins but is also found as euhedral grows in late calcite veins. Given the alteration, ore, and elemental assemblages, the district bears some similarity to those of Iron Oxide-Copper-Gold deposits, providing a potential basis for a genetic model. However, several lines of evidence suggest that the district shows deviation from typical IOCG deposits. These include the abundance of quartz, lack of regional albitisation, undifferentiated alteration and metamorphic mica compositions, and both magnetite and ore chemistry that is distinct from those of IOCGs. Furthermore, U-Pb age dating of monazite (~440 Ma) suggests that REE enrichment post-dates orogenesis and sulphide mineralisation (517-518±3 Ma; Moore, 2010) by at least 80 My. Rather than being an IOCG *s. s.*, genesis of the Onganja orebodies is possibly related to the scavenging and mobilisation of sulphides associated with the amphibolite-bearing units by sodium-rich brines. These brines likely migrated along shears that developed along bands of F₂ axial planar schistosity before migrating up through fractures that developed in the more competent fold hinges and pre-existing vein system. The upward migration of the fluids resulted in the albitisation of the wall rock and precipitation of the sulphides into the fracture spaces producing the veins and breccias observed.

Keywords: Copper mineralisation, Quartz veins, S₂ axial planar foliation, Competency contrast, Jointing, Fracturing

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Geodynamic evolution of the Giyani Greenstone Belt and its implication for gold mineralization in the region

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Abstract

The Council for Geoscience has embarked on an integrated and multidisciplinary geoscientific research in the Giyani Greenstone Belt (GGB) and surrounds. The objective of the project is to support economic growth, address water security and promote environmental stewardship through an integrated approach that covers multi-discipline tasks (i.e. detail geological mapping, soil geochemical mapping, geophysical investigations, geotechnical, groundwater and environmental studies). This data is also targeted toward understanding the geodynamic evolution of Archaean environments and how these affected various mineralizing systems.

The GGB is situated along the boundary between the Kaapvaal Craton and the Southern Marginal Zone of the Limpopo Metamorphic Belt. It comprises largely of tonalite-trondhjemite-granodiorite rocks, metavolcanic and metasedimentary rocks and various Archaean-Palaeoproterozoic granitoids. The belt formed one of the first continental fragments on earth and key component in the development of the Kaapvaal Craton.

Six 1:50 000 geological maps covering the entire GGB and the surroundings were produced. A Magnetotelluric (MT) survey focusing on deep crustal features (>15km) was conducted in the central part of the GGB along a profile of about 30 km, oriented NW-SE. This included the delineation of deep crustal shear zones and subsidiary structural zones. Integration of MT and historical geological datasets on deep geological structures confirmed that these subsurface structures hold potential for structurally controlled gold mineralization in the area. This is corroborated by the results of the Induced polarization Survey in one of the generated mineral targets. Soil geochemistry delineated previously unmapped sequences in the region. Follow up geochemical studies of the generated mineral anomalies confirm some of the promising anomalies. The results of this study are now being used to define a new tectono-stratigraphy of the GGB. This will include targeted isotope geochemistry and geochronology to determine the precise formation and evolution pathway of the GGB.

Keywords: Archaean, Integrated geoscientific mapping, Magnetotelluric survey, Geochemistry, Giyani Greenstone Belt, South Africa

Orogen-Scale, Regional Zonation of Pegmatites Lacking Parental Granites

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Abstract

Current models for the zonation of pegmatite types associated with a parental granite are not viable where parental granites do not exist. Where both lithium-cesium-tantalum (LCT) and niobium-yttrium-fluorine (NYF) pegmatites intrude in the same regional orogenic system the synchronous occurrence of these two types of rare-metal pegmatites needs an explanation which is currently lacking. In the Central Zone of the Damara Orogen in Namibia, a variety of pegmatites exposed over a strike length of ~120 km, are post-tectonic, crustally-derived, post-metamorphic intrusions well known for their uranium, tin-tantalum, lithium and gemstone mineralization. These pegmatites show a distinct spatial distribution related to metamorphic grade, whereby pegmatites with uranium mineralization coincide with the high-grade core of the orogen, while lithium-, tin-tantalum-, and gem-bearing pegmatites occur in areas of lower-metamorphic grade. In Namaqualand a similar spatial distinction is made between Zr-Nb-REE (NYF) pegmatites and lithium-mineralized pegmatites (LCT). Here, there are two groups of LCT pegmatites, one at either end of the Orange River Pegmatite Belt, while the NYF pegmatites predominate in the central part. In both regions, the primary control on the distribution of pegmatite types would appear to be related to metamorphic processes rather than a parental granite. In the Damara Orogen, metamorphic grade is a much better indicator of pegmatite metal enrichment rather than proximity to a putative parental granite. It is therefore pertinent to consider the source and derivation of the parental melt for the pegmatites, not in terms of lithology but focusing on the potential minerals that have contributed to the melt. Geochemical diagrams distinguishing between derivation from muscovite or biotite breakdown are used to suggest that NYF and LCT pegmatites are derived from different breakdown reactions in the Damara Orogen.

Keywords: Pegmatite, Regional zonation

An emerging 3T's (tin-tantalum-tungsten) metallogenic province in the Uis district of central Namibia – geological and metallogenic framework

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Abstract

Several belts of pegmatite intrude both granitic and metasedimentary lithologies of the Pan-African Damara Orogen, Namibia. The Uis mining licence in central Namibia falls entirely within the Uis – Cape Cross swarm and contains Sn-Nb-Ta type pegmatites which also host significant petalite (LiAlSi₄O₁₀). Highly Sn- and Ta-mineralized pegmatites appear to be restricted to the metasedimentary host rocks whereas, intragranitic pegmatites adjacent to the license area display abundant columbite-group minerals (CGM). Lithium-mineralized pegmatites occur only within the porphyroblastic biotite schists (known as 'knottenschiefer') of the Amis River Formation, Zerrissene Group. Pegmatite emplacement is controlled by sinistral fractures or sigmoidal structures associated with north-northeast – south-southwest striking half-graben faults. Tungsten-Sn (without Li) mineralization is also known elsewhere in the district, in particular within quartz veins at the historical workings of Brandberg West, and the region shows promise as an emerging critical metals province of note. The Uis pegmatites are granitic in composition and primarily occur as homogeneous intrusions that do not appear to contain a distinct mineral zonation. The primary mineralogical composition is quartz, feldspar, petalite and muscovite, with accessory cassiterite, CGM, apatite, ilmenite, beryl and tapiolite. Other lithium minerals known to occur at Uis, in addition to petalite, include montebrasite (Li,Al(PO₄)(OH)), lepidolite (K(Li,Al)₃(Al,Si,Rb)₄O₁₀(F,OH)₂) and cookeite ((Li,Al₄)(Al,Si₃O₁₀)(OH)₈). The highest grades of tin and tantalum mineralization are associated with greisens and albitised aplitic units. The metasedimentary host lithology of the Uis pegmatites is primarily a quartz muscovite schist, likely a greywacke protolith. The schists hosting the Uis pegmatites experienced multiple phases of deformation resulting in folding and faulting prior to the emplacement of the pegmatites which appear, therefore, to be late in terms of Damaran orogenesis.

The area appears to have been relatively stable post- pegmatite emplacement, as little faulting and no folding of the pegmatites has been observed. The Uis pegmatites have yielded a U-Pb zircon age of 520 Ma, and thus formed during the late stages of the Pan-African orogeny – soon, therefore, after the ultimate assembly of Gondwana at around 550 Ma. Recent U-Pb dating of the Uis cassiterite provides an identical age of 519.8 ± 4.0 Ma (2s).

Keywords: Pegmatite belt, Uis district, Geochronology, Namibia

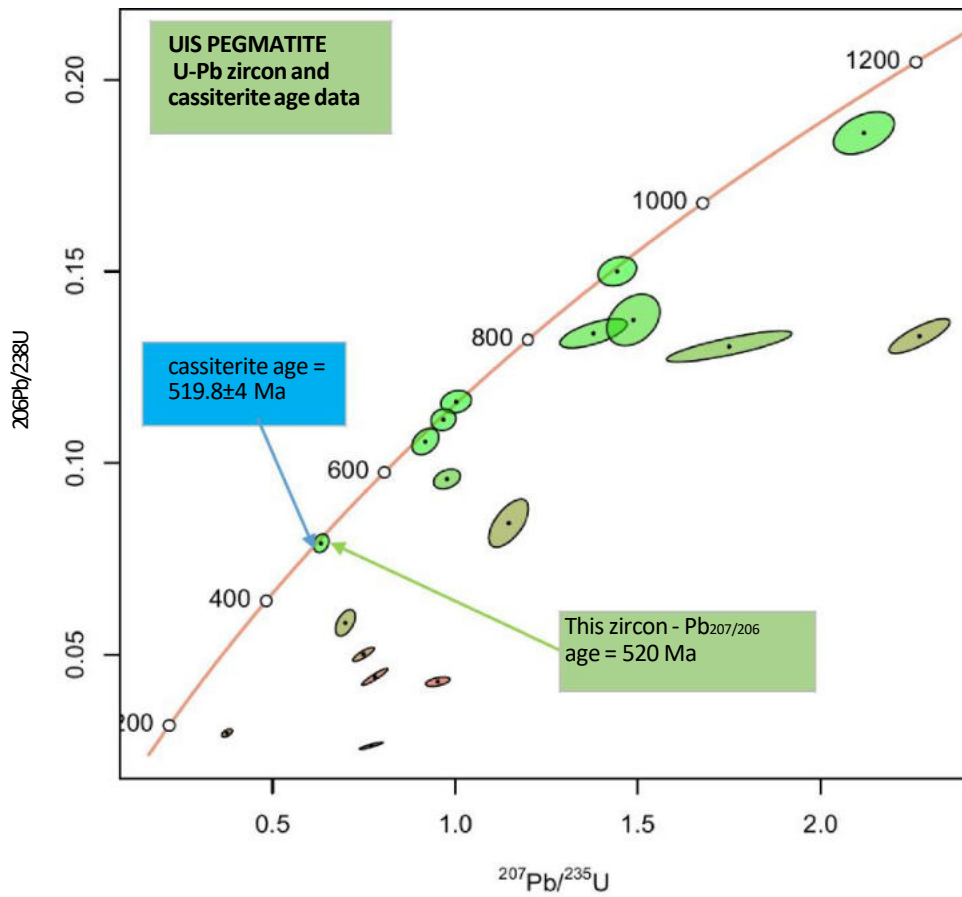


Figure 1: Concordia plot showing the U-Pb isotopic characteristics of largely xenocrystic zircons from the Uis pegmatite. Uis cassiterite is essentially indistinguishable in age from the youngest concordant zircon grain at 520 Ma, the latter possibly also reflecting the age of the Uis pegmatites

Mineralogy, geochemistry and genesis of the metamorphosed manganese silicate rocks (Gondite) of Téra, west Niger (West Africa)

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Abstract

The manganese deposit found in Téra, West Niger are part of the manganese mineralization within the West African Craton, specifically in the Palaeoproterozoic greenstone belt formations. This manganese deposit is located in the contact between Diagorou-Darbani greenstone belt and Téra granitoid pluton. The rocks hosting manganese mineralization in this area are predominantly gondites in form of hill, which are composed of spessartite-type manganese silicate garnets. These gondites present a manganese duricrust with botryoidal texture on top of the hills, while the surrounding gondite exhibit a high concentration of manganese oxide concretions. The methodology employed in this study involves a field investigation followed a petrographic analysis done by using a transmitted and light polarized microscope. Additionally, XRD and ICP-MS analysis have done. The field study (mapping and sampling), combined with microscopic analysis, reveals that the gondites in Téra are associated with mica schist-bearing kyanite and staurolite, as well as garnet-bearing amphibolite. XRD analysis identified two types of garnets in the gondites: spessartite, ranging from 21.4% to 53.8%, and almandine, ranging from 0% to 12.2%. Supergene weathering processes, including oxidation, hydrolysis, and leaching of chemical elements, have led to the development of a saprolitic profile on the gondite protore, forming a secondary manganese deposit. Manganese oxides, such as lithiophorite, pyrolusite, and cryptomelane, typically replace manganese garnet (spessartite). Pyrolusite is the first oxide to form around the garnets (spessartite), while the mesostasis is infiltrated by pyrolusite, often accompanied by lenses of lithiophorite, which gradually transition into pyrolusite. In the botryoidal concretions, pyrolusite alternates with cryptomelane colloform. This level with colloform texture has a maximum content of 47.92% MnO. The normalized Rare Earths Elements compared to PAAS (Post-Archaean Australian Shale) and major element analysis show that the gondites derived from a plagioclase-rich quartzitic source. This observation is supported by a positive anomaly in europium (Eu). Moreover, the elevated levels of transition elements such as nickel (Ni) ranging from 380 to 990 ppm, vanadium (V) ranging from 282 to 659 ppm, and cobalt (Co) ranging from 164 to 332 ppm indicate the involvement of a mafic source. The major element contents reveal significant leaching, resulting in increased manganese (Mn) and aluminum (Al) concentrations during weathering. Both the Chemical Index of Alteration (CIA) and the Plagioclase Index of Alteration (PIA) exhibit similar trends, indicating progressively higher values and approaching the Al_2O_3 pole on the Al_2O_3 -CaO* + Na₂O-K₂O diagram. This indicates increasing alteration along the profile, characterized by a transformation from plagioclase-smectite to kaolinite on one hand, and from illite to kaolinite on the other hand.

Keywords: Gondite protore, Manganese, Palaeoproterozoic greenstone belt, West African Craton, Supergene alteration

Controls and development of disseminated-type orogenic gold mineralization under ductile deformation and high-grade metamorphic conditions: 3D implicit modelling of the Twin Hills Deposit, Namibia (Poster)

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Abstract

The Twin Hills deposit is a large (>12 km strike length), disseminated, low-grade mineralized gold-sulfide (pyrrhotite > arsenopyrite >> pyrite) system hosted by amphibolite-grade metaturbidites of the Pan-African Damara Belt in central Namibia. It is a new gold deposit in the Damara Belt, recently discovered by Osino Resources. The deposit comprises distinct clusters of economic-grade gold mineralization, measuring several hundred meters along strike, separated by several kilometre-long intervals of only sporadic and sub-economic gold grades. Using 3D implicit modelling of about 185 km exploration drill holes, gold assay data and ore-grade distributions combined with structural analyses and oriented drill-core observations of the Twin Hills deposit, this study aims to: (1) contextualize the controls of mineralization on a deposit-scale; and (2) discriminate factors that distinguish zones of economic-grade mineralization from intervening sub-economic domains that may guide exploration. Individual higher-grade clusters are controlled by the combination and interplay of two main factors, namely lithological contacts and subtle deflections of bedding of the highly-strained, subvertical metaturbidites. The ENE-trending mineralized corridor of the Twin Hills deposit is largely confined to imbricated and/or tightly folded packages of interbedded psammite-pelites within the otherwise pelite-dominated sequence. It is these units that promoted fracturing, fluid flow and the development of fine-scale vein networks as a result of pronounced strain partitioning between schist units (ductile) and interbedded metapsammites (brittle) during regional deformation (flexural-slip folding). Clusters (shoots) of higher-grade mineralization (>1.5 g/t Au) follow these main lithological contacts, but are laterally confined to subtle (5-15°) clockwise deflections of bedding (dilatational jogs) from its regional ENE trends. Outside these deflections, gold mineralization is patchy and only sub-economic. On a regional scale, the Karibib Fault Zone is considered to be the first-order structure for the mineralization and the position of the Twin Hills deposit coincides with the inflection of the vergence direction of second-order folds. The structural and lithological controls of the mineralization at Twin Hills closely resemble those of orogenic gold deposits, but the fine-grained and dispersed textures of gold and associated sulfide mineralization are more reminiscent of those found in disseminated gold deposits. The development of disseminated mineralization at Twin Hills suggests that hydrothermal fluid flow was pervasive. The pervasive fluid flow relates to the pervasive deformation/strain that is distributed over a thick rock package and is a function of the high metamorphic grade (amphibolite facies) and ductility of the rocks.

Keywords: Orogenic gold, Dissemination, Damara Belt, Mineral exploration, Namibia

Assessing the significance of the Vredefort Impact in the augmentation of Witwatersrand Gold Deposits

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Abstract

The 2.9 Ga Witwatersrand Basin is one of the best-known goldfields on Earth, with an intracratonic sedimentary succession, found in the central portion of the South African Archaean Kaapvaal Craton. It accounts for a third (52 000 tonnes) of the gold produced in the world to date. The origin of the gold in the Witwatersrand Basin has been a heated debate for decades. There are three ore-forming models; (1) the placer model, (2) the hydrothermal model, and (3) the modified palaeoplacer model. Three significant events affected and metamorphosed the Witwatersrand Basin, (1) the emplacement of the Ventersdorp lavas (2.7 Ga), (2) the intrusion of the Bushveld Igneous Complex (2.06 Ga), and the (3) Vredefort impact event (2.02 Ga). All three events could have triggered and controlled the regional hydrothermal activity for an extended period. Petrological and geochemical studies have been carried out on the conglomerates and arenaceous quartzites from the Kimberley Formation, Central Rand Group of the Witwatersrand Supergroup, to determine the provenance, depositional environment, and the effect of impact-induced hydrothermal system on gold mobilisation throughout the basin. Samples are from the Vredefort impact structure and the Tshepong Gold Mine within the Witwatersrand basin to allow for comparison. The contrast within these units is evident in the hand specimens, with the Vredefort samples exhibiting a red to pinkish colour, and the Tshepong samples exhibiting a black, dark grey and green tinge. Weathering parameters include the chemical index alteration (CIA), index of compositional variation (ICV), $\text{SiO}_2/\text{Al}_2\text{O}_3$, Rb/Sr ratios and A-CN-K ternary diagram. The high values CIA (86.5 – 88.27, average = 78.2) for the source rocks at Vredefort and low to high ICV values (0.25 – 3.19; average = 0.71), alongside the ratios Rb/Sr (0.26 to 2.11, average = 1.06) and $\text{SiO}_2/\text{Al}_2\text{O}_3$ (7.28 – 41.02; average = 17.43) indicates intermediate to intensive chemical weathering and recycling. For the source rocks at Tshepong the high CIA (86.05 – 88.27, average = 78.2), low to high ICV values (0.27 – 7.53; average = 3.38), alongside the ratios Rb/Sr (0.22 to 9.66, average = 1.44) and $\text{SiO}_2/\text{Al}_2\text{O}_3$ (4.32 – 48.78; average = 29.65) indicates intermediate to highly intensive chemical weathering, recycling, and mature sediments. The paleoclimate discriminant diagram shows an environment characterized by warm and humid conditions at Vredefort and Tshepong. Interpreted composition of source rocks at Vredefort include quartzose sedimentary and predominantly intermediate igneous provenances. The source rocks interpreted at Tshepong are of mafic igneous provenance and mixed composition of volcanic rocks. Mineralization includes hematite and sulfides such as pyrite, chalcopyrite, sphalerite, and gold. Gold content ranges from 35.41 ug/kg to 143 346.93 ug/kg. Three generations of pyrite identified. Based on the several tectonic setting discriminant function diagrams, the Kimberley Formation sediments were deposited on a passive continental margin that was formed in response to a series of crustal plate movements from the north and west in a foreland basin setting, after the intrusion and collision of the Zimbabwe and Kaapvaal Cratons and derived from continental island arc of the extrusion of the Dominion lavas.

Keywords: Vredefort impact, Witwatersrand Basin, Hydrothermal, Mobilisation, Tshepong, Gold

The Geodynamics of Matchless-type mineral systems in the Matchless Belt, Damara Orogen, Central Namibia: Insights from geology, whole rock geochemistry and H-O, Rb-Sr, U-Pb isotope systematics

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Abstract

This study focusses on the VMS mineral systems of the Matchless Belt to constrain the geodynamic evolution of the mineralized zones, the associated Kuiseb Formation and the extensive magmatism recorded in the Matchless Amphibolite. The Matchless Belt mineralization is characterized by four clusters made up of eighteen individual volcanogenic massive sulfide (VMS) copper-polymetallic deposits that are intimately associated with the Matchless Amphibolite and the Kuiseb Formation. The Matchless Amphibolite is a ~350 km long unit of metabasalt and metagabbro, which are intercalated with metamorphosed turbiditic and immature clastic sediments of the lower Kuiseb Formation. It is widely accepted that the deposits in the Matchless Belt mimic Besshi-type mineral systems due to their host rock characteristics. Herein, we report combined outcomes from field work, microscopic studies, whole rock and geochemical analysis of the Ongombo, Ongeama (Otjihase cluster), Gorob, Hope and Matchless deposits. We have coupled these results with quartz H–O isotope systematics and Rb–Sr geochronology of the Matchless Belt deposits and detrital Zircon U–Pb dating of the psammitic schists of the Kuiseb Formation (upper Swakop Group). By taking a mineral system approach, the deposits of the Matchless Belt emerge as unique VMS deposits which do not fit in the three common sub-categories of VMS mineral systems (Cyprus-, Kuroko-, Besshi-type). The H–O isotope systematic data show a pronounced shift in δD but only minor changes in $\delta^{18}O$. Twenty-eight spot analyses of detrital zircons of the psammitic schist yielded a $^{206}Pb/^{238}U$ concordia diagram intercepting ages of 591 ± 14 Ma and 1835 ± 25 Ma with an MSWD of 0.85. The age of 591 ± 14 Ma falls within the timing of the S_1 deformation in the Damara Belt. Rb–Sr geochronology of pyrite yielded an errorchron age of 529 ± 67 Ma representing the timing of S_2 deformation, which may have remobilized the initial mineralization of the Matchless deposits. Combined outcomes from deposit geology, deformation, geochemistry and regional tectonics reveal a superimposition of three hydrothermal regimes: (1) a primary Matchless-type VMS regime during the spreading of the Neoproterozoic rift system with limited ocean floor formation and mineralization around volcanic epicenters, (2) syntectonic remobilization (metamorphic devolatilization) and deformation of epicenters into (structurally-controlled) ore shoots thrust into the Kuiseb Formation during the collision of the Congo and Kalahari Cratons, and (3) lastly a supergene enrichment period.

Keywords: VMS, Matchless-type polymetallic deposits, Damara Orogeny, Pyrite Rb–Sr dating, Zircon U–Pb dating, H–O isotopes

ST03_S02: Ore deposits, exploration and metallogeny**Morphological Features of Diamonds from Cretaceous Conglomeratic Palaeoplacers (Tortiya, Cote d'Ivoire)**

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Abstract

Tortiya diamonds in central-western Côte d'Ivoire are derived from weathered conglomeratic palaeoplacers. Eighteen diamond samples were described in terms of cut, carat, morphology, colour, clarity, fluorescence and inclusions of microdiamonds through macroscopy, microscopy and MEB, which revealed important morphological features. The most informative trends reflected by the Seguela diamonds is probably that of the diamonds' increased development of dodecahedral forms at the expense of octahedral shapes. These trends are associated with the relative abundance of transitional forms which indicate that most diamonds apparently originated as octahedral shapes and were later modified to the dodecahedral forms. Dissolution is a principal morphological process. Tortiya diamonds bearing prospect stones whose weight varied from 0.3 to 1 carat are mostly small. Most microdiamonds are either non-fluorescent or only very weakly fluorescent. Concentrations of mineral inclusions range from colourless to pale-green to black. Associated with the microdiamonds are garnet, olivine, pyroxene chromite, spinel and graphite.

Keywords: Palaeoplacers, Diamonds, Octahedral, Dodecahedral, Dissolution, Tortiya, Côte d'Ivoire

Preliminary Mineral Potential Maps of SW Angola

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Abstract

A seven-year project (Plano Nacional de Geologia, PLANAGEO) was conducted in SW Angola, which involved geological mapping at 1:250.000 and 1:100.000 scales, airborne geophysical (magnetics, radiometrics) and geochemical surveys at 1:250.000 scale, and investigated the mineral exploration potential for metallic and non-metallic minerals. The selection of potential target areas for metallic mineral exploration was backed by the study of old exploration reports, the Mineral Catalogue of Angola, other publications, as well as unpublished theses that were compiled to build a comprehensive mineral database. The area was divided into clusters, which was based on the locations of known deposits with higher mineral potential, the geological potential of the host formations and the newly acquired airborne geophysical survey. The commodities were chosen based on the demands of today's international markets and energy transition value chains. The resulting mineral potential maps were compiled at 1:50.000 scale. The objective was to delineate smaller target areas with increased mineral potential. The targets chosen were REE at the southwestern end of the alkaline-carbonatitic belts, namely Serra da Neve, Bonga-Tchivira and Catanga in greenfield areas, brownfields areas containing Au-Fe in the Jamba-Cassinga-Tchamutete, Chipindo and Cuima-Samboto areas, Cr-Ni, Cu and rare minerals in the ultramafic intrusions of the Chibia-Humpata region and the granitic rocks and Giraúl pegmatites, respectively, in the Namibe region. The maps were produced by integrating the geological maps at 1:100.000 scale, available airborne magnetic and radiometric maps and pXRF results from field reconnaissance and known mineral occurrences. Additionally, alkaline-carbonatitic field surveys also included gamma-ray spectrometry. Field pXRF and gamma-ray spectrometry were used to measure rocks, soils and stream sediments, selected in the planning stage, and using the criteria of best efficiency to obtain the proper geochemical signal. CMR such as NIST 2711 (USA Montana soil), GBM 911-15 (Ni ore, Eastern Goldfields, Western Australia), and OREAS 904 (Cu ore, Queensland, Australia) were used for the instrument's calibration check. Univariate, bivariate and multivariate analysis was performed for the selected chemical elements and groups of pathfinders such as Factor 1 - Cd, Hg, Fe₂O₃, As, V, Ni (from rocks in the Chipindo region, or Factor 1 (21.41% of total variance) - Fe₂O₃, As, Sn, Sb, Ta in rocks of Jamba. Those groups resulting from multivariate analysis (factorial analysis with varimax rotation) were identified as Au pathfinders. Univariate and multivariate maps were produced observing distribution of one and several chemical elements in QGIS software. Mineral potential maps were based on the geological and geophysical information and the multivariate analysis of correlations between pathfinders represented above the 80th percentile of those correlations (for instance for F1, the Au pathfinders in Jamba >0.838 correlation between the group and the factor and the area includes BIF rocks, bimodal metavolcanic rocks of the Jamba group). Potential areas with increased mineral potential for REE, Au-Fe, Cr-Ni and Cu-rare minerals were delimited. Within the clusters selected for study, the maps show new target areas of interest for the selected mineralization.

Keywords: Mineral potential, Exploration, Mineralization, Pathfinders

Xixano Copper–Zinc Mineralization: Geological Context and Its Economic Importance

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Abstract

The Xixano Complex in the north of Mozambique is a N-S trend elongated geologic structure, confined within Mesoproterozoic rocks of Nairroto/Montepuez and Marrupa gneissic Complexes, which outcrops on its the southern edge and truncated by the NE-SW trending Lúrio Belt. The Xixano Complex consists of metasediments and meta-volcanics, which were strongly deformed, metamorphosed to granulite grade and locally migmatized. copper-zinc mineralization is reported from the Xixano Complex. On the basis of recent field data, we present a re-interpretation of the lithostratigraphy and propose a model for Copper-Zinc ore formation within regional tectonics framework. In this study, 4 samples were used for Pb/Pb isotopic analyses, 10 for REE and 50 for petrographic study. An additional set of 229 chemical analyses of surface and drill core samples with major and trace elements were also considered. The mineralization style resembles differences in the distance from the main vent and/or position in the stratigraphy, because they display areas associated with chalcopyrite, pyrite/pyrrhotite and sphalerite, with minor iron oxide and others by pyrite and iron oxide, resembling ocean floor formations. A data set of 229 chemical analyses was examined for hydrothermal alteration trends and two trends were defined on the diagram, regional diagenetic and hydrothermal alteration. The hydrothermally altered trends show AI from 78 to 80 and CCPI from 83 to 98. For estimation of origin, the majority of samples plotted on the Zn/Cu area or VMS origin, on the ternary diagram of Zn-Cu-Pb. Secondary biotite fills fractures of the sulphides and silicates, indicating later crystallization after sulphides and during metamorphism and deformation phase. Petrographic examination showed corona texture of gahenite around sulphide, suggesting formation of gahenite as a result of sulphide consumption during prograde metamorphism. Second phase of garnet recrystallization was observed in combination with biotite described earlier and is interpreted as formed during retrograde phase. Metamorphic assemblages are characterized by gahnite-garnet - biotite- (sillimanite) and Garnet-sillimanite-cordierite. Pb isotope study indicate an age of 881 Ma for sulphide mineralization, while the *Plumbotectonic* model suggests orogenic lead, mobilized during a continental rifting as a consequence of Marrupa/Nairroto opening during the initiation of Neoproterozoic continental rifting or juvenile ocean floor deposits, with melting of hydrated mafic crust, as demonstrated by low HFSE (Zr < 200 ppm) in the felsic rocks and Pb isotope behavior. The deposit is interpreted as a VMS with minor SEDEX contribution, in origin. The study concluded that the cataclastic, annealing and fracture-filling textures in pyrite represent the granulite facies at 735 Ma and show that the precipitation of sulphide is prior to the referred metamorphic event.

Keywords: Xixano Complex, Lithostratigraphy, Geochronology, Northern Mozambique, Xixano copper–zinc mineralization, Mozambique

New insights on the Neoproterozoic Rosh Pinah Formation carbonates from the Rosh Pinah Zn-Pb-Ag deposit, Namibia: Petrographic and Geochemical characterisation

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Abstract

Sedimentary basin hosted mineral deposits are the most important global resource for Zn and Pb. Many of these deposits occur in Proterozoic basins. The Neoproterozoic Rosh Pinah Zn-Pb-Ag-Ba deposit in the Gariep Belt, southern Namibia, is a significant sulphide resource (19.94 Mt at 7.3 wt% Zn, 1.83 wt% Pb and 27.7 g/t Ag) occurring mainly as sphalerite and galena. It is hosted within the volcano-sedimentary units of the Rosh Pinah Formation of the Port Nolloth Group. The Rosh Pinah deposit occurs in carbonates, argillites, siltstones, and minor volcanoclastic rocks within an arkose-dominated sequence. Most of the economic sulphide mineralization is hosted in the carbonates. Despite their economic importance, the genesis of the Rosh Pinah carbonates is only poorly constrained. The host rocks have been overprinted by hydrothermal and deformation events, leading to multiple authigenic carbonate precipitates. Due to this complex paragenesis, bulk analytical techniques, which were previously employed to constrain carbonate formation, may give mixed or equivocal results. Further caveats for bulk rock techniques are contamination from other mineral phases such as silicates, oxides and sulfides. In this study, we combined field observations, transmitted light petrography, cathodoluminescence and backscatter electron microscopy, laser ablation ICP-MS trace element analysis, $\delta^{13}\text{C}$, $\delta^{18}\text{O}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for an in-depth and detailed investigation of carbonate formation and subsequent events. The carbonate bodies from surface outcrop exposures reveal central maximum thicknesses of approximately 3 m and they clearly pinch-out laterally within the Rosh Pinah Mine. These geometries suggest local accumulations with a pronounced topographic relief above the surrounding sediments in shallow water areas, reminiscent of carbonate build-ups. Six different carbonates phases were identified. Two of these carbonates are interpreted to be early diagenetic, and are cloudy, fibrous, and isopachous dolomite cements consistent with a shallow subaqueous depositional environment. Four are recrystallised and/or hydrothermal cements, relatively enriched in Mn, Fe, Sr and Ba compared to early diagenetic dolomites. Chondrite normalised rare earth elements (REE+Y) display LREE enrichment and slight depletion of the HREE. This could reflect local recrystallisation of the pre-existing phases without significant further fractionation, consistent with the simultaneous dissolution-precipitation processes. The Ce anomalies (around 1) suggest that these carbonates formed in a sub-oxic environment. The preservation of positive Eu anomalies in hydrothermal dolomites, are consistent with hot fluids (>200-250°C) that subsequently cooled below 200-250°C before the formation of the dolomite. The carbonate bodies seem to have played a major role in localising high concentrations of economic Zn and Pb mineralization, therefore an understanding on their origin and distribution/controls is key in further exploration activities on and near the mine as well as within the Gariep Belt.

Keywords: Neoproterozoic carbonate cement, Sedimentary basin hosted Zn-Pb deposits, Carbonate geochemistry, Rosh Pinah Zn-Pb-Ag deposit, Namibia

Lineament analyses of Precambrian basement of Central Nigeria: Understanding the controls for resource exploration (Poster)

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Abstract

The structural evolution of pan-African basement in Central Nigeria has made the broadly deformed belt to be replete with lineament trends that depict a high strain transition along shear zones that coincide with seismic trajectories and resource belts. Geological evidence from aeromagnetic grid data, and lineaments extracted at different three azimuth combinations of 30m resolution SRTM data covering eleven 1:100,000 Nigerian Survey Sheets over the seismically active and resource dominated basement shield that stretches from highly deformed Archaean gneisses in the Kaduna region to the phyllite and schist hosted pegmatites of Udege in Central Nigeria has shown that there is a consistent but not strictly systematic relationship between the NE-SW, NNE-SSW, N-S, and E-W structural patterns. The epicenters of the 2016 shallow tectonic tremors, the gold mineralization belt, and the rare metal - Spodumene tantalum rich pegmatite belts all fall within trajectories that define structural levels. A good understanding of the structural controls of both the surficial and buried lineaments linked to intra-cratonic fracture systems of the Atlantic will result in a better modelling of controls for resources and hazards in Central Nigeria, and the basement geology.

Keywords: Precambrian basement, Lineament, Resource exploration, Nigeria



Airborne Geophysics in “under cover” exploration for Sedimentary Copper in the Kalahari Copper Belt, Namibia

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Abstract

Sedimentary Copper Deposits have been significant copper producers for over a hundred years and are now more important than ever in the growing need for more environmentally sensitive Copper production. Explorers in the copper belt of the Kalahari Copper Belt are utilising modern geophysical and geochemical exploration techniques to unlock the belts significant potential that has been hidden by younger Kalahari Sands that vary from 0 to 120m thick. High-quality aeromagnetic data defines the contact of the non-magnetic Ngwako Pan Formation (NPF) with the more magnetic D’Kar Formation. Levelling of regional government and company tenement scale surveys has better defined this prospective contact. A structural interpretation has mapped a thrust ramp-fold pattern with a south-eastern closure direction with associated back thrusts. The prospective carbonaceous shale is developed at the NPF contact along basin margins, in domal structures with relic hydrocarbons and on major shear zones. Drill targets are defined for potential major copper deposits based on this magnetic signature interpretation. Where the cover is not too conductive Airborne and Heli- electro-magnetic (AEM) allows mapping of the conductive carbonaceous shale conductors. A number of company helicopter borne EM surveys utilising the Xcite and VTEM Max systems demonstrate where the cover sequence is not too conductive can be modelled in 3D to provide sub-surface interpretations. The modelling highlights lower conductivity zones where mineralizing fluids alter the host rock and deposit copper, frequently at fault tip zones in antiformal overturned fold closures. These have assisted and led to new discoveries, such as the A4 deposit (10Mt @ 1.4 % Cu) in the Botswana sector of the belt. Interpretation of the Noronex Ltd AEM survey over the known outcropping Witvlei Copper deposits (10Mt @ 1.3% Cu) in Namibia has assisted in understanding the known mineralization and defining new targets. Airborne EM also defines the nature of the Kalahari cover sequence. Reprocessing of a large Questem survey flown in 1996 at 250m spacing over the Namibian northern margin of the Copper Belt maps significant lithological characteristics beneath the Kalahari Sands and more recent superimposed drainage in the cover sequence. Ground follow up with IP and MT surveys followed by drilling has helped provide more detailed information on the cover sequences and demonstrated the conductive and in parts chargeable nature of zones within the Kalahari sands. Electro-magnetics is shown not to be effective in over 50m of Kalahari sands especially where wet clays are developed. Regional scale gravity gradiometric surveys have recently been completed in Botswana to provide further structural and geological interpretations. Sedimentary Copper Deposits have been significant copper producers for hundreds of years and are now more important than ever due to their relatively small environmental and social footprint. Greater understanding of the mineralizing system and interpretation of new geophysical surveys is unlocking the mineralization potential of the Kalahari Copper Belt. Electromagnetic (EM) surveys effectiveness varies depending on the depth and type of the cover sequence. Shallow cover with less than 100m of dry Kalahari Sands is being drill tested by targeted by structural interpretation and modelling of geophysical magnetic data. Copper production is increasing, and new deposits are being discovered in Botswana and increasingly in Namibia at the Witvlei and Fiesta project areas.

Keywords: Sedimentary copper, Kalahari Copper Belt, Airborne geophysics, Exploration

Geology Overview of the Artisanal Mining Sites of Baye in the Province of Bas-uele, DR Congo

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Abstract

The artisanal mining sites of Baye are currently being investigated by identifying and describing all lithologies in the sector. Geological parameters show that the mining sites are part of the Bomu-Kibalian craton. The Bomu Complex comprises mafic orthogneisses (3.42-3.0 Ga), garnet-amphibolitic gneisses, undifferentiated mafic intrusives and migmatites, and is overlain by intercalated paragneiss and thin shale beds. The Bakouma-Poubou terrane in the Bomu Complex is characterized by the Ganguan greenstone (shale) belt consisting of relatively thick sequences of metamorphosed quartzite, slate, jaspilite and talc schist. The Gangu Supergroup is intersected by aplitic and quartz veins and small doleritic massifs. The quartz veins contain the ore mineral galena. This terrane is re-interpreted to represent the reworked part of the central Kibalian Superterrane. The main lithologies described in the Baye region are iron-rich banded quartzites and grey shales with minor dykes of foliated dolerites. The mineralization at the artisanal mining sites is hosted in quartz veins striking parallel to the host lithologies, which contain two sets of foliations and banding oriented NE-SW and NW-SE. Two main types of gold deposits characterize the Baye area, i. e. alluvial and placer. The former was originally associated with white quartz veins locally laminated, while the latter, consists of red pisolithic laterite, locally limonitized. This mineralization is associated with pyrite, and very minor silver extracted from quartz veins or disseminated in schist.

Keywords: Artisanal mining, Quartz veins, Gold mineralization, Foliation and banding, Baye area

Provenance of the Chimanimani diamondiferous sediments, Umkondo Basin, Zimbabwe: a systematic review

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Abstract

The Umkondo Basin over the past few years has been the least studied Proterozoic sedimentary basin in Zimbabwe, but the discovery of diamonds in Chiadzwa in its western section in 2006 and in Chimanimani in the east in 2008, has increased the interest in this area. Topical is the debate on possible provenances of the Chimanimani grits-hosted diamonds, which sit way up in the stratigraphy of the Lower Argillaceous Series unlike the diamonds in Chiadzwa that overly Archaean granites basal to the Umkondo. Three possible sources of the Chimanimani diamondiferous sediments presented by various authors in different contexts are appraised in this paper. These are the Frontier Series, the intrabasinal and the Zimbabwe Craton foreland Basin. This appraisal shows that the intrabasinal model appears to have more systematic and empirical evidence. Evidence of the intrabasinal source of the Chimanimani diamondiferous sediments is largely based on the following: the abundance of octahedron diamond crystals that suggests a proximal source; micro-ilmenites in the heavy mineral concentrates after milling, which do not survive long distances of travel, except when transported by rivers; mineral chemistry of spinels that comprised high Cr₂O₃ content that plotted in the diamond inclusion and intergrowth field. This is further supported by the mantle plume model where older hotspot volcanoes drifted westwards towards the Craton as new ones were formed in Chimanimani in the east. Overall, it appears that this process was a continuum prior to Umkondo Basin formation across the Craton to a period during Umkondo Sedimentation, thus forming kimberlites of various ages. In addition, two ages of diamond formation were discovered by Koornneef et al. (2017) at Venetia Mine, an Archaean (~2.95 Ga) and a Proterozoic (~1.15 Ga), that support this concept that similar tectono-magmatic events that triggered diamond formation at Venetia Mine, which involved rifting accompanied by the widespread Umkondo dolerites (Koornneef *et al.*, 2017) could have been the source of the Chimanimani diamonds. The Frontier Series model which considered Lower Argillaceous Series that hosts the diamondiferous grits to be derived from the nearby Frontier Series is considered in this appraisal as less likely than the intrabasinal model because there is still some controversy on the timing of deformation of the Frontier Series that would have effected thrust development of the sediments to the west into the Zimbabwe Facies, as the deformation is considered Pan African, i. e. post deposition of the diamondiferous sediments. Possibilities of a distal allochthonous source of the Frontier Series sediments have also been suggested thereby making it difficult to explain the abundance of octahedron diamond crystals and above all there is no clear relationship with the diamondiferous Lower Argillaceous sediments. The foreland basin /Zimbabwe Craton model is valid for the deposition of Marange diamonds in the western part of the Umkondo Basin that were basal to Umkondo sedimentation, but there is no evidence in the Chimanimani area. Thus, this appraisal concludes that an intrabasinal source for the Chimanimani Diamonds in Zimbabwe is more sustained by geological evidence.

Keyword: Provenance, Chimanimani diamonds, Umkondo Basin, Zimbabwe

Mineralogical and geochemical characteristics of the Omatapati copper-silver prospect, Opuwo District, Kunene Region, Namibia

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Abstract

The Omatapati copper and silver prospect is part of the mineralized Kaoko Belt, situated in the Opuwo District, Kunene Region, Namibia. The prospect is hosted by the siliciclastic and carbonate rocks of the Devede Formation of the Ombombo Subgroup and has been excavated by small-scale miners in shallow open pits. A mineralized zone with 1.63 to 5.02 wt % Cu and 31 to 312 g/t Ag along a 19 m interval of drill cores has been recognized; however, its mineralogy and geochemical characteristics are still uncertain. This study aims to reveal mineralogical and geochemical characteristics of the Omatapati prospect. To this end, field observation, core-logging, petrographic, and bulk and mineral composition, sulfur isotope and fluid inclusion analyses were carried out on ores and host rocks. The Omatapati prospect is characterized by primary mineralization at a depth range of 72 to 90 m, which consists predominantly of chalcopyrite, bornite, sphalerite; secondary chalcocite and digenite define a Ccp-Bn zone. In the Ccp-Bn zone, deformed chalcopyrite and bornite are disseminated in calcareous chlorite schist. Chalcopyrite and bornite occur within stage 1 calcite veins, and stage 2 quartz veins, which are subparallel or discordant to the foliation of the schist. Another ore body of secondary mineralization is located from surface to a depth of 50 m and consists of semi-massive chalcocite and covellite accompanying malachite, hematite and goethite defining a Cct-Cv zone. Chalcocite and covellite occur within steeply dipping quartz, calcite and barite veins in stage 3 hosted in brecciated dolostone composed of dolomite clasts in a chlorite and sericite matrix. Bulk geochemistry indicates relatively low average Cu-concentration in the Ccp-Bn zone (3.6 wt.%) compared to the Cct-Cv zone (9.5 wt.%). The average Pb and Ag contents in the Ccp-Bn zone are 300 ppm and 128 ppm, while in the Cct-Cv zone they are 393 ppm and 347 ppm, respectively. The PAAS (Post-Archaean Australian shale)-normalized REE patterns of the ores show positive Eu anomalies and enrichment of LREE for the Ccp-Bn zone, and depleted LREE in the Cct-Cv zone. Silver is elevated in chalcocite (~6303 ppm), digenite (~4425 ppm) and covellite (~3060 ppm). Chalcopyrite contains impurities at maximum 1260 ppm Ag, 550 ppm Co, 360 ppm Zn and 300 ppm Cd. $\delta^{34}\text{S}_{\text{CDT}}$ values of chalcopyrite and bornite range from -10.8 to +1.3 ‰, and those of chalcocite and covellite range from +4.9 to +11.2 ‰. Modes of homogenization temperatures and salinity of fluid inclusions in quartz and calcite veins in the Ccp-Bn zone are 290 to 300 °C, and 14.2 to 16.9 wt. % NaCl eq., while in the Cct-Cv zone they vary from 190-200 °C to 220-230 °C, and 2.8 to 20.5 wt. % NaCl eq., respectively. The fluid inclusions in the Cct-Cv zone are dominated by H₂O (ca. 99 mole %), N₂ (ca. 0.5 mole %), where Ar/He vs. N₂/Ar and CO₂/CH₄ vs. N₂/Ar, indicate a magmatic signature. Based on observations and analyzed data, the primary mineralization of the Omatapati prospect is epigenetic hydrothermal likely to have formed by fluids with magmatic contribution.

Keywords: Omatapati Cu-Ag prospect, Ombombo Subgroup, Hydrothermal mineralization, Supergene mineralization

Occurrence and lithogeochemical composition of iron ore in the Ngororero District, Rwanda

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Abstract

We present the results of geological and geochemical investigations of iron ore deposits in the Muhororo sector, Ngororero District, Rwanda. The objectives of this study were to determine the elemental composition, mineral species, and morphology of the iron ore samples collected from various locations using X-ray Fluorescence (XRF), X-ray diffraction (XRD), and scanning electron microscope (SEM). The results show that Ngororero iron ore has high Fe₂O₃ content ranging from 73% to 76%, making it suitable as a raw material for iron production. The Al₂O₃ and SiO₂ contents are very low, ranging from 0.798% to 1.974% and 5.56% respectively, indicating low gangue and impurities. The low Phosphorus and Sulfur content make this iron ore economically viable. These findings suggest that Rwanda has untapped potential in exploiting mineral resources, especially iron, which could reduce the cost of importing metallic products from other countries. However, detailed exploration is needed to characterize and determine the tonnage of the iron ore to evaluate its exploration potential.

Keywords: Iron ore, Mineral resources, X-ray Fluorescence (XRF), Fe₂O₃, Rwanda



Revision of the timing of accumulation of the raised beach deposits of the central Sperrgebiet, Namibia

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Abstract

The presence of Cenozoic marine sediments in the Sperrgebiet, was noted as early as 1908 when diamonds were found at Kolmanskop. Because of the economic interest of these deposits, geological investigations led to detailed mapping, initially by Beetz in 1926. In the central Sperrgebiet early investigators correlated the 'highest' beach deposits (ca. 160 m above present-day mean sea level) with the Eocene, referred to in the old literature as 'Höchster Stand der Eocänsee' or the 'Eocäne Marine Inundation'. Liddle (1971) extended this « ancient » strandline a few kilometres northwards to Elfert's Tafelberg. Dingle *et al.* (1983), dated it as late Palaeocene – early Eocene. In contrast, along the Namaqualand coastal plain in South Africa, marine deposits attributed by Pether (1994) to the 90 m beach and lower altitude beaches (50 m beach, 30 m beach) were correlated with the Miocene. Re-examination of the beach conglomerates at Eisenkieselklippenbake and Buntfeldschuh, which outcrop at ca 150-160 m above sea level, reveals that some of the deposits are considerably younger than Eocene, being instead of early Miocene (Aquitainian-Burdigalian) age. The beach conglomerates at both of these localities contain well-rounded and polished cobbles of densely ferruginised gravel and sand associated with cobbles of a great variety of other rock types (quartzite, silcrete, silicified freshwater limestone, vein quartz, agates, pebbles of banded ironstone formation (BIF), jasper etc.). This conclusion follows from the observation that the ferruginisation of near-surface deposits in the sector of the Sperrgebiet between Kerbehuk in the south and Elisabethfeld-Grillental in the north occurred during the Oligocene (more precisely, the Chattian) petering out during the Early Miocene (Aquitainian-Burdigalian), and ceasing altogether with the establishment of hyper-aridity in the region (onset of fully desert conditions in the Namib) ca. 17 Ma. This means that cobbles derived from the break-up of the ferruginised deposits must be younger than the Chattian. Many of the cobbles of ferruginised sediment contain clasts of agate, BIF and jasper, vein quartz, silicified limestone etc. which were already present in the superficial deposits of the region prior to the Chattian, supporting the old conclusions concerning the presence of Eocene marine deposits in the Sperrgebiet. The revised age of the Eisenkieselklippenbake and Buntfeldschuh beach conglomerates means that the timing of the geomorphological development of the region, such as the back-cutting of the Buntfeldschuh Escarpment, requires revision, as do the correlations of near-surface deposits such as the fluvial Gemboktal and Blaubbock formations which are of Oligocene and Miocene age.

Keywords: Sea level, Oligo-Miocene, Sperrgebiet, Raised beaches

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Geochemical signatures and nature of the mineralization resulting from the installation of the Tulua pegmatites: A contribution to the knowledge of the Nacala-a-Velha pegmatite field, Nampula Province (Poster)

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Abstract

Mozambique is known in mining sector for the occurrence of important mineralized pegmatite fields, occurring in NE of the country: Nampula, Zambezia, Sofala, Manica, Cabo Delgado and Tete. The implantation of pegmatite bodies can mobilize chemical elements at interface with host rocks, promoting specific mineralization's. These mineralization's, combined with the resulting from mineralogical and compositional zoning within the pegmatite, confer great economic importance to these deposits. This research aims to study the paragenetic diversity of pegmatites from Tulua (Nacala-a-Velha), for contributing to the identification of their base resources and the classification that has not yet been carried out. To this end, paragenesis and microparagenesis were screened from the sterile host rock, through the host rock-pegmatite transition, to the zonal units in the pegmatite body. In the case of zoned lithological units, the microscopic observations were made through thin sections in the transmitted light optical microscope, accessible at National Museum of Geology. Tulua pegmatites are characterized by zoned, consisting of border, mural, intermediate and nuclear zones. Petrographic analyzes revealed a strong presence of colored tourmalines and litiniferous micas suggestive of the lithium cesium and tantalum (LCT) feature in these pegmatites. However, amazonite concentrations were observed, reporting a niobium, yttrium, and fluorine (NYF) feature, therefore, based on these observations, supported by the criteria of Černý and Ercit (2005), it's proposed that Tulua pegmatites be classified as mixed pegmatites. Two metallogenic hypotheses were proposed to explain the hybrid nature of these pegmatites, which will be discussed in later works: i) The NYF character of the Nacala-a-Velha pegmatites is regional and expands to the provinces of Niassa and Cabo Delgado, in northern Mozambique, resulting in contamination between NYF pegmatitic magma and metasedimentary rocks with appropriate composition to generate an LCT lineage; ii) The LCT character is strong in Zambézia, south of Nampula, and considering Nacala-a-Velha as a border zone between two geochemical lineages, there is the possibility of occurrence of LCT pulses causing NYF-LCT intercalation (mingling) before the final consolidation of pegmatites. Chemical analyzes of the total rock may contribute to confirm or reject these hypotheses. It is therefore concluded that potential resources of colored tourmaline (rubellite and dravite) and lepidolite occur in the transition front between the intermediary zone and the nucleus. The distribution of mineralization suggests that these are pegmatites of rare elements (Černý and Ercit, 2005), with metalliferous zones, generally LCT in the innermost parts and NYF in the outermost parts of the pegmatite. The hybrid character of the pegmatite is probably due to the occurrence of LCT lineage pulses in NYF pegmatites or to the local contamination of NYF pegmatites by rocks with LCT character.

Keywords: Paragenesis, LCT-pegmatite, NYF-pegmatite, Mixed pegmatites, Mozambique

Reference: Černý, P. and Ercit, T. S. 2005. The Classification of Granitic Pegmatites Revisited. *Can. Mineral.*, **43**, 2005-2026, <https://doi.org/10.2113/gscanmin.43.6.2005>.

Petrography, ore mineral paragenesis, and gold deportment of the Twin Hills Gold Deposit, central Namibia

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Abstract

The Twin Hills Gold Deposit is an orogenic gold deposit hosted within the metamorphic turbidites of the Kuiseb Formation in the Southern Central Zone of the Damara Belt. This study aimed to understand the petrography of the host rocks, the formation of the ore minerals and assess the deportment of the Twin Hills Gold Deposit. Methods used in this study included drill core logging, transmitted and reflected light microscopy and a scanning electron microscopy (SEM) based TESCAN Integrated Mineral Analyzer (TIMA). The host rocks are characterized by graded bedding with gradations ranging from pelitic mica-rich interbeds to psammitic quartz-rich interbeds, together forming an interbedded metagreywacke package. Interbedded metagreywacke is the main host unit to gold mineralization and is made up of quartz, biotite, muscovite, plagioclase, orthoclase and cordierite. The ore mineral assemblage is characterized by the presence of gold and three major sulphide minerals namely, pyrrhotite, arsenopyrite, and pyrite. Gold mineralization at the Twin Hills Gold Deposit is associated with two main hydrothermal alteration styles, namely, potassic alteration and silicification. This research suggests at least three stages of gold mineralization within the Twin Hills Gold Deposit. The first stage is the diagenetic stage, which involved the enrichment of diagenetic arsenian pyrite (Py₀) in the turbiditic sediments with gold and other trace elements via the exhalation of reduced, deep-seated Au-As enriched H₂S-rich basinal brines onto the sea floor. The second stage involved the release of gold initially locked up within the arsenian pyrite (Py₀) crystal lattice into metamorphic fluids and the subsequent precipitation of free gold (Au₁) from gold-bearing fluids via phase separation due to a drop-in fluid pressure. This resulted in the formation and concentration of disseminated gold to economic grades. The third stage is the quartz veining stage, which was characterized by increased permeability and advanced fluid flow due to progressive metamorphism and deformation. This stage was responsible for the remobilization of fine gold grains (Au₁) that were disseminated within the groundmass of the meta-greywacke and concentrating them into the biotite selvages. This stage is also believed to be responsible for the exsolution of gold from the arsenopyrite crystal lattice resulting in very fine gold (Au₂) grains included within arsenopyrite crystals. This led to further upgrading of the gold grades to higher economic levels. The gold deportment analyses revealed three modes of occurrences of gold within the Twin Hills deposit. This includes gold disseminated within the groundmass, gold grains disseminated within biotite selvages associated with quartz veinlets and gold grains included within arsenopyrite crystals. This study recommends a two-stage recovery procedure to ensure maximum gold recovery, this includes gravity separation methods followed by a cyanide leach process.

Keywords: Twin Hills gold deposit, Orogenic gold, Kuiseb Formation, Petrography, Gold deportment

Trace element characteristics of the sulfide mineralization of the Tsumeb deposit, Otavi Mountain Land, Namibia

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Abstract

The polymetallic Tsumeb deposit in the Otavi Mountain Land in the northern part of the Damara Belt, Namibia, is well-known for its large mineralogical variety and complexity. Mineralization is hosted in dolomite of the Neoproterozoic carbonaceous units of the Otavi Group. Sulfide mineralization, over a depth range of about 1900 m, displays mineral assemblages that are typically Cu-rich (pyrite-galena-tennantite-renierite, carbonate-galena-pyrite-sphalerite, renierite-galena-chalcocopyrite-chalcocite-digenite-renierite). We describe the distribution of Ga, Ge and associated trace elements (Ag, As, Cd, Co, Cu, Fe, In, Ni, Pb, Sb, Zn) in the sulfide ore from historical deep underground mining (mining levels 16, 17, 18, 19, 20, 29, 30, 32 and 46) of the Tsumeb Mine. Additionally, we report preliminary bulk-rock compositional $\delta^{66}\text{Zn}$ and $\delta^{65}\text{Cu}$ isotope analyses, which were carried out on selected samples, for the purpose of understanding the ore forming processes associated with the Tsumeb deposit. Samples were collected from the historical Schneiderhöhn Tsumeb sample collection hosted at the National Earth Science Museum of the Geological Survey of Namibia. Electron microprobe results of the samples analysed reveal that renierite and enargite are significant carriers of Ge, with averages of 8.21 wt% and 0.78 wt%, respectively, while Ga is mainly incorporated in renierite and sphalerite (av. 0.12 wt%, 0.11 wt%). Sphalerite trace element abundance is characterized by elevated Cd, Ge, and Ga, suggestive of low formation temperatures. Cadmium forms a solid solution within the mineral phase crystal lattice and enters sphalerite via a simple substitution defined by $\text{Cd}^{2+} \leftrightarrow \text{Zn}^{2+}$. Critical elements such as Ga and In may have entered the sphalerite lattice by coupling with Cu^+ as $2\text{Zn}^{2+} \leftrightarrow \text{Cu}^+ + \text{Ga}^{3+}$ and $\text{Cu}^+ + \text{In}^{3+} \leftrightarrow \text{Zn}^{2+} + \text{Fe}^{2+}$ while, Ge is possibly incorporated in the Ge-rich phases which exists as micro-inclusions in sphalerite. Our data reveal that the bulk-ore Zn isotopic composition of the Tsumeb deposit ($\delta^{66}\text{Zn} = -0.0133\text{‰}$ to 0.125‰) is within the range of typical Zn-rich massive sulfide deposits and the range of sphalerite from the Irish MVT deposits, while the range of $\delta^{65}\text{Cu}$ varies from 0.80‰ to 1.32‰ , which is consistent with mineralization within a hypogene environment.

Keywords: Tsumeb deposit, Sulfide mineralization, Trace element geochemistry, Copper isotopes, Zinc isotopes

Namdeb's Offshore Diamond Mining Legacy – Unlocking the Next Phase

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Abstract

The world's largest diamond placer lies on the southwestern coast of Namibia, within the restricted area known as the Sperrgebiet - "The Forbidden Area". Diamonds have been mined from various sedimentary settings since 1908 with their discovery in the area. The Sperrgebiet hosts three major placer types: fluvial, marine (spit/barrier beaches, linear beaches, pocket beaches) and aeolian (including deflation). This regional composite placer deposit has yielded over 100 million carats of >95% gem quality stones. Namdeb Diamond Corporation (Pty) Ltd currently holds three offshore mining licenses. The offshore mining licenses span between the towns of Oranjemund to 45km's south of Lüderitz. The offshore extent of the licenses covers the area from the low water mark to 129m below mean sea level. The surface area is approximately 1 500 km². Several attempts have been made since the early 1960s to exploit the diamonds within the marine setting. Through comprehensive research, Namdeb has developed a framework to de-risk, evaluate and unlock the potential of the targets in its offshore mining concessions. To define the diamondiferous resource, technical datasets were gathered using seismic technology, bathymetric survey techniques, as well as sampling data. These in turn were used to delineate the primary targets, which are sediment filled bedrock depressions. The combination of these datasets assists in synthesizing the evolution of the deposits. This allowed for a comprehensive understanding of the combined effects of mineralization, geomorphic features, and geomorphological processes. Two study areas, Bogenfels and Purple, were selected to showcase the workflow, data generated, and the results modeled. Bogenfels, located in the central portion of the offshore Sperrgebiet, represents an area influenced by aeolian, alluvial, fluvial and marine processes. The combination of varying natural forces has led to the development of a unique sedimentary package and bedrock morphology. Purple located 70km north of Oranjemund, represents the interaction between fluvial material deposited and reworked in a marine setting. Gravel lag deposits and cobble gravel berms are well developed in this area. The final step in any successful mining project is the development of a business model for the resource. The Contractor Operations is the foundation for building a strong and robust marine mining business and allows Namdeb to look at the next steps in the continuation of its offshore mining legacy. Namdeb's focus now turns to finding mining solutions that can deliver on the full potential of this deposit and how to extract it in an environmentally friendly manner.

Keywords: Diamonds, Sperrgebiet, Placer exploration, Namibia

Geology and prospectivity of the Schlangental (Cu-V) deposit in the Otavi Mountainland (Northern Namibia)

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Abstract

The Schlangental mineral deposit is located west of the historical Guchab Mine which lies 10 km to the east of the Kombat copper mine. These deposits are situated in the Otavi Valley Syncline within the Otavi Mountainland in the Northern Platform of the Damara Pan African Orogenic Belt. The deposit is hosted in dolomites of the Elandshoek Formation which form part of the Damara supergroup. Although most of the Cu-Pb occurrences along the Otavi valley syncline which is said to be tectonically controlled and of epigenetic characteristics of the Mississippi Valley Type (MVT) deposits, little is known about the genesis and prospectivity of the Schlangental mineral deposit. To better understand the geology and genesis of the Schlangental deposit, this study aims to use geological mapping, core logging, petrographic and geochemistry to characterize the mineralization, genesis and prospectivity of the deposit. There exist historical shallow open pits which were previously excavated in the early 1900s to a depth of 3-4 meters. The prospect area is covered in soil, mineralized halos are observed surrounding the open pits. The Schlangental prospect is believed to have produced 5.5 t of export ore at 8% copper, 26.1% lead, 10.8% vanadium oxide; plus 30.5 t of concentrate at 3.3% copper, 11.7% lead, 4.7% vanadium oxide over an unspecified period from an excavation along a vein of mineralized jasperoid striking east-northeast. Strong copper mineralization has been observed along the pits and outcropping of Elandshoek Formation. The mineralization observed comprise mainly of copper secondary minerals of malachite and chrysocolla along with some chalcocite and chalcopyrite sulfides ores. The mineralization occurs primarily along fractures and veins of calcite and Quartz within a massive light grey dolomite towards the East and a highly siliceous light grey dolomite in the western areas. Calcification and silicification appears to be the main dominating alterations. The geophysics and geological anomalous data suggested that the causative fluids and metals are controlled by intense fracturing extensional structures. Strong outcropping mineralization zones are observed, positive exploration results from trenching work and constructive historical geophysics anomalies all suggest that the Schlangental prospect has a great potential for Cu-V exploration. Some samples are selected for further X-Ray Fluorescence for whole-rock geochemical analysis, X-Ray Diffraction for the mineralogy and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) for major and trace elements geochemistry, and for the lead and sulfur isotopes to characterize the deposit in terms of the genesis and prospectivity.

Keywords: Mississippi Valley Type (MVT) deposits, Schlangental deposit, Otavi Mountainland, Geochemistry

Structural, geophysical and geochemical studies for gold prospecting in the Omaruru area, Namibia (Poster)

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Abstract

The Central Namibian Gold Belt, forming part of the Pan-African Damara Belt, hosts well-known gold mines, i. e. the Navachab and Otjikoto Mines. Prospecting and exploration within the Navachab-Ondundu gold trend is still ongoing, culminating in recent discoveries such as the mineralization of Twin Hills area. It is believed that mineralization in the Central Namibian Gold Belt is largely structurally controlled orogenic gold, with some of the gold associated with skarn and greisen (Au, Cu, Bi). The identification of a possible new discovery relies upon various combined approaches at different prospecting stages in order to identify surface signatures associated geological structures and pathfinder elements to determine a target area. Systematic prospecting by soil sampling was successfully performed in the Erongo Gold Project in 2020. Samples were analyzed using the portable X-ray fluorescence and inductively coupled mass spectrometry (ICP-MS) techniques, and preliminary target areas for continued exploration were tentatively determined; however, there was a need to further characterize the potential mineralization and to identify additional targets. The latter was done by 1) determining pathfinder elements associated with the gold and base metal mineralization, 2) determining the relationships between geological structures, geophysical data and pathfinder elements, and 3) the application of multi-variate graphs for data analysis, using QGIS software. The results show three main future target areas and a possible fourth (northeast, north, east, south targets). All target areas are associated with the pathfinder elements As, Ag, Cu, Ni, Pb, Sb, Te, W, Zn and in some areas the anomaly is characterized further by Ca, Cd, Se and Ti. All target areas are also clearly associated with high magnetic anomalies and tectonic structures (faults).

Keywords: Damara Belt, Gold, Pathfinder elements, Targets, Anomalies, Namibia

Pb-Cu-Zn mineral potential of the Namaqualand Province, South Africa

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Abstract

The Northern Cape Aggeneys-style mineralization in South Africa has potentially exploitable resources that are deep and structurally complex. Spatial modelling and subsequent mineral resources estimation of the orebody are necessary for future exploration of the potential unknown mineral deposits within the terrane. The aim of this work is to present an inventory estimate of lead, copper and zinc (Pb-Cu-Zn) mineral potential in the Namaqualand Metamorphic Province. Preliminary results for both the regional and local target generation and mineral resource estimation is presented. Sixteen prospective target areas has been selected around historic mineral occurrences guided by an integrative approach with multi-source geoscientific data. Each area has a drill target borehole to which a 3D geological model was created. The methodology includes fundamental techniques used to develop a mineral system knowledge base for the Namaqualand Province, which guides mineral potential prediction for unknown Pb-Cu-Zn deposits. Pb, Cu and Zn grade distribution is presented for the Namaqua 3D geological model. The subsurface 3D geological model is informed by integrative techniques using geophysical, geochemical, historical drillcore and geological data. The surficial multi-source geoscientific data, especially the Pb-Cu-Zn concentrations are compared with the subsurface geological model predictions. Ultimately, the potential host rocks for Pb-Cu-Zn mineralization has been delineated, targeted and measured.

Keywords: Namaqua-Natal Metamorphic Province, Pb-Cu-Zn mineralization, Spatial modelling

The mineral potential of Niger – status of knowledge and prospects

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Abstract

The Republic of Niger, in sub-Saharan Africa, has benefited through the implementation of the GOLD project (formerly PRACC) financed by the World Bank. This study, conducted in 2020 – 2022 by Beak Consultants in partnership with GOLD and CRGM was in part to identify priority intervention zones and define the geological work to be carried out in them. The main targeted precious metals in Niger are Au, Sn, Ta, W, other rare metals, Cu, Pb/Zn and U. The project also resulted in the drafting of Terms of References (ToR) detailing the expectations for the future exploration projects, and to an exploration programme for Li in brines. The study included a comprehensive review of the state of knowledge of the mineral potential of the country, including an inventory of mineral occurrences at the country scale. A selection and ranking of target commodities and zones (ZIP: Priority Intervention Zones), necessary orientation geochemical stream sediments survey, as well as recommendations for the future exploration works were to be implemented in the three selected ZIPs. In this study, stream geochemistry sampling was conducted by the CRGM institute of Niamey (*Geological & Mining Research Center*) within the prospective Aïr Massif region in the Tarouaghi Massif, a “young” intrusive known for occurrences of gold and rare metals, and in the Pic d’Aouzégueur area where a “gold rush” is going on. The samples were analysed by ALS laboratories in Canada with an independent QA/QC in a certified laboratory in Europe. The result show 100 – 500 µm grainsize fractions of the stream sediments as carrier of the most significant geochemical signal, while eliminating distal wind-blown material. This sets a fundamental precondition for the future exploration campaigns using stream sampling. The results of the survey highlight the important and under-explored mineral potential of the country. For example, regarding strategic metals such as lithium in brines, uranium and gold, around 1500 artisanal and small-scale mining (ASM) sites that have been remotely detected during the project.

Keywords: Aïr Massif, ASM, Minerals, Mining exploration, Metals, Niger

ST03_S03: Critical raw materials-strategic minerals**Origin of heavy rare earth element mineralization within the Naauwpoort Formation volcanics, in relation to Lofdal magmatics, Lofdal West, Namibia (Poster)****Alfeus Alfeus^{a*}, Rainer Ellmies^b, Mbili Tshiningayamwe^a, Absai Vatuva^a**^a*Geoscience Department, University of Namibia, Keetmanshoop*^b*Namibia Rare Earths (Pty) Limited, Windhoek, Namibia***Corresponding author: chikiezoalfeus@gmail.com***Abstract**

The Naauwpoort Formation, likely the extrusive equivalent of the Oas Alkaline Complex (OAC) about 50 km west of Khorixas, is of potential interest for its rare earth element (REE) mineralization. It is mainly comprised of volcanic rocks with associated sedimentary and metamorphic rocks. Carbonates, phyllitic schists and brecciated ignimbrites (hosted in a fine-grained carbonate matrix) constitute the main lithologies, which are cross-cut by massive gabbroic dykes trending NE-SW and fine-grained tuffs. Immediately southeast of the main lithologies there is an occurrence of a meta-phonolite as well as a metamorphosed volcanic rock comprising felsic leaf-like veinlets. Using a portable X-Ray Fluorescence (pXRF) device, five carbonate samples, two from the phyllitic schist, two from the ignimbrite, four of metavolcanic rock and three of meta-phonolite were analyzed. Total REE concentrations include lanthanum (La), cerium (Ce), praseodymium (Pr) and neodymium (Nd), with results ranging from 188-473 ppm for phyllitic schist, 573-992 ppm for carbonate rocks, and 493-929 ppm for metavolcanic rocks. REE concentrations in ignimbrite and meta-phonolite range from 155-369 ppm and 199-518 ppm, respectively. The meta-volcanic rock shows anomalous concentrations of yttrium (Y: an indicator of the presence of heavy REE) (33-245ppm) and thorium (Th) (40-81ppm) that are not detected in other lithologies. Results from petrography and geochemistry will also aid in characterizing and relating the heavy REE mineralization from the Naauwpoort Formation to the known Lofdal mineralization, and determining its economic potential.

Keywords: Naauwpoort Formation, Heavy rare earth elements, Yttrium, Lofdal, Namibia

Fluid Inclusion Studies on the Kenticha rare-element granite pegmatite, Southern Ethiopia

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Abstract

A series of barren to rare metal-bearing pegmatites are intruded into the Neoproterozoic Adola Belt of southern Ethiopia. The rare element pegmatite hosts world-class Nb-Ta mineralization, as well as significant reserves of Li and Be minerals. In this study, fluid inclusion data and feldspar geothermometry have been used to define the crystallization conditions of the Kenticha rare metal pegmatite. Primary and complex assemblages of secondary fluid inclusions representing episodic fluid circulations have been identified in quartz and spodumene. A primary aqueous-carbonic fluid of low salinity aqueous solution with liquid and vapour CO₂ phases, secondary carbonic-rich to carbonic fluids, and multiple generations of secondary aqueous inclusions that represent sub-solidus hydrothermal circulation have been identified. Upon heating, all aqueous inclusions were homogenized on the bubble point curve to the liquid phase between 100 - 290 °C. Aqueous-carbonic inclusions were commonly homogenized via critical transition ($T_h(LV \rightarrow SCF)$) between 241 - 397 °C, less commonly via a dew-point transition ($T_h(LV \rightarrow V)$) between 213 - 264 °C. The fluids entrapped during last-stage of pegmatite crystallization are low salinity aqueous-carbonic fluids which may be approximated by an H₂O-CO₂-NaCl system. A combination of microthermometric data and existing experimental data of flux and volatile-bearing haplogranite solidus suggest exsolution of fluids from hydrous silicate melt during crystallization of the granite-aplite layer around a pressure of 2.7 kbar and temperature of 530 °C. The fluids were then trapped and isobarically cooled along a reasonable geothermal gradient within the pegmatite unit down to a temperature of around 397 °C.

Keywords: Fluid inclusions, Micro-thermometry, Pegmatite, Cooling-path, Kenticha, Ethiopia

Lithium pegmatites in the Karagwe-Ankole and Kibara belts of Central Africa

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Abstract

The Great Lakes region in the eastern DRC, southwestern Uganda, Rwanda and Burundi (Central Africa) are rich in deposits of tin (Sn), tantalum (Ta) and tungsten (W), collectively known as the 3Ts. In 2022, the region supplied 62.5% of global Ta (DRC 43%, Rwanda 17.5%, Burundi 2%). The mineralization is hosted in early Neoproterozoic pegmatites (cassiterite and columbite-tantalite) and quartz veins (cassiterite and ferberite), and in derived alluvial and eluvial deposits. The pegmatites and quartz veins are linked to S-type granites that were emplaced in Palaeo- and Mesoproterozoic metasedimentary and metavolcanic rocks. Many of the pegmatites that were mined at some stage for Sn and Ta, also host lithium-bearing minerals, such as spodumene, amblygonite-montebrazite or eucryptite, which have now become important targets for lithium exploration. While the 3Ts are amenable to artisanal and small-scale mining due to intense tropical weathering (decomposition of the rocks and concentrating the resistant 3T minerals in alluvial and eluvial cover), the lithium is largely lost during weathering. As such, only the deeper, unweathered pegmatite bodies host potential lithium, but these require significant industrial investment to be extracted. The objective of this work is to assess the lithium potential of rare metal pegmatites in Central Africa. In the DRC, important Li prospects include the world-class Manono-Kitotolo pegmatites, which represent a giant (15 km long by 200-300 m thick) spodumene pegmatite system composed of multiple pegmatite sheets with variable dips (20-50°) along strike. This deposit is currently explored by AVZ Minerals Limited (an Australian company), in a joint venture with Cominière (a Congolese company) under the name Dathcom Mining AS. In Rwanda, significant lithium-rich pegmatites are known from at least six localities, five of which are within the Gitarama-Gatumba pegmatite district (Buranga, Gatumba, Rubini, Rongi and Rusorora) and the sixth is in the more eastern Musha-Ntunga area, where spodumene deposits were recently discovered at 150 m depth in drill cores by the Trinity Metals Group. In Burundi, only one spodumene pegmatite is documented at Ndora, but exploration has ceased due to a recent embargo on the Burundi mineral sector, as the country is developing a new mining code. Using new observations from the Musha-Ntunga (Rwanda) and Manono-Kitotolo (DRC) spodumene pegmatites, insights into the mineralogical and paragenetic variability of these rare-metal pegmatites are becoming well-known. Factors such as high temperature deformation, magmatic-hydrothermal alteration and weathering, all have implications on extraction and processing.

Keywords: Lithium, Pegmatite, Critical metals, Spodumene, Central Africa

Monazite-rich carbonatite dykes at Eureka, Namibia

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Abstract

The Eureka carbonatite is located at 22.044°S, 15.254°E on Eureka Farm 99, near the town of Usakos, Erongo Region, Namibia. Rare earth element (REE) bearing dolomite carbonatite dykes (typically 1 to 2 m but up to 7 m wide) at Eureka contain visible, abundant low-Th monazite-(Ce) crystals, which even occasionally reach up to 10s cm diameter, and these are amenable to physical beneficiation techniques. The locality was first documented in the 1960's, but understanding of the deposit has been hampered by a thin cover of Quaternary gravel and calcrete obscuring much of the exposure, compounded by the tendency of the carbonatites to occur in low, weathered depressions in the landscape. Recent diamond drilling by E-Tech Resources has shed new light on the genesis of this deposit, and demonstrates that the carbonatite dykes consist of a ubiquitous assemblage of three rock types. These comprise a core unit of variably mineralized dolomite carbonatite, with magnetite, pyrrhotite, monazite, and minor calcite; an outer zone termed 'dalmatian carbonatite' or 'DCARB' consisting of calcite, olivine, serpentine, pyrrhotite, magnetite and graphite; and a skarn rock, termed 'GCARB', consisting of diopside, tremolite-actinolite, pyrrhotite, graphite, and large monazite crystals with locally developed allanite-apatite coronas. All of the carbonatites strike roughly parallel to the fabric developed within intensely deformed schists and quartzites of the Etusis Formation of the Damara Supergroup. Previously published ⁸⁷Sr/⁸⁶Sr isotope data support a mantle origin, with only minor crustal input, and U-Pb dates of 548 ± 4 Ma suggest a Pan-African related event was important in petrogenesis. It is possible that the monazite-(Ce) may have recrystallized at this time. Based on the contact relationships observed, and the published isotopic data, the deposit is interpreted as a metamorphosed carbonatite, with the surrounding monazite-bearing silicate rocks (GCARB) interpreted as a reaction product between the carbonatites and surrounding siliceous country rocks. This interpretation suggests other metamorphosed carbonatites may be present within Etusis-age (and older) rocks of the Damara Supergroup and active exploration for REE by E-Tech Resources Inc. is now expanding the area of known mineralization.

Keywords: Carbonatite, Monazite, Rare earth elements, Namibia

Detection of Lithium-Rich Pegmatites Using ASTER Multispectral Image Analysis: insights from the Karibib Pegmatite Belt, Namibia

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Abstract

Lithium (Li) is an energy critical raw material that plays a key role in renewable energy transition initiatives, particularly for rechargeable Li-ion batteries. With demand expected to increase substantially in the coming decades, new exploration efforts for Li-bearing minerals are emerging globally. Employing a data fusion approach, this study detects and highlights the potential locations of Li-bearing pegmatite occurrences in the Karibib Pegmatite Belt (KPB), a known Lithium-Cesium-Tantalum (LCT) mineralization prospective zone in Namibia. The KPB has been prospected for lithium mineralization since the 19th century. However, there is need for innovative and non-invasive approach to disentangle the LCT complex mineralization associated with the KPB in this area. We use Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) remotely sensed multispectral imagery to establish spectral detection techniques for Li-rich minerals. We applied multiple spectral algorithms: False Color Composites (FCC), Band Ratio (BR), and Principal Component Analysis (PCA) to determine the spectral characteristics of Li-bearing pegmatites and ran a Spectral Angle Mapper (SAM) algorithm to detect Li-rich pegmatites. Considering spectral characteristics of lepidolite as a main Li-bearing mineral in the KPB area, we used lepidolite's USGS Spectral Library Version 7.0 convoluted to ASTER Sensor Bandpass for spectral interpretation of lepidolite's unique reflectance behavior. Spectral analysis results show similar unique absorption depths at 2.2073 μ m for both image spectrum extracted at Helikon 4 in the image, and USGS library spectrum. Based on the results, ASTER data effectively detected Li-bearing pegmatites in the Karibib area. We propose new spectral algorithm combinations of 3-2-9 and 2-1-9 for FCC, principal component combinations of 1-2-3 and 3-2-4 and BR spectral indices of B4/B1 and B4/B6, which indicate high concentration of Li-bearing pegmatites over the study area. The results were juxtaposed with 48 ground truthing Li-bearing points collected from drill core and field observations, validating the remote sensing techniques. Macro-scale and microscopic analyses of samples through drill core logging and optical microscopy were applied to classify and validate the presence of Li-bearing minerals in the samples. Geochemical analysis revealed four lithium-mineralized zones composed of coarse radial shaped grains of micaceous lepidolite, albite-quartz-lepidolite, massive fine-grained purple-grey lepidolite and massive white petalite, respectively. Our approach reveals how medium-resolution remote sensing imagery combined with field observations and geochemical data can provide new insights and efficiently map exploration targets of lithium-rich pegmatite occurrences in complex terrains. This approach is transferable to other minerals relevant to mining spectroscopy.

Keywords: Karibib, ASTER, Lithium, Pegmatites, Remote Sensing, Namibia

High-Grade Rare Earth Carbonatites at Ondoto, Namibia

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Abstract

Occurrences of carbonatites in the southern periphery of the Kunene Igneous Complex (KIC) have been under intense exploration for their Ta-Nb-U-pyrochlore, Light Rare Earths Element (LREE) and Ni-Co-Cu-Mo-sulfide potential by our companies for more than 10 years. The following data result from detailed mapping, magnetic, heli-EM and radiometric surveys, more than six hundred (600) exploration boreholes, 2,036 ICP-MS analyses and QEMSCANS of the various mineralization types. LREE-carbonatites with generally 18 to 22% Total Rare Earth Oxides (TREO) were discovered in form of dykes in regional shear zones and dyke clusters in a 25 km long belt between Epembe and Swartbooisdrift. Only the Ondoto dyke cluster near Swartbooisdrift is of economic importance, where cogenetic LREE-carbonatites and ferrocarnatites intruded the older White Anorthosite of the KIC. The LREE-carbonatites of dark red to pinkish-red color and occur as flow bands within several meter thick (max. 30 m) ankeritic ferrocarnatites and breccias. At Ondoto, carbonatites occur as an irregular dyke swarm with dykes bending in all directions. However, LREE-mineralized dykes associated with the main, commonly NW-striking structures, can reach up to 1.5 km length and present simple exploration targets with constant strike and shallow dip (20-50° in northerly directions). In zones where structures are bending, jogs of massive LREE-carbonatites can reach several meters width and several tens of meters length. The pinkish red LREE-carbonatites represent a fine-crystalline (at 10-30 µm), irregular intergrowth of bastnaesite and calcite at a ratio of 1:2. From extensive and detailed field data it is assumed that these LREE-carbonatites derived from a monomineralic precursor of likely burbankite composition, which intruded as an immiscible melt contemporaneously with the prevailing ferrocarnatites. Accessory minerals in the red LREE-carbonatites are a constant amount of 1-2% hematite as 1-5 µm pigments occurring in both main minerals as well as locally significant amounts of interstitial barite, apatite, and monazite. The monazite-rich varieties seem to have formed in a pegmatitic or later hydrothermal stage of mineralization. In addition, in the upper part of some larger LREE-orebodies occur up to several decimeter wide monomineralic, coarse-crystalline to massive flow bands of bright orange to red carbocearnate. Ferrocarnatites enveloping the LREE-carbonatites commonly show disseminated mineralization with molybdenite (100-3000 ppm Mo) and bands or veins of massive sulfides with pyrite, chalcopyrite, millerite, and Co-Ni-Cu thiospinels like fletcherite, linnaeite and polydymite, which are regarded as a potential by-product of the planned mining operations.

Five areas with large-scale jog structures have been identified, of which two structures underwent intense exploration by drilling by now. Based on pilot-scale hydrometallurgical test work conducted at Anzaplan in Germany and company-internal resources regarded as "measured," a production of about 2,000 t/a of Mixed Rare Earth Oxide (with >98% TREO) is anticipated from 2025 onward.

Keywords: Ondoto Mine, Rare Earth Elements (REE), Namibia

Rare-Earth Element (REE) Composition of Mineral Phases Within the Epembe Carbonatite Dyke, North-West Namibia

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Abstract

Rare-earth elements (REEs) are of economic importance due to their application - among others - in the manufacture of electric vehicles, permanent magnets and solar panels. China has been the largest supplier of REEs in the last decade; however, due to its stockpiling policy, there has been an increase in REE exploration in other parts of the world, including Namibia. Carbonatites are the major producers of REEs worldwide, although the enrichment mechanisms (magmatic or hydrothermal) and the REE host minerals are poorly understood. This study used GIS technology (QGIS and ArcMap) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) analysis to identify the mineral phases containing the highest concentration of REEs within the Epembe Carbonatite (north-western Namibia). The regional geology setting of the area comprises gneisses and metasedimentary rocks of the Epupa Metamorphic Complex (EMC) as well as the Kunene Anorthosite Complex (KAC). The carbonatite (calcite-carbonatite) dyke intrudes the EMC and extends for about 7 km with a width of about 250 m. The dyke is fine- to very coarse-grained and the dominant minerals include apatite, biotite, feldspar, calcite and pyrochlore in varying amounts. Analytical results show that fluorapatite, pyrochlore and monazite contain the highest concentrations of light rare-earth elements (LREE) and low heavy rare-earth elements (HREE), followed by calcite, pyroxene, biotite and feldspar. However, zircon displays a unique graph with a high concentration in HREE compared to LREE. Comparison of Y/Ho ratios of the minerals supports amagmatic origin of the mineralization influenced by factors such as ionic radii and melt composition.

Keywords: Epembe Carbonatite, Rare-Earth elements, Apatite, Monazite, Namibia

Distribution of Rare Earth Elements in the Epembe Carbonatite Dyke, Kunene Region, Namibia (Poster)

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Abstract

The Epembe carbonatite dyke of the Epembe Carbonatite-Syenite Complex, Kunene Region, northwestern Namibia, was emplaced along a northwest-trending fault zone into syenites and nepheline syenites and extends for approximately 6.5 km in a northwest to southeast direction with a maximum outcrop width of 400 m. The Epembe carbonatite has a Mesoproterozoic age of 1184 ± 10 Ma which is only slightly younger than the host nepheline syenites (1216 ± 2.4 Ma).

Following geological mapping and sample collection, the latter were analysed [using optical microscopy, X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS)] to determine the geochemical composition of the Epembe carbonatite dyke. This study presents new geochemical data for the Epembe carbonatite showing the distribution of rare earth elements within this dyke.

The carbonatite displays heterogeneous characteristics both texturally and mineralogically, highlighting at least three successive magmatic pulses. Irrespective of the differences, all carbonatite phases are inferred to be sourced from the same magma as they have a similar geochemical signature of both major and trace element composition. They are characterised by high concentrations of calcium (CaO: 38.01 - 55.31 wt.%), phosphorus (P) (up to 18076 ppm), titanium (Ti) (up to 5122 ppm), strontium (Sr) (up to 12315 ppm) and niobium (Nb) (up to 2022 ppm), alongside low concentrations of iron (FeO: 0.87 - 9.29 wt.%), magnesium (MgO: 0.19 – 1.33 wt.%) silica (SiO₂: 1.30 – 10.89 wt.%) and total alkalis (K₂O + Na₂O < 2.0 wt.%), and therefore are regarded as belonging to the same carbonatite dyke.

Petrography and whole-rock element compositions of major elements have demonstrated the Epembe carbonatite is primarily made up of course-grained calcite (~92%) with a CaO/(CaO+MgO+Fe₂O₃+MnO) ratio of 0.93 relative abundances (in wt. %), and thus is classified as calcio-carbonatite. The total REE content of the Epembe carbonatite is high (406 – 912 ppm), with a high LaN/YbN value (10.19 - 28.49), which is atypical of calcio-carbonatites. Chondrite normalized REE patterns for the carbonatite exhibit a strong steady decrease (negative slope) from LREEs to HREEs with a slight negative Eu anomaly, but those are relatively low (average: 2,323.71) compared to global average calcio-carbonatites (average 12,342.86). Even though the Epembe carbonatite is enriched in rare earth elements, there are no REE-bearing minerals observed except for monazite in trace amounts. Geochemical results show that the REE are either included in several accessory minerals such as apatite and pyrochlore or possibly in gangue minerals (i. e. silicates [including calcite and zircons] and carbonates) through enrichment processes related to fractional crystallisation and chemical substitution.

Keywords: Rare Earth Elements, Epembe Carbonatite, Geochemistry, Mineralogy

Battery metals from Africa – Now and for the future

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Abstract

To achieve reductions in fossil fuel use, nations are clamouring to replace carbon-based transport by alternative technologies. Although research is underway to improve electric vehicle batteries, the current technology is likely to play a crucial role in the next few decades. Such technologies require more metals than cars using fossil fuels and consequently require more mining. Currently lithium-ion batteries are in huge demand in cars, computers, cellphones, solar panels, and many other applications. These batteries include a range of metals such as lithium-iron-phosphate, lithium cobalt oxide, lithium manganese oxide, lithium manganese cobalt oxide, and lithium nickel cobalt aluminium oxide. The various batteries have different advantages and disadvantages based on energy output, cost, thermal stability, lifespan, density, safety in use, and cost of components. Africa can make a significant contribution to the increased demands for metals needed in lithium-ion batteries. DRC produces 70% of the world's cobalt; South Africa, Cote d'Ivoire, and Gabon collectively produce 41% of the world's manganese; and nickel is produced in several countries, including as a by-product of platinum group element (PGE) extraction in Zimbabwe and South Africa. Several countries have the potential to produce pegmatite-hosted lithium ore especially Zimbabwe, Namibia, DRC and Ghana. Graphite is commonly in the anode of lithium-ion batteries due to its energy density and relatively low-cost. Madagascar and Mozambique provide 5% of world graphite. In addition, electric vehicles typically require 3 to 5 times more copper wiring than internal combustion engines and Africa produces 13% of the global production of copper with the DRC and Zambia being the major producers in Africa. Energy storage is vital as power is required when it is dark or when wind doesn't blow. Vanadium batteries are typically used for grid energy storage, and while South Africa only produces 9% of world vanadium, it is the third biggest producer behind China and Russia. PGE have been used for autocatalysts to reduce noxious gas exhaust from vehicles. With decreasing use of fossil fuel, a demise in PGE demand might be envisaged. However, platinum is at the forefront of proton exchange membrane technology used in hydrogen fuel cell electric vehicles, a market that will grow significantly especially in the heavy-duty sector. Together South Africa and Zimbabwe produce >80% of the world's PGE metals. Unfortunately, African nations are not benefitting from the bonanza they are producing. Most commodities are exported as raw materials without the benefits accrued from beneficiation in terms of income or job creation. To promote development, African resources need to be processed closer to home so that refined materials and products can be sold globally at higher prices, thus creating jobs, and boosting growth. Easy to say but not easy to do, due to a lack of infrastructure, electricity supply and skilled local knowledge. In 2022 the US launched the Mineral Security Partnership with 11 other developed nations to ensure mining maintains high standards of ESG, with investment along the whole supply chain so that African countries derive a greater benefit.

Keywords: Critical materials, Africa supply

Preliminary results of mineralogical investigations on differently coloured petalites from the Uis Mining District, Namibia

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Abstract

The increasing demand for lithium requires exploration and development of many mineral resources as possible leading to search for alternatives to the primary lithium deposits currently being exploited. Thus, the lithium minerals lepidolite, petalite, montebrasite and lithium clay minerals are becoming potential sources with some already being processed to produce a saleable product. Mineral characterisation of these lithium-bearing minerals is crucial for technological advancement and the improvement of mineral processing and recovery. In this study, the lithium aluminosilicate mineral, petalite, was investigated due to different colourings of the same mineral within a single pegmatite. The region around Uis in Central Namibia, is host to several pegmatite belts, although the pegmatites are primarily known for the tin and tantalite-bearing minerals. The studied intrusion lies within the Uis–Cape Cross pegmatite belt, which extends southwest-northeast between the Brandberg mountain and Cape Cross. The belt comprises several pegmatite swarms and includes the Uis, Karlowa, and Strathmore pegmatite swarms. These commonly zoned pegmatites were intruded into Damara-age metasediments and have lensoidal and sigmoidal morphologies. In the Uis pegmatite, both markedly orange and greenish varieties of petalite occur, in addition to the more abundant white to greyish varieties. To understand the causes of these colour differences, each variety of coloured petalite was analysed by microscopy, electron microprobe, X-ray diffraction, and ICP-MS. The gangue minerals of the petalite-bearing pegmatites comprise feldspar, quartz, and muscovite, with other commodity minerals such as cassiterite, columbite-tantalite group minerals, pollucite, and several different phosphate minerals also being identified. Characteristically elevated element concentrations found in the petalite, by electron microprobe and geochemical trace element analysis using ICP-MS, are manganese and zinc. In the green petalite variety, zinc levels up to 240 ppm and manganese (with trace amounts of iron) concentrations are also elevated compared to the white and orange variants. The orange colour varieties would normally be easily explained by an iron to manganese ratio, however, there is no correlation between these two elements in the analytical results from this study. In contrast, there is a strong correlation between tin and zinc in the petalite samples analysed. In the transparent white petalite, the trace elements are only present in trace concentrations. In comparison, spodumene features coloured gemstone varieties in yellow (triphane), green (hiddenite), and pink (kunzite). The different colour variants result from variable concentrations of chromium and manganese. The orange colour in petalite may be derived from manganese, as in spodumene. To study any potential crystallographic-structural causation for the different petalite colours, X-ray diffraction refinements using the Rietveld method will be utilised in future investigations. Based on the preliminary data, the varying but elevated concentrations of iron, manganese, and zinc may be the most likely candidates causing the different colour variations of the petalites from the Uis pegmatites in Namibia.

Keywords: Lithium, Pegmatites, Petalite, ICP-MS, Uis

Secondary raw materials in Namibia – A future source for critical raw materials

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Abstract

Being one of the leading mining countries in southern Africa, Namibia hosts several well-known ore deposits. Many of the mining operations, some of which saw several decades of activity, are now closed and/or derelict. There are more than 200 abandoned mine sites in Namibia, which pose a high risk to the surrounding environment. However, many still have potential as resources for raw materials. Pegmatites in the Uis area, Erongo Region, were historically mined for tin while lithium prices were low, and minor Li-minerals were not recovered. With Li and REE prices soaring, the Uis tailings represent a valuable resource for these commodities. The fine-grained, silt-sized material, left behind in dried-out waste impoundment cells, is rich in clay minerals (illite with minor clinocllore, cookeite and kaolinite) and has a fitting, non-hazardous mineralogical and geochemical composition, allowing for solid brick production of adequate quality for the local market and traditional building style. The historic Uis Mine and its tailings represent a prime example of an efficiently practiced reprocessing of historic mining wastes, which results in a significant reduction of mining residues. Further processing to extract Li also signifies a possible future economic revenue stream. Likewise, the Okorusu tailings dump, Otjozondjupa Region, resulting from former fluorite mining, bears a high potential for relict fluorite and accessory apatite. Reprocessing of Okorusu tailings for fluorite will strengthen the local economy, while potential future production of apatite might push Namibia forward on its way to more independence from fertilizer imports from abroad. Apart from these economic aspects, the Okorusu tailings, in combination with hard rock data, contribute to our scientific understanding of the formation of potential REE deposits by revealing a clear trend of decreasing REE abundance from magmatic minerals (apatite, calcite, dolomite, ankerite) to hydrothermal minerals (calcite, dolomite, ankerite, strontianite, fluorite) with some REEs in REE fluorocarbonate (bastnäsite, parisite, röntgenite, synchysite) and in monazite. There is a need to actively reconsider tailings dams of abandoned mine sites as potential raw material sources since many accessory commodities in the mineral waste with no economic value in the past might be utilised nowadays based on significantly increased demand and prices.

Keywords: Secondary raw materials, Uis tailings, Brick production, Okorusu tailings, Fluorite-apatite resources

Integrated Multidisciplinary Geoscience Mapping of Polymetallic Sn-W-Be-REE-F Mineralization in the Namaqua-Natal Metamorphic Province, Northern Cape (South Africa)

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Abstract

The Mesoproterozoic Namaqua-Natal Metamorphic Province along the western and southern margin of the Archaean Kaapvaal Craton in southern Africa is the host of a variety of syn- to late tectonic granitoid-related deposits, including Sn-W, base-metals, Li-Be, REE and fluorite veins in pegmatites, which play a critical role in the green energy revolution. A multidisciplinary approach was implemented with the integration of soil geochemistry, high resolution aeromagnetic and airborne radiometric datasets to delineate areas prospective of Sn-W-Be-REE-F mineralization in the Namaqua-Natal Metamorphic Province. The soil geochemistry dataset was processed using multivariate statistical techniques focused on pathfinder element associations, which led to the recognition of an incompatible trace element Zr-Y-Nb-Sc-Th-W proxy for Sn-W-Be-REE-F mineral exploration. Higher radiometric counts of K₂O, U and Th correlate well with the soil geochemistry association. A lineament analysis of the fractures identified from high resolution aeromagnetic data, confirms the predominantly NW-SE directed principal stresses and trending fractures that are possibly related to the emplacement of Sn-W-Be-REE-F mineralization. Fuzzification performed on the regional soil geochemical data, radiometric data and fracture data sets shows a spatial correlation between Sn-W-Be-F-REE mineral systems and NW-SE fractures within the study area, suggesting that these structures also control the concentration and distribution of the mineralization. The results of this approach accurately reflected several known occurrences in the study area, while new potential targets were outlined.

Keywords: Namaqua-Natal Metamorphic Province, Polymetallic, Integration, South Africa

Carbonatites in the Southern Periphery of the Kunene Igneous Complex, Namibia: Exploration Results and Economic Potential

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Abstract

The Kunene Igneous Complex (KIC) is a large anorthosite body that intruded the Epupa Metamorphic Complex, in north-western Namibia. Post-dating and bordering the KIC are several small satellite intrusions of mafic to ultramafic rocks, syenite and carbonatites. The shear zones in the southern periphery of the KIC are often intruded by syenite, quartz syenite, calcio- and ferro-carbonatite dykes. The alkaline intrusions caused intense fenitisation and metasomatic alteration of the older magmatic and metamorphic rocks. The alteration is traced for kilometers using geological mapping, hyperspectral imaging, and magnetic surveys. The Epembe carbonatite dyke is an amalgamated body, composed of syenite and several phases of calcio-carbonatite. The Epembe calcio-carbonatite dyke has an overall extend of more than 15 km long and measures up to 450 m width in its central part. Some flow bands of coarse crystalline calcio-carbonatite carry accessory minerals of economic interest, namely: Ta-Nb-U- and Nb-Ta-pyrochlore, Ta-ilmenite, zircon, and apatite. A first stage exploration campaign concentrated drilling on a 600 m section of Sector B of the Epembe carbonatite dyke. Bloy Resource Evaluation estimated a (non JORC-compliant) resource of 2.6 million tonnes ('Mt') at 150 ppm Ta₂O₅; 1294 ppm Nb₂O₅; 138 ppm U₃O₈ and 2.4% P₂O₅. Sector B, however, only represents 5% of the strike length of the central Epembe dyke. Roughly 22 km east of the Epembe dyke, occurs the Otjitambi carbonatite dyke swarm. Individual dykes from this area contain Heavy Rare Earth Element (HREE) content of 1000-2000 ppm. The Ehomba carbonatites, about 18 km east of Otjitambi, comprise of silico-carbonatite breccias, rodbergite and sövite dykes. Locally, REE-mineralization is observed in the form of bastnaesite and monazite. Similar to Otjitambi, individual samples contain HREE contents up to 1400 ppm. About 10 km north of the Ehomba carbonatites there is an occurrence of ferro- and silico-carbonatites at the Ondoto LREE mine. This area is currently undergoing development (abstract by Ellmies et al., this conference). The Epembe, Otjitambi, Ehomba and Ondoto rare metals and REE enriched carbonatites occur in an emerging mineral province covering an area of over 55000 ha. To date, no carbonatites have been observed west or north-west of the KIC.

Keywords: Kunene Igneous Complex (KIC), Rare Earth Elements (REE), Epembe, Ondoto, Namibia

Geological Investigation of the Chimbiya Niobium-Tantalum (Nb-Ta) Anomaly (Kasungu District, Central Malawi)

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Abstract

This paper describes the results of a geological investigation into a prominent Niobium-Tantalum (Nb-Ta) that was identified in Chimbiya village in Kasungu district, central Malawi. The anomaly was revealed by the results of the 2018/2019 geochemical stream-sediment sampling campaign which was conducted under the Geological Mapping and Mineral Assessment Project of Malawi (GEMMAP). Radiometric map of the area also showed anomalous Potassium (K) and Uranium (U) signatures like that of the famous Kanyika Nb-Ta deposit to the north of the area. The paper has been outlined as follows: introduction, outline of the regional and local geology, geochemistry (lithological, soil, and stream-sediments), discussions, conclusion, and recommendations. Annexes contain the U and K radiometric maps of the area. The main objective of the study was to identify the possible Nb-Ta orebody by tracing the source of the anomalous values. This was achieved by conducting a geological mapping and geochemical (stream sediment, soil, and rock) survey of the area. In geological mapping, some rock samples were analysed using the Spectro xepos X-Ray Fluorescence XEP05. The results were grouped into major oxides and were used for rock classification using the Total-alkali Silica (TAS) criteria of Cox *et al.* (1979) for intrusive rocks. Geochemistry survey involved collecting samples from sediments in active streams at some planned locations (confluences of first order streams) as these were deemed to be representative of the catchment area. A total of 10 samples were collected and these comprised 9 stream sediment samples and one soil sample. The latter was taken from the centre of a uranium anomaly. These were also analysed using the XRF. Geological mapping of the area revealed that the underlying lithology is predominantly supracrustal rocks of a metasedimentary nature. Intrusive rocks were restricted to meta-syenite in the northeast and meta-dolerite in the same vicinity. Analytical results from rock chip samples revealed that Nb and Ta have elevated concentrations in the meta-syenite lithology. The stream sediment sampling analysis results also indicated that the samples with the highest values for Nb and Ta were collected from streams that are spatially associated with the Kamwala hill meta-syenite body. In conclusion, the geological investigation ascertained that the source of the Nb-Ta anomaly was the meta-syenite body which was also found to be the source of the prominent U anomaly in the area. These observations raise the possibility that the mineralization on Kamwala hill could be like, and/or related to the Kanyika orebody to the north. It is therefore recommended that detailed geological mapping of Kamwala hill be undertaken. This should be done concurrently with a ground radiometric survey since the metasyenite has a distinctive K and U signature.

Keywords: Niobium (Nb), Tantalum (Ta); Meta--syenite, Geochemistry, Mapping

Reference:

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Rare Earth Elements potential in the Serra da Neve Calc-alkaline Complex, SW Angola – a first approach (Poster)

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Abstract

The Serra da Neve Calc-alkaline Complex (SNCAC) is a large set of volcanic, subvolcanic and plutonic alkaline rocks in the SW of Angola, emplaced during the middle to upper Cretaceous. The SNCAC intruded following both a WNW-ESE and NE-SW trend, conjugated to the trans-Angolan belt, that hosts several alkaline-carbonatite structures. The SNCAC is classified, based on previous work on petrography and field relations, into smaller sub-circular structures. Within the scope of the major project *Plano Nacional de Geologia de Angola (PLANAGEO)*, efforts were made to identify and search for mineral resources. The work was based on geological mapping followed by a first analytical approach using portable XRF and finally conducting lithochemical analysis of representative samples. The aim of this work is to provide an overview of the distribution of REE within the geological units of the study area. The results show different concentrations between structures and the associated geological units. There is an enrichment in Light Rare Earth Elements relative to Heavy Rare Earth Elements, while total REE content decrease with magmatic differentiation, on an average from circa 900 ppm to 200 ppm. The highest REE values are found in the Nejoio satellite structure, partly due to a very anomalous sample, even for a structure overall rich in REE, in line with other alkaline assemblages in the world. In this anomalous sample, total REE reach 3%, similar to REE concentrations found in carbonatites. Bastnäsite-(Ce) was identified by XRD in this sample. Although promising, further studies still need to be carried out in order to understand the geological processes that led to the REE enrichment. Nevertheless, the results obtained so far allowed the establishment of future lines of research and action in the field of mineral resource exploration.

Keywords: Serra da Neve Calc-alkaline Complex, Rare Earth Elements, Mineral exploration, Bastnäsite (Ce)

The Glenover Complex (South Africa): An example of extreme weathering and enrichment of critical metals including REE, Sc, P and Nb

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Abstract

The Glenover Complex is a large, circular pyroxenite and carbonatite intrusion of over 5 km diameter located in the northwestern part of South Africa. It preserves both primary igneous features related to the intrusion, cooling and crystallization of the complex, as well as a significant capping of overlying REE-, Sc-, P- and Nb-enriched regolith related to a past period of extreme humid weathering. Both these events have been studied by tracking the major changes in chemistry and texture, and included petrography, geochemistry, isotopic analysis and geochronology. A glimmerite sample has been dated by K/Ar of phlogopite to have an age of 1249 ± 27 Ma, showing that the Glenover Complex shares an age roughly that of the Pilanesberg Alkaline Complex. The suite of secondary minerals in the regolith include monazite, apatite and various iron oxides such as martite and goethite and is in agreement with those assemblages forming in carbonatite complexes located in modern day moist and humid climates. These findings further confirm the existence of a significant period of weathering in this part of southern Africa, which is here assumed to have occurred during the Palaeocene-Eocene thermal maximum (PETM). Significant amounts of sulphides such as pyrite, chalcopyrite and pyrrhotite are present in the fresh rock and are proposed as an important source of sulphuric acid which would be released during weathering. Further interesting findings include an example of a carbonatite vein which shows classic crack and seal textures, including a medial line and three progressive generations of carbonatite intrusion. Geochemical and isotopic data indicate that the carbonatite has been affected to some degree by later weathering and, even though appearing fresh, these rocks demonstrate both oxidation and more importantly, some degree of increase in the heavier oxygen isotopes, processes which are interpreted to be the result of interaction with meteoric water. It is clear from the detailed ICP-MS geochemical results completed on a meter-by-meter interval that the initial removal of Mg is recognized as marking the first onset of chemical weathering. The geological and chemical log of drill hole GHV03 shows this particularly well in the transition from dolomite carbonatite to overlying regolith. The application of this 'Relative Mg Content' as a proxy for recording weathering of carbonatite and pyroxenite is a valuable advance in our understanding of weathering. Further avenues of investigation are the roles of other potentially mobile elements such as Sr, Mn and Ba in this specific weathering environment. Recent, topographically deep, chemically driven weathering events where this regolith developed would include the moist and tropical events of the Cretaceous, Miocene and Pliocene, as potential contenders.

Keywords: Glenover Complex, REE, Carbonatite, Monazite, South Africa

Factors that contribute to REE grade changes in weathered carbonatites

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Abstract

Carbonatites are rare alkaline igneous rocks and are important sources of critical metals, the rare earth elements (REE) and high field strength elements (HFSE). Moreover, carbonatites typically have higher grades and more favourable mineralogy resulting in better metallurgical recoveries than other REE deposit types. Carbonatite deposits may be further enriched in their REE and HFSE concentrations as they are susceptible to weathering under a variety of palaeoclimate conditions, including wet, tropical conditions (e.g. Yangibana LREE deposit, Australia and Catalão I, Brazil) to semi-arid to temperate conditions (e.g. Bear Lodge, USA) to potentially multiple conditions (e.g. Gleibat Lafhouda, Morocco). The impacts of weathering on carbonatites are evaluated using bulk rock geochemical methods, mass balance diagrams, and chondrite normalised REE plots in addition to optical and SEM microscopy. The amount of weathering (e.g. intensity and/or number of events) plays an important role in critical metal remobilisation, which may help or hinder the ore tenor. At Bear Lodge, weakly to moderately weathered carbonatite REE concentrations are enhanced by 2 to 3 times. However, strongly weathered, saprolitic sections show significant variability in REE concentrations and HREE mobility compared to the least altered units. Saprolites at the Ngualla Carbonatite Complex (Tanzania) show an increase in many REE up to 3 times compared to fresh magnesio-carbonatite, but chondrite normalised REE patterns display significant variation in the HREE, similar to Bear Lodge. The original mineralogy in these deposits plays an important role in determining if weathering will positively affect the ore tenor. Minerals such as apatite [Ca₅(PO₄)₃(F,Cl,OH)], monazite [REE(PO₄)], and pyrochlore [(Na,Ca)₂Nb₂O₆] are relatively insoluble under meteoric conditions, making them resistant to remobilisation compared to carbonate minerals (e.g. dolomite, siderite, and burbankite [(Na,Ca)₃(Sr,Ba,REE)₃(CO₃)₅]), which will dissolve and may also oxidise. Carbonate dissolution and oxidation reduces mass and increases porosity, facilitating further weathering and increasing the concentration of the immobile REE and HFSE-bearing minerals. The Proterozoic Gleibat Lafhouda carbonatite is a magnesiocarbonatite with subordinate ferrocyanatite that contains up to 1000s of ppm of LREE in fluorapatite with subordinate monazite and up to 1 wt% Nb in pyrochlore. Uplift and erosion of the Reguibat Shield area hosting Gleibat Lafhouda likely subjected it to repeated episodes of wet to semi-arid to arid weathering conditions during the Miocene to Holocene. It has undergone weathering to a powdery gossan material containing approximately 17 to 55 times the amount of REE compared to the fresh carbonatite and massive ferruginous material with up to 3 times the concentration of REE compared to the fresh carbonatite. Given the prevalence of REE-phosphates and pyrochlore at Gleibat Lafhouda, initial observations suggest that eluvial processes may have played an important role in improving critical metal grades. Chondrite normalised REE diagrams of the powdery gossan, ferruginous units, fresh carbonatite shows very similar curvatures and negative Y anomalies, initially suggesting little fractionation and a lack of significant REE mobility. However, detailed mineralogical studies of these units will be required to determine if REE mobility is absent or localised to the mineralogical scale.

Keywords: Carbonatite, Weathering, REE

Rare earth element mineralization in Namibian carbonatites

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Abstract

Rare earth elements (REE) are a group of chemically coherent elements that are used in the manufacture of modern technologies including permanent magnets, lasers, computers and smart phones. Some of these technologies are essential in the transition from fossil fuels to green energy. Furthermore, there are geopolitical controls associated with the supply of REE leading to these elements being included in the latest lists of critical metals by the European Commission and the United States Geological Survey. These factors led to an increase in REE exploration globally, especially in countries with stable mining jurisdictions such as Namibia. Carbonatites are the major source of REE worldwide. This study provides a review of the geology, mineralogy, style of mineralization and to some extent the geochemistry of carbonatite related REE deposits in Namibia based on reports available in the public domain. The REE mineralized carbonatites include carbonatites from Teufelskuppe, Keishöhe, Okorusu, Lofdal, Ondoto and Eureka. The host carbonatites can be dolomitic, calcitic or ferroan in composition and may or may not be associated with silicate rocks. REE mineralization in these carbonatites occur as fluorocarbonates and phosphate minerals primarily associated with magmatic processes or hydrothermal fluids, with often secondary mineralization formed as a result of hydrothermal overprint or weathering. With the exception of Lofdal, the REE budget of these carbonatites is dominated by light REE. Although REE enrichment in the carbonatites is related to late or post-magmatic processes, it appears that the sources of the REE are the carbonatite alkaline intrusives. In post-magmatic processes fluids break down primary mineral assemblages such as apatite, monazite and calcite, transport the REE as REE-complexes and redeposit them spatially associated to the carbonatites due to changes in fluid composition, pH and pressure. Findings from this work suggests that future exploration of carbonatite related REE deposits should target those carbonatites that have experienced hydrothermal alteration or weathering.

Keywords: Carbonatite, Rare earth elements, Hydrothermal, Weathering, Namibia

Critical enrichment in carbonatite-derived laterite deposits

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Abstract

Although carbonatites are an uncommon rock type, they are important resources of rare earth elements (REEs), niobium (Nb), and phosphate (PO₄) and historical sources of vanadium (V), tantalum (Ta), copper (Cu), titanium (Ti), iron (Fe), and fluorite (CaF₂). Currently, carbonatite lateritic regolith hosted deposits are the primary source of the world's Nb and a major source of REEs. Carbonatites are defined by the International Union of Geological Sciences (IUGS) as igneous rocks composed of greater than 50 volume percent primary carbonate minerals, dominantly calcite and/or dolomite, and containing less than 20 wt.% SiO₂. Enrichment of critical elements in these regoliths occurs through two main processes: 1) mass loss due to the chemical weathering of mineral phases and the subsequent transport/removal of constituents dissolved in groundwater and 2) supergene enrichment resulting from elemental partitioning to the aqueous phase via mineral breakdown and desorption, subsequent groundwater transport, and finally sequestration by secondary mineral precipitation, sorption, or biogeochemical processes. Carbonatite mineralogy and chemistry play an important role in the fate and transport of critical elements during laterization. Rock-forming minerals in carbonatites, such as calcite, dolomite, apatite, biotite, phlogopite, and sulfides, are quite susceptible to chemical weathering. Processes controlling mineral weathering include dissolution, hydrolysis, and oxidation. Sulfide oxidation likely enhances weathering through the formation of sulfuric acid and subsequent acidification of groundwater. In carbonatites, Nb is primarily hosted by pyrochlore (Na,Ca)₂Nb₂O₆(OH,F), a mineral that is less susceptible to chemical weathering, thus Nb enrichment in most carbonatite-derived lateritic profiles is primarily due to residual concentration of pyrochlore and overall loss of rock mass during weathering. In carbonatites, REEs may be hosted in a variety of minerals including apatite, fluor-carbonates, monazite, calcite, and dolomite. Chemical weathering of these minerals releases REEs as well as Ca, Sr, Mg, PO₄, and F to groundwater. Primary igneous monazite may be stable under chemical weathering conditions in carbonatites. Secondary phosphate minerals tend to be an important host for REEs in carbonatite-derived lateritic regoliths and are a result of the chemical weathering of apatite which provides PO₄ for the secondary REE phosphate minerals. Carbonatite-derived lateritic deposits tend to be light REE enriched, similar to the parent carbonatite, but moderate enrichment in heavy REEs is observed within portions of some lateritic profiles, suggesting that LREE and HREE fractionation is likely caused by variations in groundwater chemistry. Geochemical modeling can provide insight into processes controlling REE mobility, fractionation, and deposition and is being utilized to constrain processes responsible for the fate and transport of REEs in this environment. Results from work on the Mount Weld deposit, the largest REE producer outside of China, will be discussed and compared to carbonatite-derived laterite deposits in Africa.

Keywords: Rare earth elements, Niobium, Laterite, Carbonatite

Nickel mineralization of the Molopo Farm Complex, Botswana

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Abstract

Preservation of platinum group elements (PGE) during remobilization and dissolution of magmatic sulfides when serpentinized mostly depends on PT conditions during the hydrothermal process and stability of newly formed mineral carriers of PGEs. The magmatic sulfide assemblages of the mafic-ultramafic layered intrusions worldwide contain PGE as their own discrete minerals and solid solutions in major base metal sulfides whereas the PGE mineral balance in the hydrothermal Ni deposits is distinct from that of its magmatic precursor. Hydrothermal Ni in serpentinized rocks is a relatively new type of mineralization for the Bushveld magmatic province and quantitative assessment of the ore components is important for potential ore beneficiation. Herein we report scanning electron microscope, electron probe microanalysis and laser ablation inductively coupled mass spectrometry (LA-ICPMS) spot and mapping results for relic pentlandite (Fe,Ni)₉S₈ and newly formed awaruite Ni₃Fe, heazlewoodite Ni₃S₂, mackinawite (Fe,Ni)S_{0.9}, maucherite Ni₁₁As₈ and orcelite Ni_{5-x}As₂ in serpentinized peridotites and pyroxenites of the Molopo Farm Complex in the area of Jwaneng-Makopong-Werda Kgare shear zones. Serpentinized peridotites and pyroxenite in this area underwent an additional superimposed metasomatic event, which resulted in the wide development of secondary amphiboles, recrystallization of chromite, olivine and pyroxenes, and formation of the Ni sulfide-alloy-arsenide assemblage indicative of reduced and low-S fugacity conditions. The dissolution of primary base metal sulfides during serpentinization liberated PGE that were selectively included into secondary Ni minerals with the highest PGE concentrations observed in Ni arsenides, particularly in maucherite and orcelite, in accordance with the favorable isomorphic substitution scheme. Maucherite carries as much as ~2300 g/t Pd, 44 g/t Pt and 6 g/t Au whereas orcelite is poorer in PGE, which is probably related to different degrees of the primary PGE enrichment of the lithologies, which host these two arsenides in the separate zones of mineralization. Relic Co-rich pentlandite is enriched in Ir-subgroup PGE and Rh with <13.4 g/t Ru, 7.7 g/t Rh, 1.9 g/t Os, 1.2 g/t Ir and 3.5 g/t Pd while no Pt and Au were detected. Heazlewoodite, which replaces pentlandite, is regularly poorer in PGE whereas awaruite, in contrast, showed elevated concentrations of up to (g/t) 44 Ru, 2.6 Rh, 13.8 Pd, 2.5 Os and 7.8 Au. LA-ICPMS maps demonstrate irregularly heterogeneous diffusion-type distribution of PGE and other trace metals in Ni arsenides that may reflect presence of residual relics of the primary sulfides with PGM inclusions indicating that equilibrium was not achieved during hydrothermal crystallization. No discrete platinum-group minerals were found except for nano-sized inclusions of laurite and Pd tellurides, therefore, PGE in the Molopo Farm mineralized zones are predominantly present as solid solutions in relic sulfides and secondary arsenides and alloys. Our whole-rock PGE fire-assay data suggest that PGE, Cu and Ni mobility was spatially limited to the zones of the primary magmatic PGE enrichment. We suggest that a contribution of As from host Transvaal carbonaceous shales was important for stabilizing PGE in arsenides and antimonides that prevented their losses during fluid multistage circulation.

Keywords: Serpentinization, Molopo Farm Complex, Awaruite, Hydrothermal nickel, Platinum group elements

**ST04: GEOPHYSICS, GEOCHEMISTRY AND REMOTE SENSING–
PEERING INTO THE SUBSURFACE AND INTEGRATED APPROACHES
IN GEOSCIENCES****ST04_S01: Innovation and integrated approaches in geophysics****Monitoring Subsurface Distribution of Crude-oil Spill in Costal Sandy
Soil using Time-lapse Electrical Resistivity****Margaret A. Adeniran^{a,b*}, Michael A. Oladunjoye^b, Kennedy O. Doro^c**^a*Pan-African University Life and Earth Sciences Institute, Ibadan, Nigeria*^b*Department of Geology, University of Ibadan, Ibadan, Nigeria*^c*Department of Environmental Sciences, University of Toledo, OH, United States***Corresponding author: adeniranmargaret93@gmail.com***Abstract**

Characterizing Dense Non-aqueous Phase Liquids (DNALPS) distribution in the vadose zone continues to be challenging due to their physiochemical properties and the heterogeneous nature of soils. Research on crude oil pollution in Nigeria has historically centred on a point sampling approach to quantifying crude oil contamination, with minimal attention paid to understanding of spatial and temp variation in crude oil plume development and migration. To assess the temp and spatial variance associated with crude oil migration in the shallow subsurface, time-lapse electrical resistivity monitoring of a crude oil spillage simulation under different subsurface conditions was carried out. A 3D experimental sandbox with dimensions of 200cm/60cm/40cm was constructed using 10 mm plexiglass. The sandbox was filled to a height of 40 mm with 2 mm sand devoid of organic matter, and a 20 cm headspace was kept to maintain an aerobic environment. Simulated subsurface conditions included moist, unsaturated, and fully saturated. At the initial stage of each experiment, 40 kg of sand was mixed with 1 liter of water to create moist sand, after which the mixture was flushed over 12 hours to remove suspended fine particles. In simulating crude oil spillage, two litres of crude oil were poured over the surface and monitored for 36 hours. A surface array of 98 electrodes with a two-centimetre electrode spacing was installed along two profiles with a 12 cm inter-profile separation. Before, during, and 36 hours after the injection of crude oil, continuous time-lapse measurements were acquired using a dipole-dipole array. The obtained resistivity measurements were inverted using the RESIPY software. A progressive increase in resistivity values was observed in the crude oil-impacted region. Gravity-induced vertical migration was seen to dominate at the early stage of the experiment under saturated and unsaturated conditions, but distinct lateral migration was evident over time. An increase in solute dispersivity was observed for unsaturated soil compared to saturated soil, thus establishing a positive relationship between dispersion and water saturation. The occurrence of pockets of high resistivity structures linked with localized permeable zones demonstrates the sensitivity of electrical resistivity measurement to subtle but measurable anisotropy in soil pores' distribution. Electrical resistivity measurements provided detailed spatio-temp behaviour of crude oil spillage in near-surface investigation. The time-lapse electrical resistivity technique has been shown to be successful in imaging the non-ideal behaviour of crude oil pollutants in conjunction with spatial changes in the pore-size distribution in the near-surface environment.

Keywords: Crude oil, Spillage, Electrical resistivity, Time-lapse

Lithostructural Mapping of the Neoproterozoic Basement Complex Terrane in the Wawa Area (Western Nigeria), Using Aeromagnetic and Airborne Radiometric Data: Implications for Epizonal-Orogenic Gold Potential

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Abstract

The Neoproterozoic basement terrane of western Nigeria is distinct from the one in eastern Nigeria because the former has potential for hosting gold mineralization. Several areas within the basement terrane of western Nigeria have been reported to host gold deposits, which likely formed during orogenies that occurred in the African region around 500–700 Ma. This study focuses on the lithostructural mapping of the Wawa area in western Nigeria to gauge its potential for hosting epizonal-orogenic gold mineralization using geophysical datasets. Reduced-to-pole (RTP) and derivative filters guided the interpretation of structures while creation of a ternary map of %K, eTh, and eU assisted in lithological discriminations, which were validated through field observations. Structural interpretation disclosed the existence of two regional lineaments in the study area, both trending NNE–SSW, one roughly 112 km long and the other 31 km long. Also, in the western part of the study area a roughly 105 km-long regional shear zone is revealed. Major lineaments in the study area trend NE–SW, minor lineaments are mostly E–W and NW–SE oriented. Lithological interpretation disclosed the existence of amphibolite and amphibole schists in the study area as well as granite gneiss, older granites, migmatites and migmatitic gneiss, quartz veins and mica schist. Field observations indicated that gold mineralization in the study area is mainly associated with quartz veins within amphibolite/amphibole schist and granite gneisses, which exist in the vicinity of regional lineaments and their subsidiary faults. The quartz veins' trends are similar to those of the regional lineaments and subsidiary faults. Gold mineralization in the study area is closely associated with regional lineaments and lithologies that compare well with epizonal gold mineralization in other orogenic gold provinces worldwide. The study area therefore has potential for epizonal-orogenic gold deposits. The findings of this study warrant further probing by geochemical surveys. Thus, lithostructural mapping within the rest of the Neoproterozoic basement terrane in western Nigeria is critical to assessment of its potential for epizonal-orogenic gold mineralization.

Keywords: Epizonal-orogenic gold, Aeromagnetics, Aeroradiometrics, Lithostructural mapping, Western Nigeria

A review of geothermal energy potential in Zimbabwe

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Abstract

Geothermal energy is a renewable and clean source of electricity that can be harnessed from the heat of the Earth's crust. Zimbabwe has a favourable geological setting for geothermal exploration, as it is located in the Great Rift Valley of Africa, which hosts several active volcanoes and hot springs. The Zimbabwe craton is surrounded by mobile belts that host various favourable geothermal settings – different fault orientations, ring complexes and dykes. Rupise, Hot Springs, Wengezi, Lubimbi and Chibwatata (Binga) are some of the potential geothermal fields in Zimbabwe. However, the country has not yet exploited its geothermal resources, which are estimated to be of low to medium enthalpy type, with in-situ temperatures ranging from 40°C to 97°C. In this paper, the current status and challenges of geothermal energy development in Zimbabwe are discussed, and recommendations for future research and policy actions made. It also identifies the main geothermal areas in Zimbabwe including the Limpopo Belt, the Eastern Highlands, and the Zambezi Valley, and discusses their geological characteristics, surface manifestations, and exploration activities. The technical, economic, environmental, and social factors that affect the feasibility and sustainability of geothermal energy production in Zimbabwe are also analysed. The paper concludes that geothermal energy has a great potential to contribute to the diversification and decarbonisation of Zimbabwe's energy mix, but it requires more investment, research, and capacity building to overcome the existing barriers.

Keywords: Geothermal energy, Low enthalpy, Renewable electricity, Zimbabwe

Mapping Under Cover: State of the Art Geophysical and Interpretation Methodology

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Abstract

Much of southern Africa is covered by sediments and volcanics of the Late Palaeozoic/ Mesozoic Karoo Supergroup, and by younger sediments of the Cenozoic Kalahari Group. Geophysical techniques have historically been essential and successful in mapping beneath this cover, through the acquisition of mostly magnetic, gravity and electromagnetic data. Geophysical methodology, however, continues to advance enormously in terms of instrument sensitivity, survey types and resolution, depth of penetration, processing and computational ability, and interpretation of the data using both inversion techniques and interactive modelling. The following aspects are discussed in this presentation, as being essential key components to mapping under cover, *inter alia*:

- Latest instrumentation types, platforms and advances
- Data resolution and quality; also the inherent ambiguity of geophysical data
- Processed end products used in interpretation, including advanced filtering and gridding
- Interpretation, both quantitative (inversion) and qualitative (interactively using multiple geodatasets, and an interpreter's eye and experience)
- Looking at the bigger picture: value and use of regional datasets in target area interpretation
- Inter-disciplinary training (geologists and geophysicists), essential to accurate and successful interpretation. Teamwork is stressed.

Keywords: Geophysical data, Resolution, Interpretation, Inversion

Mapping Under Cover: Damaran Central Zone Continuation under the Namib Sand Sea

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Abstract

The Namibian National Aeromagnetic Dataset has been used to interpret the continuation of the Damaran Central Zone south of the Kuiseb River. In particular, the continuity of older basement and the Damaran Nosib and Swakop Group sequences have been mapped south and south-east of Walvis Bay and Sandwich Harbour. The Khan Formation of the Nosib Group is evident from its unique Late Damaran remanent magnetic signature. This, together with magnetic units evident within the overlying lower Swakop Group, inferred to be Arandis Formation, has facilitated mapping of the extent of these sequences, and their deformation, under the sand-sea cover. A domal feature, here termed the Sandwich Bay Dome, is identified, having a disposition, signature and size similar to that of the Rossing Dome. Interpreted Khan Formation collaring the dome was proven by early exploration drilling, which also intersected leuco- and red granites. The area has been subjected to late Damaran deformation (NNE-trending; D₄), as manifested in part by the regional-scale Welwitschia Lineament. Time Domain Electromagnetic soundings were conducted in the dune straights in order to determine the sand cover thickness. It should be noted that the Namib Sand Sea, south of the Kuiseb River, now constitutes a UNESCO World Heritage Site in which no further mineral exploration is permitted.

Keywords: Aeromagnetic data set, Damara Central Zone, Khan Formation, Swakop Group, Nosib Group, Namibia

Namibian infrasound station I35NA

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Abstract

Namibia has an infrasound station (I35NA) that forms part of an International Monitoring System (IMS) and contributes to the Comprehensive Test-Ban-Treaty (CTBT) which aims to ban nuclear explosion testing worldwide. The Namibian government invests generously in data collection and as a member state benefits from these data, which can be used in various innovative ways. For instance, infrasound data can be applied to detect other acoustic observables besides nuclear weapons testing. This raises the question whether the activities of Namibia's large mining industry (e. g. blasting) will be reflected in the data, and what other relevant information may be gleaned. An analysis was carried out using dtkGPMCC-Software which is included in the NDC-in-a-Box-Packet provided by the Comprehensive Treaty Test Ban Organization (CTBTO). Detected signals are compared both with ground truth information and with observations collected by other Infrasound stations.

Keywords: Infrasound, Acoustic, Nuclear-weapons testing, Mine blast



Soil and rock melted by lightning in stormy weather at Guéhiébly (Western Côte d'Ivoire, West Africa)

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Abstract

Following alarming reports of a volcanic eruption in Guéhiébly (500 km west of Abidjan) on the night of Wednesday May 17, 2023, the Geophysical National Station sent a team to the site. On May 25 and 26, 2023 and from June 09 to 11, 2023, joint Geophysical National Station and Félix Houphouët-Boigny University of Abidjan-Cocody missions visited Guéhiébly. According to the Head of the local Geological Survey, the day after a very stormy night, agents of the National Electricity Company discovered a fallen electricity pole, and the effusion of dark matter through the hole in the ground left by the collapsed pole. No seismic activity has been recorded by the National Geophysical Station. A few granite outcrops are visible on the site. These granites represent the continuity of the region's prominent hills. They belong to the Archaean domain of Côte d'Ivoire. This cratonic domain has been stable since at least 1.6 to 1.8 Ga and has been the subject of several PhD thesis works. The effused material is light, vitreous, translucent, dark-brown in color and structured in thin lamellae (barely 1 mm) defining an infinite number of cavities. The inside of the effused masses is hollow, and the shell has an average thickness of 5 to 7 cm. The striations on the masses correspond to the movements of the fluid prior to its solidification. The various analyses carried out show that the effused material is derived from the fusion of the site's telluric entities (soil, concrete, and rock). K, Th and U contents are within a very narrow range of similar variation in soil, concrete, and rock. K, which is relatively mobile compared to Th and U, is slightly leached away from the hill. Magnetic susceptibility is very low to zero in soil, concrete, and effused mass. The latter would essentially come from the melting of soil and concrete, and very secondarily from granite. This is confirmed by chemical analyses, which show a high Al and Fe content in the effused material; these two elements are indeed abundant in the soil. The fusion of soil, concrete and rock is a combination of lightning and electricity. The source of fusion was generated by the impact of lightning on the electricity pole. This impact allowed an electrical discharge resulting from the combination of lightning and current from the medium-voltage line to pass through the ground. The effect of lightning alone would have generated a fulgurite, a rather linear structure of very little volume. The current from the medium-voltage line, combined with the lightning, created a larger, hotter and more active plasma (for a few tens of seconds?) capable of melting concrete, soil and even rock. Excavation of the impacted site indeed shows that the rock has partially melted, and the plasma has reached a maximum depth of 2.5 m. The effused mass is therefore not material of deep-seated origin. These rules out the possibility of a volcanic eruption.

Keywords: Guéhiébly, Medium-voltage electric line, Lightning, Soil melting, Effusion, Côte d'Ivoire

Testing the capability of hyperspectral imaging to characterise South African coal

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Abstract

Coal resources and reserves are determined through exploration, which involves drilling, core logging, and sample analysis. Traditional core logging and laboratory-based analyses can be time-consuming, and the accuracy of the logging data depends entirely on the experience of a geologist. Hyperspectral imaging (HSI) is an automated technique that can be used in exploration projects, to improve the level of accuracy of core logging and to rapidly acquire data. The technique measures the spectral response of samples based on their reflectance properties, and the data is presented as a function of reflectance vs wavelength. HSI is used extensively in many commodities, but there is limited information pertaining to benefits in coal exploration. In this study, a borehole core from Zibulo Colliery (Witbank Coalfield, South Africa) was imaged within the visible and near- (350 -1000 nm), shortwave (1000 - 2500 nm), and longwave (8000 to 12000 nm) infrared ranges. The coal spectra were classified within the visible and near-shortwave infrared (VN-SWIR) spectral region, as determined by low reflectance and a gradual increase of reflectance towards the SWIR region. To assess the capability of HSI to characterise coal and associated inorganic matter, the HSI data was compared to X-ray diffraction (XRD) data, FTIR and SEM-EDS, supported by proximate analysis and X-ray fluorescence (XRF) data. The coal spectra were classified within the VN-SWIR region, as determined by low reflectance and a gradual increase of reflectance towards the SWIR region. The positive slope of the coal spectra is influenced by the amount of fine-grained clay and Fe-rich minerals intimately associated with organic matter. The coal functional groups were identified as aliphatic, aromatic rings, and oxygenated groups by HSI and FTIR. However, the absorption features of HSI are poorly developed, but they can be enhanced by using Hull corrections. Some of the absorption features between 2100 and 2450 nm overlap with bands of inorganic matter, resulting in uncertainty in the accuracy of data interpretation. The image maps of extraction feature D2200 can adequately distinguish coal lithotypes and allow extrapolation of inertinite and vitrinite. The D2200 feature can also distinguish coal from carbonaceous shale based on the proportion of kaolinite in both rock types. The HSI can characterise the South African coal based on type, relative size, distribution, and association of inorganic phases, presented as mineral maps. XRD generated data confirmed 80 % of the inorganic phases identified by HSI in the scanned core. HSI did not identify pyrite which is a significant inorganic phase within South African coal due to pollution concerns. This could be due to the camera pixel size (1.5 mm) versus the <100 µm grain size of pyrite, which was confirmed by SEM-EDS. This study established that HSI can indicate the presence of organic matter within the borehole core but cannot adequately separate data on coal functional groups. Development of an additional camera covering the MWIR could be beneficial. The technique is a useful tool to characterise inorganic matter within borehole core, however more research is still required on certain minerals such as pyrite.

Keywords: Coal, Hyperspectral imaging, VN-SWIR, LWIR, Feature extraction

Seismicity in the Northwest of Namibia: 01 January – 31 May 2012

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Abstract

The WALPASS experiment comprised 28 temporary seismic stations which were deployed in NW Namibia from October 2010 to November 2012. The WALPASS project aimed to image the lithospheric and deeper upper mantle structure in the ocean-continent transition beneath the passive continental margin of northern Namibia and find seismic anomalies related to the postulated hotspot track from the continent to the ocean along the Walvis Ridge. Bird *et al.* (2006) and Viola *et al.* (2005) resolved the presence of Wegener stress anomalies in southern Africa with a NW-SE compressive horizontal principal stress. A shell finite element model by Bird *et al.* (2006) predicted a high strain rate along the western arc through Angola, Namibia and South Africa. The local seismicity was analysed using SEISAN software and relocation of the Khorixas cluster by hypoDD programme using the IASP91 velocity model. On the 24th of March 2012, an earthquake with origin time 4:43:52, location -20.127° S and 14.146° E, depth 0.1 km and magnitudes of 4.7 M_L occurred approximately 60 km northwest of Khorixas in the Damara Orogenic Belt. Relocation of the 24 March event with hypoDD programme was -20.14° S and 14.48° with reduced uncertainties. A study from January to May 2012 about the seismicity recorded 281 earthquakes of which 149 were aftershocks with local magnitudes ranging from -0.4 to 4.7 M_L . Seismicity recorded correlated to Walvis Ridge, Damara Orogenic Belt, Okahandja Lineament and Windhoek Graben seismic zones. Two clusters oriented NE-SW and NW-SE which may be due to complex faulting in the Khorixas area, were resolved. There was also an observation of several foreshocks around the mainshock, which might have been a signal associated with stress build-up in and around the fault leading to the major rupture. Focal mechanism solutions for these events show the direction of the fault plane as E and NE, with the orientation of the most compressive stress being NW-SE. There is a strong correlation between seismicity recorded and the predicted high strain rate through Angola, Namibia, South Africa and to less active Mozambique.

Keywords: Wegener stress, Seismicity, Walvis Ridge, Damara Orogenic Belt, Okahandja Lineament, Windhoek Graben

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Resolution of magnetic data over the Usakos Dome, central Namibia: A comparative analysis of two data sets

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Abstract

In the world of geophysical data digitization, a continuous, smooth function of time or distance can be expressed digitally by sampling the function/signal at specified fixed intervals and recording the instantaneous value of that function at each sample point. This process is inherent in many geophysical surveys, where readings are measured at the value of some parameter i. e. geophysical field strength at points along survey lines. The extent to which the digital values accurately represent the original function depends on the accuracy of the amplitude measurement and the intervals between measured samples. Inadequate digital sampling of a continuous function may lead to a loss of information in the resultant digital signal since the latter is sampled by discrete values at a series of points. To explain this phenomenon, two magnetic data sets over the K1 Prospect, Usakos Dome (central Namibia), acquired at two different line spacings were compared. The two datasets used are the high-resolution aeromagnetic data from the Geological Survey of Namibia acquired at 200 m line spacing and the high-resolution ground magnetic survey from Navachab Gold Mine (50 m line spacing). Notwithstanding the fact that, one is an aeromagnetic data and the other a ground magnetic survey, the two data sets are compared over different data enhancement filters in order to delineate as much geological structural information as possible, as well as to map out local geology. Results show that, although both magnetic data sets are referred to as high-resolution, the ground magnetic data reconstructs the magnetic field strength and maps the local synclinal structure much more effectively than the 200 m aeromagnetic data. It is further observed that the ground magnetic survey generates better targets for drilling and mineral exploration purposes than the aeromagnetic data. Therefore, it can be concluded that the 200 m line spacing is suitable for regional mapping and delineating deeper geological structures, while the 50 m spacing ground magnetic data is favourable for detail mapping and delineation of drilling targets. Although, the aeromagnetic data is considered high resolution in mapping regional geology, it does not reveal localised features less than 200 m wide. This data set has been largely informative in guiding exploration companies within their Exclusive Prospecting Licences (EPL) to identify areas of interest, but to further delineate local geology and structure, a much higher resolution airborne/ground surveys is needed.

Keywords: Function, Aeromagnetics, Prospect, Resolution, Delineation

A review of Hydro-geophysics successes in enhancing groundwater exploration in Southern Africa

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Abstract

Integrated geophysical methods can be a useful tool in mapping the subsurface characteristics that are likely to control groundwater occurrence and hence are useful tools in identifying potential drill targets in different aquifer formations in Southern Africa. This study reviews the application of hydro-geophysical methods (natural electromagnetic methods, electrical and electromagnetic methods) in groundwater exploration to identify potential groundwater bearing targets within the crystalline basement and Kalahari sand aquifers in Southern Africa. The results suggest that hydro-geophysical assessment in Kalahari aquifers could clearly show that the system exhibits a well-defined layered multiple aquifer formation that is likely recharged from surface water. On the other hand, in crystalline basement formations, hydro-geophysics could be combined with geological and earth observations to identify groundwater controls such as lineaments and depths to fractured zones. The magnetic method, horizontal and vertical frequency domain electromagnetic geophysical methods presented herein managed to delineate the main dykes and lineament features associated with groundwater occurrence in typical crystalline basement aquifers while the natural magneto telluric investigations managed to delineate the deep and shallow aquifer formation in Kalahari sandstone aquifer formation. Different site-specific cases studies are presented and discussed. The study advocates for the integration of geophysical methods with local and regional geology for groundwater evaluation to provide a more detailed approach for the for-resource assessment in some of the vulnerable aquifer systems in Southern Africa. Results from this study are useful for technical groundwater management as a climate resilient strategy in Southern Africa.

Keywords: Hydro-geophysics, Kalahari sand aquifer, Crystalline basement aquifer, Groundwater assessment, Groundwater controls

Geothermal Potential and Exploration Opportunities in Central Tanzania, East Africa

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Abstract

Geothermal power presents a sustainable and renewable energy source that can enhance the country's energy independence and decrease its dependence on fossil fuels. Geothermal power generation provides a stable and reliable energy source that can support industrial growth and stimulate economic activities by creating employment opportunities, attracting investment, and fostering local expertise in the geothermal sector while enhancing international competitiveness. Also, geothermal power generation aligns with global initiatives to combat climate change and transition to a low-carbon economy. Tanzania is well known for its diverse and abundant natural resources and is increasingly focusing on the exploration and utilization of geothermal energy. Central Tanzania, situated in the East African Rift System (EARS), is a region characterized by tectonic activity spanning multiple countries and offers an ideal setting for geothermal energy generation. The presence of numerous fault systems, high heat flow, and active volcanism in the Central Tanzania Rift Valley (CTRV), are evidence of promising indicators of geothermal resources, with temperatures estimated to exceed 250 °C at depths ranging from 2 to 3 kilometres. These conditions make central Tanzania a promising prospect for geothermal exploration and development. Harnessing geothermal energy in this area can yield substantial economic benefits for the region. Thus, comprehensive geothermal resource assessment studies are necessary to accurately determine the size and quality of the geothermal reservoirs.

Keywords: Geothermal energy, Renewable energy, Geothermal exploration, Tanzania

Setting Up a Seismic Network around Mt. Kenya Area (Poster)

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Abstract

This study presents an exciting project focused on establishing a seismic network around the remarkable Mount Kenya region. Mount Kenya's unique geological setting and its connection to seismic activity prompted our initiative to better comprehend the movements beneath the surface. Our project involves strategically placing a network of specialized instruments designed to detect and record ground vibrations caused by natural processes deep within the Earth. These instruments, known as seismometers, act like sensitive microphones capturing subtle tremors and vibrations that are usually imperceptible to humans. Through this setup, we've been able to listen to the Earth's rumblings and analyze the patterns of seismic activity. This information holds the key to understanding the geological dynamics of the area and the potential for seismic events, such as earthquakes, or volcanic activity. In addition to seismometers, we've incorporated Global Navigation Satellite System (GNSS) technology to monitor ground movements. By combining data from both seismometers and GNSS, we're gaining a comprehensive view of how the Earth's crust is behaving around Mount Kenya. Our study illustrates the process of setting up this network, collecting data, and the insights we've gained so far. We'll be sharing findings about the Earth's movements, how different forces interact beneath the surface, and what this could mean for the future. The implications of this project are far-reaching. By understanding the seismic behavior of the Mount Kenya region, we contribute to enhancing the safety and preparedness of local communities and provide valuable information for geological research.

Keywords: Seismic Network, Mount Kenya, Ground Vibrations, Geological dynamics, Seismic activity, GNSS Technology, Earthquake Detection, Kenya

Hydrogeophysical investigations and mapping of ingress channels along the Blesbokspruit in the East Rand basin of the Witwatersrand, South Africa

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Abstract

Mining has been the cornerstone of the South African economy for the last century. Most of the gold mining in South Africa was conducted within the Witwatersrand Basin, which contributed to the rapid growth of the city of Johannesburg and catapulted the city to becoming the business and wealth capital of the country. But with a gradual depletion of resources, a stoppage in the extraction of underground water from mines and other factors relating to survival of the mining operations over a lengthy period, most of the mines were abandoned and left to pollute the local waterways and groundwater with toxins, heavy metal residue and increased acid mine drainage. The Department of Mineral Resources and Energy commissioned a project whose aim is to monitor, maintain and mitigate the adverse environmental impacts of polluted mine water flowing into local streams affecting local ecosystems and livelihoods downstream. As part of the mitigation efforts, the diagnosis and monitoring of ground and surface water channels has become important. Geophysical surveys, in particular resistivity and magnetics, were selected as the most suitable techniques for investigation of local ingress points along one of the major streams cutting through the Witwatersrand Basin, the Blesbokspruit in the eastern part of the basin. The aim of the surveys was to provide information that could be used to assist in determining possible water loss/ingress from the Blesbokspruit. Modelling of geophysical survey results offered an in-depth insight into the interaction and pathways of polluted water through mapping of possible ingress channels near the Blesbokspruit. The resistivity - depth profile of the surveyed site exhibits a three-layered model with (1) low resistivity (10 to 200 $\Omega\cdot\text{m}$) overburden, underlain by (2) a moderate resistivity weathered layer ($>300 \Omega\cdot\text{m}$), which sits on (3) a more resistive crystalline bedrock ($>500 \Omega\cdot\text{m}$). Two locations of potential ingress channels were mapped across the two traverses at the site. The magnetic survey detected a major NE-SW trending regional lineament, with a strong magnetic signature, which was modeled to a depth beyond 100m; this lineament has the potential to act as a conduit for dispersion of stream water away from the stream, as it shares a similar orientation with the potential ingress channels mapped with the resistivity method.

Keywords: Witwatersrand, Blesbokspruit, Resistivity, Magnetics, Contamination, Geophysical survey, South Africa

Preliminary structural interpretation of high resolution airborne magnetic data in the Kamanjab area, Namibia (Poster)

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Abstract

With the aim to produce a mineral prospectivity map of the area covered by the 1:250 k map sheet 1914 Kamanjab (northwest Namibia), magnetic and radiometric data have been used to delineate structures and discriminate lithologies, based on various high-resolution surveys flown at 200 m line spacing and 80 m terrain clearance in 1995 and 1996. The study area contains outcrops of metamorphic rocks well suited to preserve magnetic properties. Analysis and qualitative interpretation of high-resolution airborne magnetic data was carried out to investigate structural lineaments such as faults, contacts and joints which govern mineral deposition. This was achieved by using a number of filters applied to the magnetic data reduced to pole (RTP). The first vertical derivative and analytic signal were applied to the RTP data to investigate the presence of shallow features. The analytic signal along with the tilt derivative have been used to determine edges of magnetic fabrics. To aid the interpretation, magnetic enhancement for edge detecting and shallow feature enhancement, tilt derivative, horizontal derivative, analytical signal, first and second vertical derivative enhancement and sun shading were applied in Geosoft Oasis Montaj and ArcGIS software. Radiometric data were used to discriminate distinctive areas with concentrations of three natural radioactive elements, i. e. potassium, uranium and thorium. The ternary image of the three elements (with RGB colour coding) was used to discriminate lithological units which correlate well with the mapped geology. Granites are usually high in potassium and uranium concentration, but locally contain all three elements in equal proportions, producing a red-pink to white appearance on the ternary image. Also, a distinctive contact between the Neoproterozoic carbonates of the Damara Supergroup and the Palaeoproterozoic gneisses and granites of the Kamanjab Inlier has been mapped from the ternary image. Ground truthing will be conducted to confirm and assess these interpreted features. To produce a preliminary mineral prospectivity map, structural information was integrated with geochemical and economic data. The main faults trend NW-SE and NE-SW, whereas minor faults are oriented randomly, clearly indicating that the area underwent strong deformation during the Pan-African Damara Orogeny. Few known mineral occurrences coincide exactly with the interpreted structures. These areas have been marked as potential exploration targets for copper (Cu), gold (Au), lead (Pb) and other commodities.

Keywords: Airborne magnetics, Airborne radiometrics, Interpretation, Mineral exploration, Namibia

The Seismological Network of Namibia

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Abstract

Seismicity in Namibia has been monitored since the 1900s by International Seismological Centres, such as the International Seismological Centre (ISC) of the UK, the Council of Geoscience (CGS) of South Africa, the Bulawayo Seismological Observatory (Zimbabwe) and the United States Geological Survey. In 2010, the Namibia Seismological Network (NSN) had only six permanent stations with outdated seismic equipment which was rapidly failing, making it difficult to monitor earthquake activities. In 2014, a capital project to expand the seismological network (Network Expansion Project), was initiated to completely overhaul the national seismological network. With the advent of social media, information on earthquakes felt by people around Namibia spread much more rapidly and the Geological Survey was at the time unable to accurately confirm the event locations and magnitudes. Currently, the National Seismological Network of Namibia consists of ten (10) seismological stations in Windhoek, Rundu, Kamanjab, Aus, Ariamsvlei, Opuwo, Gobabis, Karibib, Katima and Tsumeb. The ten permanent seismic stations are located approximately 500 km apart making it more challenging to detect micro-seismicity. The current stations are a mix of broadband and single-phase stations, and are powered by national grid and solar energy. The recorded data are transmitted in real time via the GPRS mobile network to the main server located in Windhoek. In addition, the Tsumeb station forms part of the Global Seismological Network and Incorporated Research Institutions for Seismology (GSN/IRIS), and contributes to worldwide earthquake monitoring. It is also one of the CTBTO's IMS AS067 stations monitoring worldwide nuclear explosions. The highest event magnitude ever recorded in the country was a local magnitude of 5.6 (*ML*) in 2009 and 2021, both in north-western Namibia. The national seismic data are used to monitor earthquakes countrywide, provide information for an earthquake hazard map of Namibia for civil and scientific applications, such as land use planning and research, and to compile monthly bulletins. Moreover, the network also provides data to the International Seismological Centre in the UK to compile a Global Seismic Hazard map.

Keywords: Seismological network, Seismicity, Namibia

Hydrogeophysical investigation of Aquiferous Formations in Basaltic lavas of Mount Cameroon, Buea, Southwest Region, Cameroon

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Abstract

Basaltic lavas forms aquifers which are an important source of groundwater supply in many regions of the world, they can be easily accessed due to their high variable permeability especially when confronted with water shortages as a result of low river discharges and increasing population growth. Successful execution of groundwater exploration of basaltic lava formations using geophysical methods requires knowledge of the relationships that exist between hydrogeological and geophysical parameters. This makes data interpretation and delineation of groundwater zones easier, thereby avoiding the drilling of marginal holes. This study was carried out in Buea Municipality and was aimed at determining the hydro geophysical parameters such as hydraulic conductivity and transmissivity via the vertical electrical sounding method. The obtained resistivity and saturated thickness were used to compute transverse resistance (T_r) and longitudinal conductance (S_c) which has shown to be useful in obtaining values for hydraulic conductivity and transmissivity. The values for hydraulic conductivity of the study area ranges from 0.047 – 92.4m²/day with a Mean value of 6.9m²/day and a Standard Deviation of 20.9m²/day. The hydraulic conductivity ranges from 0.002 – 7.6m/day having a Mean value of 0.82m/day and a Standard Deviation of 1.8m/day. This shows that a greater part of the area under investigation has high porosity and interconnected fractures which gives a potential for groundwater productivity that can support individual consumption and communities found within the study area.

Keywords: Hydrogeological parameters, Groundwater, Electrical sounding, Basaltic lava, Aquifer, Buea, Cameroon

Geochemical and palaeomagnetic investigation of the Karoo dolerite dykes, Highveld Coalfield: South Africa

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Abstract

56 Karoo dolerite dykes and sills were sampled from nine unoriented drill cores between depths of 13.20 to 140.32 m at the Matla Coal Mine located in the Highveld Coalfield (Mpumalanga Province). A subset of the samples was selected for palaeomagnetic experiments using a modern JR-6A Spinner Magnetometer and LDA5 AF demagnetizer to determine past geomagnetic field directions. During the demagnetization process, a stepwise progressive alternating field (AF) demagnetization was applied to randomize the remanent magnetization by applying an oscillating magnetic field with linear decay in amplitude at varying peak field intensities ranging from 5-120 mT. The magnetic moments within the samples are progressively randomized thereby defining the Characteristics Remanent Magnetization (ChRM); i. e. the primary magnetization during magma cooling at ca. 180 Ma. The NRM intensity decay curves show a rapid decrease in intensity with 90% of magnetization removed by 40 mT or less. This observation is consistent with a Ti-rich titanomagnetite with magnetic grain sizes in the pseudo-single domain. By 60 mT most of the NRM is removed indicating no indication of magnetic hard materials such as titanohematite. The median destructive field (MDF) ranges from 10-20 mT. Because the drill cores were not oriented the declination of the field was unusable. However, the inclination of the palaeofield was determined and a direction of magnetization is calculated using the least square technique of Kirschvink (1980). These inclination values were then averaged, and core levels and overall mean directions determined from which a palaeolatitude was obtained. When these values were plotted on the South African Apparent Polar Wander Path (APWP) curve of Besse and Courtillot (1993; 2002), a small circle is drawn about the sampling site that includes the overall mean direction; the small circle cuts the APWP at different locations, including at ages of 170-190 Ma, which is consistent with published ages for the Karoo volcanics (e. g. Fitch and Miller, 1984). Consequently, the palaeomagnetic analysis provides valuable information about the magnetic properties of the dolerites and their emplacement age. Another subset of the samples was used to characterize the mineralogy and textures of the dolerite dykes, to aid the identification of the source and nature of the magma. The whole rock geochemical data were generated by microprobe and utilized to assess the chemical composition of the dolerite dykes and provide insights into the petrogenesis of the Karoo magmas. Thus, the results are envisaged to provide a comprehensive understanding of the geological history, tectonic processes and magnetic properties of the rocks and minerals of the Karoo Intrusive Province and the evolution of the African plate.

Keywords: Karoo Intrusive Province, Dolerite dykes, Geochemical data, Palaeomagnetism, Magnetic moments, Palaeofield

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Delineation of gold potential zones within Kaiama (northwestern Nigeria) using airborne magnetic and radiometric data

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Abstract

The mapping of lithology, structures, and hydrothermal alteration zones in Kaiama, northcentral Nigeria, was carried out to locate possible gold mineralization zones. Both aeromagnetic and airborne radiometric datasets were used in the investigation. Enhancement techniques such as first vertical derivative, analytic signal, Euler deconvolution, 2D power spectrum, center for exploration targeting (grid and porphyry) as well as ratio and ternary maps were employed to aid in the interpretation process. The study reveals NE-SW, NW-SE, E-W, and N-S structural orientations dominate the area. The most important was the NE-SW, which was thought to be the best direction for mineral resources within the region. Also, depth estimation of shallow and deep-seated structures calculated using Euler deconvolution technique ranged from 250 to 1546m, while power spectrum gave a range of 468-1853m. Airborne radiometric analysis based on the concentrations of equivalent thorium (eTh), equivalent uranium (eU), and percentage potassium (%K), as well as radiometric ternary map, revealed the presence of six (6) lithological units and hydrothermal alterations. Finally, a composite map was created that included geology, structures, and hydrothermally altered zones. From the map, tight concordance between known gold mineralization locations and the interpreted structural and hydrothermal complexities sheds fresh light on similar mapped features that may be new promising sites for gold exploration.

Keywords: Aeroradiometrics, Aeromagnetics, Hydrothermal alteration, Gold mineralization, Nigeria

ST04_S02: Advances in geochemical exploration techniques and data interpretation**An assessment of pXRF capability in exploration and mining using different Certified Reference Materials****Shipandeni Abraham*, Philadelphia Mbingeneeko***Geological Survey of Namibia, 6 Aviation Rd, P/Bag 13297 Windhoek, Namibia***Corresponding author: Shipandeni.Abraham@mme.gov.na***Abstract**

This study evaluates the capability of the portable XRF for its use in the mineral exploration and mining industry by determining the figures of merit, specifically, accuracy and Relative Standard Deviation (RSD = precision) for specific elements in diverse suites of Certified Reference Materials (CRMs). The XL3t GOLDD+ 950 Thermoscientific Niton pXRF spectrometer of the Geological Survey of Namibia was used to carry out the analyses on 32 CRMs ranging from lake sediment to slate, hornblendite, granodiorite, andesite, gabbro, rhyolite and basalt. The CRMs were analyzed using the default factory calibration on TestAll Geo, Soil and Mining Cu/Zn modes. Each CRM was analyzed five times for 120 seconds at every 30 degrees rotation interval. The CRM data obtained by pXRF were compared to the respective certified values. The performance of the instrument for specific elements was then evaluated by calculating the mean, standard deviation, RSD, %RSD and %Accuracy for different elements. The study is restricted to the following elements: Zr, Sr, Pb, As, Th, Mn, Ti, Ca, Si, Fe, Cu, V, K, Ba, Al and Zn.

The results show excellent accuracy to within $\pm 20\%$ and less than 5% RSD (precision) for Zr, Sr, Pb, As, Th, Mn, Ti, Ca and Si. The performance of the pXRF shows accuracy which is moderately well above 20% but less than 30% and %RSD above 5% but less than 20% for Fe, Zn, Cu, V, K, Ba and Al. The evaluation was also done in the Soil and Mining Cu/Zn modes; the performance of the elements is consistent with no significant variation in these two modes. Poor accuracy and precision are attributed to poor optimization of the instrument for the elements with moderate accuracy, e. g. Fe, Zn, Cu, V, K, Ba and Al, elemental interferences that could not be corrected, and elements at low concentration. As a result, analysis of the different suite of 32 CRMs showed significant differences in performance for different elements. In a nutshell, the pXRF capability to measure specific elements vary generally from excellent and moderately well to fairly poor, using the TestAllGeo mode. However, the study recommends the use of results from conventional analytical instruments, such as wavelength XRF, AAS and ICP-OES for detailed assessments, and the optimization of the instrument to attain more accurate results for elements showing moderate and poor accuracy results.

Keywords: Portable XRF, Certified reference materials, Relative standard deviation and accuracy

Implications of Standard Laboratories for Geochemical Mapping in Africa: Challenges and Opportunities – A Case Study from Nigeria

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Abstract

Geochemical mapping is a technique rooted in mineral exploration and provides a means of visualizing spatial variations in the composition of the earth surface. It is a very versatile tool that provides information on the concentration levels and spatial distribution of chemical elements in the near-surface environment, which sustains human existence.

The chemical signature of any specific mineral deposit will reflect the commodities that it contains and is likely to contrast with that of the surrounding rocks. The purpose of geochemical mapping is to generate high quality baseline geochemical data through the collection and analysis of stream sediments, stream water, residual soils and rocks. It provides information on prospective areas for mineral exploration and also reveals the relationship between public health and trace element deficiencies and toxicities in the environment. In order to obtain high quality geochemical baseline data, a good knowledge of the application and operation of analytical equipment, such as X-Ray Fluorescence (XRF) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) used in the analyses of geochemical samples, is required. Fire Assay analysis offers much improved detection limits for key elements of interest in geochemical mapping. However, analytical equipment is expensive and costly to maintain. Adequate training is, therefore, required for efficient handling and generation of quality geochemical data. Painstaking efforts in sample preparations, analyses, data quality control and other logistics are necessary for a successful geochemical mapping programme. The application and opportunities in geochemical mapping are vast. With a workforce well-trained in the methodologies of geochemical mapping and the interpretation of the obtained data, the challenges in geochemical mapping in Africa can be turned into opportunities that can be effectively applied to meet mineral, health and environmental needs.

Keywords: Geochemical mapping, ICP-MS, XRF, Fire Assay, Nigeria

Petrography and Geochemistry of Schists and Amphibolites from the Palaeoproterozoic Birimian Suhum Basin, Southeastern Ghana

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Abstract

Of the six main Palaeoproterozoic Birimian granite-greenstone belts and their intervening metasedimentary basins in Ghana, the Suhum basin, found at the eastern portion of the Cape Coast basin has over the years, received very little attention in terms of petrographic and geochemical studies. The general geology as well as the petrogenesis, provenance and tectonic settings of the rocks within this Basin have not been extensively documented. The Suhum Basin comprises metavolcanic rocks, granitoids and metasedimentary rocks. In this paper, the petrography as well as major and trace-element geochemistry of the metasedimentary rocks and amphibolites from the northwestern portion of the Suhum basin, were evaluated to determine the provenance, and tectonic implications of the Basin in relation to surrounding Birimian rocks. The metasedimentary rocks studied are mainly schists of variable composition. From the petrography, the schist is made up of biotite schists, hornblende-biotite schists, and muscovite-biotite schists. From the major and trace element geochemistry, the protolith of the schists may be classified as Fe-shales and greywackes. By their geochemical compositions the amphibolites may be grouped into para-amphibolites and ortho-amphibolites. From Chemical Index of Alteration (CIA) values, the source area of the schists underwent incipient to intermediate degrees of weathering. The schists are texturally and mineralogically immature and derived from mafic to felsic rock sources with very low degree of sediment reworking (recycling). Petrographical and geochemical characteristics suggest that deposition of the schist took place in an active continental margin setting. The geochemical characteristics of the schist suggest Young Undifferentiated Arc (YUA) provenance. Hence, the source area for the sediments of the schists is most likely the adjacent Birimian metavolcanic rocks. The amphibolites from the study area may be classified as metaluminous, gabbroic, and subalkaline (tholeiitic). Both para-amphibolites and ortho-amphibolites were identified to have been derived from subduction zones typically characteristic of Mid-Ocean Ridge Basalts (MORBs), Island Arc Tholeiites (IATs) and Continental Arc Basalts (CABs). The amphibolites were most probably derived from the adjacent Birimian granite-greenstone belts and show characteristics similar to the Archaean greenstone belts. And supports the fact that the Palaeoproterozoic terranes of the West African Craton resemble the Archaean greenstone terranes.

Keywords: Birimian, West African Craton, Provenance, Petrogenesis, Suhum Basin, Ghana

Phytoextraction potential of metals from native plant species “*Cynodon dactylon*, *Sporobolus africanus* and *Combretum imberbe*” at Klein Letaba Tailing Storage Facility, Limpopo Province, South Africa (Poster)

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Abstract

Phytoextraction is one of the phytoremediation techniques currently in use for the remediation of tailings storage facilities. It has gained economic favour and public acceptance due to it being environmentally friendly and aesthetically pleasing. This technique makes use of green plants to extract metals proving its worth as a cleaning tool. Thus, it is clear that the remarkable potential of native plants to accumulate elements and compounds from the environment will provide a green cure technology for the agro ecosystem in the future. This study focuses on the effective use of native plants species growing and thriving well on the tailing's storage facility for rehabilitation and extraction of metals which could not be extracted by the mine using physical-chemical techniques and seeking ways of stabilising the soil. Furthermore, establish whether or not they are hyperaccumulators and determine the rate of their metal uptake as well as their potential for metal extraction. A total of 80 plants and tailings samples were randomly and seasonally collected at Klein Letaba TFS for metals concentration analysis as part of the feasibility study. 5 control samples were collected away from the mine site but within similar geological setting. This helped during comparative study to ascertain that these metals are indeed extracted from the mine due to anthropogenic activities. The metal concentration results from the reconnaissance study were used to develop evidential uptake of the dominant plants in the study area. Each composite sample was split into two representative aliquots for chemical and mineralogical analysis. The first aliquot was analysed using X-ray fluorescence spectrometry (XRF) and the second aliquot was digested using microwave digestion technique then sent out for Inductively coupled plasma optical emissions spectrometry (ICP-OES) analysis. Three dominant plant species growing and thriving well were identified growing on the TSF: *Combretum imberbe*, *Cynodon dactylon* and *Sporobolus africanus*. These plant species were found to be hyperaccumulators of Pb and Ni ($> 1000 \text{ mg kg}^{-1}$) because they were able to uptake and translocate metals from the roots to the shoot then leaves. Pb (KLT1S14) recorded 1700 mg kg^{-1} on the roots and Ni (KLT1S14) recorded metal concentration of $1101.03 \text{ mg kg}^{-1}$ on the roots for the *Combretum imberbe* plant, whereas Pb (KLT1S1) had concentration of $1525.8 \text{ mg kg}^{-1}$ on the roots and $1204.3 \text{ mg kg}^{-1}$ on the stem. These values exceed the ground tissues in concentration which are present in the soil (Baker and Brooks 1989). The uptake of metals by *Combretum imberbe*, *Cynodon dactylon* and *Sporobolus africanus* was following the order roots>stem>leaves. This study revealed that the native plants species growing and thriving well on the TSF are hyperaccumulators of Pb and Nickel during summer (wet) season. It can therefore be concluded that there is a relationship between the metal uptake by the plant and the metal content in the tailings and in the soil.

Keywords: Phytoextraction, Native plants, Hyperaccumulators, Metals

The geochemical characterization of Lake Oponono in the Cuvelai Etosha Basin, Northern Namibia

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Abstract

Wetlands are one of the most valuable ecosystems on earth. Besides their biological diversity and high productivity, they contribute significantly to livelihood and economic development. However, in southern Africa, they are currently being lost at alarming rates and thus, threatening the livelihoods that depend on them. The future of these wetlands is therefore dependent on effective assessment and monitoring initiatives that can inform policy and decision-making to promote their sustainable management. In this study, the wetlands located northwest of the Etosha Pan commonly known as Lake Oponono, were characterized using hydrogeochemistry and stable isotopes. A total of 11 surface water samples were collected along the lake in April 2022 and analyzed for major ions and stable isotopes. Field observations shows electrical conductivity ranged from 2.26 μ S/cm to 1968 μ S/cm. Major ions results show chloride as a dominating anion whereas the dominant cations were sodium and potassium. According to Namibian drinking water standards and WHO guideline values, the water quality is of high risk and is not suitable for human consumption due to high amounts of Cl⁻ and Na⁺ being above the permissible. The isotope values of the water ranged from -2.54‰ to 3.83‰ and -27.5‰ to 11.1‰ for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ respectively. All samples plotted below the Global Meteoric Water Line (GMWL) on the regression line $\delta^2\text{H}=6.09\delta^{18}\text{O}-14.58$ which signifies evaporation as a dominant process in the area. Characterizing the wetlands improves the understanding of effective planning, use, and conservation of wetland ecosystems. Therefore, it is recommended that further studies should evaluate temp variations in the water composition and stable isotopes as the current samples were only collected during the rainy season.

Keywords: Stable isotopes, Hydrogeochemistry, Cuvelai-Etosha Basin, Lake Oponono, Namibia



Soil geochemistry and multivariate statistical assessment of Copper–Gold-PGEs mineralization in parts of the Singida Region of the Tanzania Craton, Tanzania, East Africa

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Abstract

Multi-element mineralization of copper (Cu), gold (Au), and precious group of elements (PGEs) in the Kishapu-Igunga-Iramba areas in the central parts of Tanzania was evaluated in the study. The main aim was to characterize the mineralization with a focus on the pathfinder elements and the controls of the mineralization in the area through soil geochemistry and multivariate statistics and multivariate linear regression (MLR) methods. From the multivariate statistical methods applied, the Cu, Au, and PGEs mineralization in the area is associated with arsenic (As) and antimony (Sb). The Cu and Au occurrence in the area is a likely porphyry Cu-Au from their strong association. The mineralization (multi-elements) is strongly controlled by mafic-ultramafic rocks and volcanoclastics in the northern, southern, and central parts of the study area. From the MLR, Cu is strongly predicted by Zn, Ni, and Au with an error of ± 0.230 , with Pd being predicted by only Pt and vice versa, with an error margin of ± 0.001 . Au on the other hand is predicted by Cu, Fe, and Cr with an error margin of ± 0.473 . The style of mineralization of these elements is comparable to their occurrence in the Neoproterozoic setting and the Palaeoproterozoic Ubendian Belt of Tanzania as well as the PGEs occurrence in South Africa and Canada. Coupling MLR with hierarchical cluster analysis and factor analysis brings out a more definitive elemental association to precious minerals occurrence from the study and is strongly recommended.

Keywords: Soil geochemistry, Multivariate statistics, Cu-Au-PGEs mineralization, Singida region, Tanzania Craton

Biogeochemistry of different plant species with potentials for mineral exploration and phytoremediation in some parts of Middle Benue Trough, Nigeria

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Abstract

This study is aimed at the biogeochemical evaluation of some adapted plant species growing and thriving over limestone terrains in some parts of the Middle Benue Trough, Nigeria. It is focused on identifying the plant species, their distributions and to assess their biogeochemical characteristics as indicator plants to be adopted as potential alternative tools for mineral exploration and (Phyto-) remediation purposes. Five native plant of different plant species, namely: *Calopogonium mucunoides* (VLA, VLAN), *Ipomoea Spp* (VLB), *Calotropis procera* (VLC VLCN), *Clerodendrum capitatum* (VLD), *Dichrostachys cinerea* (VLE, VLEN) were identified. It was observed that the dominant plant family/species is the *Calopogonium mucunoides*. 18 leaf samples of these plant species were collected in the field from areas underlain by limestone and shale separately; of which the latter were to serve as a control. The major and trace elements in the soil and the plants were determined using Inductively Coupled Plasma – Mass Spectrometry (ICPMS). The results show significant concentrations of CaO and K₂O in all the plants species, a reflection of major chemical constituent of host limestone upon which the plants grow. The concentrations of trace elements (Cu, Pb, Zn, Ni, Co) are relatively higher in the shaly soils (25.50, 27.80, 100.30, 29.80, 12.80 ppm) than in the limestone soils (6.70, 13.47, 73.70, 14.90, 8.10 ppm) respectively. However, majority of the plant species were identified to have Bio-Concentration Factor (BCF) of Cu, for example, (between 1.72 and 1.21) (*Calopogonium Mucunoides* (VLA) BCF = 1.35, *Calotropis Procera*, (VLC) BCF =1.72, *Dichrostachys Cinerea* (VLE & VLEN) BCF =1.47 & 1.21 respectively). A few plant species grown on shale ground displaying BCF ≥ 3 of Cu (*Calopogonium Mucunoides* (VLAN) BCF = 3.75 and *Clerodendrum Capitatum* (VLD) BCF=3.03, which indicate tolerance of these plants to excessive uptake/concentrations of these metals and depicts their potential for both mineral exploration and Phyto-remediation. All the plants exhibit consistent Biological Absorption Coefficient (BAC) (0.01 – 1.0) signifying a moderate to weak absorption capacity of the different plant species. Both BAC and BCF of the plant species studied, are in support of their use as a valuable alternative in mineral exploration and remediation of contaminated land.

Keywords: Biogeochemistry, Mineral exploration, Phytoremediation, Benue Trough, Nigeria

A geochemical baseline study of a giant kelp forest farm in the Lüderitz area (Namibia) to assess carbon sequestration potential

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Abstract

The raised levels of carbon dioxide (CO₂) in the earth's atmosphere have contributed to global climate change, which has adversely affected a wide range of individuals, communities, and organizations. One of the mitigation to combat climate change is to grow a huge amount of kelp forests that can absorb carbon dioxide from the atmosphere and sequester it in the deep ocean. In order to grow these forests the right geochemical conditions (temperature, nutrients, oxygen, salinity, pH, trace metals and ions) need to be considered. This study aimed to monitor the biogeochemical changes at the proposed Kelp Blue farm and surrounding areas and further from the farm and then develop a geochemical baseline of the farm and parts of the Lüderitz areas. With these two aims successfully carried out in the end, the study will use these findings to assess the potential of the giant kelp to sequester CO₂. This study measured the geochemical parameters using both in-situ probes and laboratory analyses at 10 different locations in Lüderitz (both offshore and coastal). This study also collected sediment samples at different offshore sites close to Lüderitz and further north of Walvis Bay at the different latitudinal transects. The sediments were analyzed for trace metals by using an XRF and carbon content by determining LOI (Loss on Ignition). Another geochemical analysis done was the titrimetric method for CO₂ determination of seawater, whereas the nutrients were measured using a spectrophotometer. The geochemical parameters changed in relation to the seasonality and geographical positioning; in a season when the upwelling system was strong the concentration nutrients, acidity and the value of the pH, salinity, other geochemical parameters increased more compared to other seasons and the further southern sampling sites resembled to that of the Southern Benguela Upwelling System (SBUS). Higher concentrations of phosphates were found in areas close to the islands. These remarkable long duration geochemical measuring results shows that the cultivated kelp can co-exist with other natural existing kelp beds in this ecosystem and they can thrive more predominantly in season of great influx of nutrients during the season of strong winds. With a dynamic eastern boundary like this, grown more and will act as carbon absorber and eventually sequester more carbon when cultivated at large scale. To quantify the carbon sequestration potential of these giant kelps there are other areas to be looked into that cannot be included in this research due to the duration allowed for the study, other areas includes developing a sediment carbon baselines using isotopic analyses, lipid biomarkers, identifying sediment hotspots where the kelp will be deposited, developing a carbon dioxide removal model and geochemical dispersion models. All these other areas will be developed from the baseline being developed by this study. This study recommends that a continuous and rigorous monitoring of the water and sediment geochemical changes be done as the kelp forest grows and as the scale of operation expands.

Keywords: Climate change, Carbon sequestration, Marine geology, Benguela Upwelling System

Geochemical analysis and Physiochemical characteristics of Omaruru River Sediment, Namibia

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Abstract

This study assessed the nutrients, physiochemical characteristics and concentrations of heavy metals (Ni, Fe, Cr, Mn, Al, Zn, As, K, Ca, Co, Pb) and U in sediment samples collected from the Omaruru Stream Basin using an X-ray fluorescence spectrometer. P, S, N ions were determined using Ion Chromatography, while the physico-chemical characteristics of the sediment were determined using multiparameter tester, and the total organic carbon (TOC) was evaluated with a Total Organic Carbon Analyzer. The river sediment samples recorded mean concentration ranges from 17.01 ± 0.6 to 19.0 ± 2.2 mg/kg for Ni, 6041 ± 244 to 8554 ± 861.8 mg/kg for Fe, 189 ± 59.38 to 222 ± 10.6 mg/kg for Cr, 161 ± 5.36 to 239 ± 16.2 mg/kg for Mn, 57652 ± 460.6 to 53925 ± 458.6 mg/kg for Al, 18 ± 1.13 to 20 ± 0.9 mg/kg for Cu, 19 ± 1.1 to 27 ± 3.2 mg/kg for Zn, 4 ± 0.3 to 6 ± 0.4 mg/kg for As, 41 ± 4.8 to 43 ± 6.0 for Co, 43 ± 5.2 to 56 ± 8.6 for Pb and 7 ± 0.8 to 10 ± 1.5 for U. The nutrient mean concentrations range from 16262.3 ± 22212.56 to 29816.1 ± 3862.99 for Ca, 44027.7 ± 3222.66 to 45182.7 ± 2762.73 for K, 158.8 ± 36.57 to 182 ± 61.28 for S, 5.34 ± 0.71 to 5.51 ± 0.43 for N, 860 ± 93.17 to 999 ± 140.15 for P and 3.5 ± 0.76 to 4.72 ± 0.43 for TOC. The sequence of the heavy metal concentrations in the sediment was Fe > Al > Cr > Mn > Pb > Co > Zn > Cu > Ni > U > As. The concentrations of Cr, Co and U suggest that the sediment samples were heavily polluted, whereas Ni, As and Pb concentrations suggest moderately pollution according to USEPA regulatory guidelines for heavy metals. The nutrient concentrations were below the USEPA guidelines. The pH values measured were between 7.57 ± 0.39 to 8.14 ± 0.43 , and the electrical conductivity ranged from 131 ± 32.30 to 151 ± 70.70 mS/cm.

Keywords: Physico-chemical characteristics, Nutrients, Electrical conductivity, Heavy metals, Sediment, Omaruru River, Namibia

Oxygen and sulfur isotope composition of gold-bearing granite gneiss and quartz veins of Megele area, western Ethiopia: implications for fluid source

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Abstract

The Megele area gold-bearing Neoproterozoic rocks in the Western Ethiopian Shield has been under exploration for the last few decades. The geochemical and ore petrological characterization of the gold-bearing granite gneiss and associated quartz vein is crucial in understanding the gold's genesis. The present study concerns the ore petrological, geochemical, and stable O₂ and S characterization of the gold-bearing granite gneiss and associated quartz vein. This area is known for its long history of placer gold mining. The presence of quartz veins of different generations and orientations, visible sulfide mineralization, and oxidation suggests that the Megele area is geologically fertile for mineralization. The Au and base metals analysis also indicate that Megele area rocks are characterized by Cu (2-22 ppm av. 7.83 ppm), Zn (2-53 ppm av. 29.33 ppm), Co (1-27 ppm av. 13.33 ppm), Ni (2-16 ppm av. 10 ppm), Pb (5-10 ppm av. 8.33 ppm), Au (1-5 ppb av. 2.11 ppb), Ag (0.5 ppm), As (5-12 ppm av. 7.83 ppm), Cd (0.5 ppm), Li (0.5 ppm), Mo (1-4 ppm av. 1.6 ppm), Sc (5-13 ppm av. 9.3 ppm), and Tl (10 ppm). The oxygen isotope ($\delta^{18}\text{O}$) values of gold-bearing granite gneiss and associated quartz veins range from +8.6 to +11.5 ‰, suggesting the mixing of metamorphic water with magmatic water within the ore-forming fluid and/or two different sources of origin of fluids. The Sulfur isotope ($\delta^{34}\text{S}$) values of gold-bearing granite gneiss range from -1.92 to -0.45 ‰ (mean value of -1.13 ‰) indicating the narrow range of value. This suggests that the sulfides have been precipitated from the fluid system originating from a single source of the magmatic component under sulfur isotopic fractionation equilibrium condition. The tectonic setting of the host rocks, the occurrence of ore bodies, mineral assemblages of the host rocks and proposed ore-forming fluids of the Megele area gold prospects have similarities with features of orogenic gold deposit. The $\delta^{18}\text{O}$ and $\delta^{34}\text{S}$ isotopic values also suggested a metamorphic origin with the magmatic components. Thus, the Megele gold prospect could be related to an orogenic gold deposit related to metamorphism and associated intrusions.

Keywords: Fluid source, Geochemistry, Mineralogy, Stable isotopes, Ethiopia

Regional geochemical mapping of the Okahandja area (Central Namibia)

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Abstract

Geochemical mapping in Namibia, a project implemented by the Geological Survey of Namibia (GSN), started in 1999. The Regional Geochemical Sampling Programme (RGSP) was established based on the final report of the International Geological Correlation Programme (IGCP) Project 259. RGSP aims at establishing a National Baseline Geochemical Database of elements in the anthropogenically undisturbed geosphere. Baseline geochemical surveys have applications in medicine, agriculture, land use planning, mineral exploration and environmental monitoring. The geochemical sampling survey so far has covered nine 1:250 000 map sheets (approximately 180 000 km² or 20% of the country's surface area) collecting over 21 000 samples. The sampling media preferred for the RGSP are stream sediments; however, due to variations in landscape, topography and geomorphology across the country, soil samples were also taken in areas of poor or no stream development. Samples were collected from pre-selected locations identified during the planning stage. At each site five sample pits were dug, and a composite sample obtained and screened. Two samples were collected: a) a coarse (< 2 mm) fraction sample stored in a 5 kg polystyrene bag and b) a fine fraction sample (<180 microns) placed in a 60 g polystyrene bag. Collected samples were deposited at the GSN facilities in Windhoek, where they were riffle-split and homogenized to obtain samples for analyses and archiving. A representative portion of each sample was powdered to < 64 µm fineness; preliminary analytical data for the Okahandja area (map sheet 2116) was acquired using a handheld Niton Energy Dispersive XRF (ED-XRF) spectrometer at the GSN laboratory in 2018. The geochemical analytical data obtained was evaluated, interpreted and plotted on geochemical maps in order to delineate regional geochemical trends and anomalies. Generalized spatial distribution maps showing the concentrations for elements such as Cu, Sr, Zn, Fe and Pb were compiled using ESRI ArcGIS software. Regional geological maps as well as descriptions from each sample site were consulted in the interpretation of the resulting maps, and values obtained were compared with known crustal abundances. These comparisons have shown that some elements (e. g. strontium) fall within the range of crustal abundances, whereas elements such as Fe have higher concentration levels above the crustal thresholds. These disparities in the measured values may be attributed to specific local bedrock composition.

Keywords: Geochemical mapping, Sample collection, Sample preparation, Namibia

ST04_S03: Remote Sensing Studies**Mapping Orogenic Gold-Related Alteration Signatures using Fused Satellite Imagery and Geochemical Data in the Wawa Area, Western Nigeria****S.A. Alimi***, E.J.M. Carranza*Department of Geology, University of the Free State, Bloemfontein, South Africa***Corresponding author: alimi.sodiq@gmail.com***Abstract**

Gold mineralization in Nigeria is confined mainly to the western basement complex terrane. It is closely associated with the NNE–SSW-trending Proterozoic schist belt and transcrustal lineaments formed during the late stages of the Pan-African orogeny. The study area is a southern extension of the Zuru schist belt, and alteration styles related to gold mineralization therein are still understudied. Alteration mapping is a vital tool for the rapid location and identification of signatures of specific mineral deposits, especially at a district scale. As such, the study aims to map orogenic gold alteration signatures in the Wawa area using remote sensing and geochemical data to identify the various alteration styles related to gold mineralization in the area. The study applies Sentinel-2A satellite data whose bands were fused for spatial resolution enhancement and accurate alteration mineral identification using Gram–Schmidt techniques. The fused bands were applied for alteration mapping by using band ratios in principal component analysis. Field investigations and X-ray diffraction results were applied for validations. The findings show that the significant lithologies in the Wawa area are migmatite, granite gneiss, amphibolite/amphibole schist, granites, phyllite, and quartzite. Gold occurs as micro-veins within amphibolite/amphibole schist and granite gneisses in close association with pyrite. Geochemical data support the findings that most of the existing gold mining sites are within intense iron oxide and clay alteration zones. Future exploration targets for orogenic gold in Wawa area should be concentrated within similar alteration zones where no gold mining sites exist.

Keywords: Alteration mapping, Sentinel, Fusion, Pan-African orogeny, Pyrite

Remote sensing application on mineralization associated with Cu-Pb-Zn deposits in Pofadder, Northern Cape, South Africa

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Abstract

The mining industry is a major contributor to the economy of South Africa. Minerals are an essential raw material in our daily lives and are vital for economic, social, and technological development. The demand for base metals like copper, lead and zinc is increasing to meet development imperatives and transition towards renewable energy assets. Mineral exploration is a crucial step in finding minerals that can be potentially mined. Traditional mineral exploration relied on field observation, which covered relatively smaller areas and required substantial time and financial investment. Remote sensing provides a quick means of assessing large areas and identifying mineralization. This study used remote sensing to investigate potential areas of copper-lead-zinc mineralization in Pofadder, Northern Cape, South Africa. The geology of the study area incorporates rocks of the Bushmanland Group, Little Namaqualand Suite, and Gladkop Metamorphic Suite; mineralization is hosted within the Little Bushmanland Group (Aggeney's Subgroup). Band ratios and colour composites were created from ASTER and Sentinel-2 data to highlight iron and carbonate mineralization that is associated with Cu, Pb and Zn. Sentinel-2 colour composites: (b12/b11; b12/b8; b4/b3), (b11/12; b4/b2; b12/b8+b3/b4) and ASTER colour composites: (b13/b14; b7+b9/b8; b6+b8/b7), (b5/b8; b4/b3; b2/b1) highlighted iron and carbonate minerals. The results were analysed in conjunction with the locations of mineral occurrences which were obtained from the South African Mineral Deposits Database (SAMINDABA), geological data and geophysical datasets. The areas of iron and carbonate alteration correlate with 16/20 points of the historical mineral occurrences of copper-lead-zinc-rich mineralization in the area. Airborne magnetic data showed anomalies that correlate with some of the mineral occurrences and the mineral alterations obtained from ASTER and Sentinel-2 data. The airborne magnetic data confirm the results, suggesting that the remote sensing data provides surface expression of possible Cu, Pb, and Zn mineralization at depth. Historical geological structures within the area were overlaid. The occurrences of these minerals are associated with geological structures. Therefore, in prospective areas of mineralization, the integration of remote sensing images with other datasets is advantageous for exploration. Due to the satellite data's limited spectral and spatial resolution, some misclassification may occur; this misclassification was determined by integrating these results with other geoscientific datasets. Fieldwork is required to verify the results.

Keywords: ASTER, Sentinel-2, Mineralization, Remote sensing, Airborne magnetics

Structural geology and hyperspectral mapping of the Kunene Complex, Red Granite Belt, SW Angola

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Abstract

The 80 km-long and up to 3 km-wide, NE-SW striking, 1411-1370 Ma Red Granite Belt (RGB) divides the NNE-SSW-trending Kunene Complex (KC) massif-type anorthosite into a northern 1380 Ma troctolitic facies and a central 1412-1400 Ma noritic facies. The RGB is a structurally intriguing geological feature critical to understanding the tectonomagmatic evolution of the KC. In this study, field-based structural and hyperspectral mapping (PRISMA L2D) were combined to characterise the structural, microstructural, and mineralogical variations of the RGB. Field structural data for the RGB reveal gneissic and shear foliation vary from N-S striking (SW sector) to NE-SW striking (central sector) and E-W striking at the NE tip. The SW sector, located at the margin of the KC, reveals locally developed, margin-parallel, steep, N-S striking shear zones carrying steep feldspar and corrugation lineations in m-thick RGB granite and adjacent KC anorthosites, suggesting vertical stretching under E-W shortening. The granites in the central sector of the RGB have steep N-S striking magmatic layering overprinted by discrete NE-SW striking shear bands. The shear bands run parallel to RGB gneissosity, which dips moderately to steeply to the SE and, locally, to the NW with down-dip stretching lineation marked by feldspar and quartz. It parallels the RGB-anorthosite contacts and magmatic plagioclase lamination in the adjacent anorthositic rocks to the SE. The parallelism of RGB gneissosity and anorthosite magmatic lamination suggests that the shortening direction was the same, i.e., NW-SE during crystallisation of the noritic facies and solid-state deformation of RGB and adjacent anorthositic rocks. E-W striking gneissic foliation and open-to-tight folds developed within an LS-mylonite zone in the NE tip of RGB. Fold axes parallel quartz and feldspar stretching lineation, and the axial plane is parallel to the gneissic foliation and RGB geometry. Field and microstructural kinematic indicators suggest ductile thrusting compatible with E- and W-block-up in the SW sector, NW- and SE-block-up in the central sector, and folds in NE tip are interpreted as formed during intense ductile thrusting to the NNW. Quartz recrystallisation microstructures (grain boundary migration to bulging) suggest that deformation operated at a range of temperatures from high to low. To complement the structural geological features, unsupervised hyperspectral mineral mapping was performed to correlate spectral signatures with ground data and petrography to accurately classify and map lithological units and structures across the study area. Mineral maps for the VNIR and SWIR clearly show the rotation from N-S to E-W geometry in the SW and NE sectors of the RGB, respectively, and show that reflectance within the KC anorthosites is a function of metasomatism and olivine present/absence. The interpretation of the data is that the highly sheared RGB deformed during a progressive ductile thrusting event. The results suggest that the deformation recorded in the RGB was already active during the emplacement of the south-eastern adjacent KC anorthosites, which questions the widely accepted anorogenic setting for massif-type anorthosites and favours an orogenic environment for the formation of the KC.

Keywords: Massif-type anorthosite, Kunene Complex, Hyperspectral remote sensing, Structural geology, Thrusting

Lithological mapping of the Nama Group units using SENTINEL-2 imagery: A case study from the Witpütz Sub-basin, southern Namibia

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Abstract

In recent years, open data systems have allowed access to high spatial and spectral resolution multispectral satellite imagery, most notably ASTER, SENTINEL and ESRI Image. The use of satellite data and remote sensing techniques has proved very effective in mapping the flat-lying, sedimentary units of the Nama Group within the Witpütz Sub-basin around Aus and Rosh Pinah (southern Namibia). In 2013, The Geological Survey of Namibia embarked on the project of updating its geological maps of the //Karas Region at a scale of 1:50,000 with the aim of providing more detailed information, enhanced by modern interpretative concepts and analytical techniques. Spectral bands of Sentinel-2A and 2B images were manipulated through band ratios and band combinations to highlight different sedimentary rock types of the Nama Group, which is divided into three subgroups, i. e. the lower Kuibis Subgroup, the middle Schwarzrand Subgroup and the upper Fish River Subgroup. The present mapping focused on the Kuibis and Schwarzrand Subgroups, where previously undifferentiated units (Dabis and Zaris Formations) could be successfully differentiated into members with the aid of satellite imagery, supported by ground truthing. ESRI Image was used to delineate contacts between basement and Nama Group rocks. SENTINEL-2 band combinations (RGB-8,4,3) and (RGB-12,8,2) and band ratio (RGB-12/11, 12/8,4/3) were used to map out the Kanies, Mara and Kliphoek Members (Dabis Formation) and the Mooifontein Member (Zaris Formation) of the Kuibis Subgroup, while in the overlying Schwarzrand Subgroup the Nudaus and Urusis Formations could be distinguished. In addition, the Vingerbreek Member of the Nudaus Formation, and the Nasep and Huns Members of the Urusis Formation, were mapped out. The use of SENTINEL-2 data in geological mapping not only improves geological knowledge and map products, but also speeds up the process of map compilation by reducing field mapping time to verification of the identified units on the ground.

Keywords: Nama Group, Witpütz Sub-basin, Sentinel-2, Lithological mapping, Remote sensing, Namibia

A Geodynamic Interpretation of Southwestern Gondwana using Landsat8 OLI satellite imagery

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Abstract

Geology mapped on surface and indirectly through specific rock properties in the subsurface, by geophysical methods, has provided a fundamental understanding of the large-scale, spatial distribution of geological features or geodynamics. The geodynamic interpretation from a collage of processed Landsat8 OLI images covering continents, remains unique. A dataset of this scale, capturing the short-wave infrared mineral response (albeit broad band) from space, provides the context for further understanding the geology on the earth's surface. Initial interpretations using these data were verified by correlation with local geophysical datasets covering the Damara Belt. The continuity and strong Pan-African-Brasiliano structural overprint seen in images covering Africa and eastern South America provides a means to unravel mega-scale structures that affected Southwestern Gondwana. Form lines defining fold structures in the Neoproterozoic Damara Belt, Lufilian Arc and Zambezi Belts in Zambia as well as those that affected the Dom Feliciano Belt in South America, relate to pre-breakup Gondwana configuration ca. 500Ma. The main feature of lithospheric folds is that they strike perpendicular to the maximum stress direction of the active tectonic stresses. By identifying these strike directions, crustal movements of a very large scale, not observable on the ground, can be interpreted. The fold structures, seen in the satellite images covering Africa and eastern South America and brought together in the Gondwana pre-breakup configuration (500Ma), show that compressional stress prevailed following the opening and closure of the Iapetus Ocean during the Neoproterozoic and opening of the Rheic Ocean in the Palaeozoic. Several structural features observed in these images are discussed in relation to key economic areas in Southern Africa. Broad-band Landsat8 OLI satellite data, used to interpret large-scale structures and covering 1,000s of square kilometers do not replace mapped geology or geophysical interpretation but were used in conjunction with geophysical and geological data, the latter datasets are enhanced making for additional clarity of geological interpretation.

Keywords: Satellite images, Damara Belt, Lufilian Arc, Neoproterozoic, Economic areas

ST05: HYDROGEOLOGY AND WATER SUSTAINABILITY UNDER A CHANGING CLIMATE**ST05_S01: Hydrogeology and Water Sustainability Under a Changing Climate****Production Boreholes Water Quality Evaluation Using GIS-Based Geostatistical Algorithms in Windhoek (Poster)****Silas David****Namibia University of Science and Technology***Corresponding author: Silasdavid071@gmail.com***Abstract**

Knowledge of the manifestation of production boreholes, their replenishment and chemical characteristics have distinct significance in semi-arid zones like the Windhoek area, where production boreholes are an important source of water for domestic use. The goal of this study is to provide an overview for evaluating the water quality of production boreholes in Namibia's capital by using GIS (Geographic Information System) and geostatistical algorithms. Water quality parameters, i. e. pH, chloride, iron, electrical conductivity and temperature were sampled and analyzed from production boreholes in Windhoek. Maps of each parameter were produced by means of geostatistical techniques (kriging). Moreover, semi-variogram values were tested for different ordinary kriging models to ascertain the superlative fit for the five water quality parameters; the best models were selected based on the average standard error, root mean square standardized error, root mean square error and mean square error. Five maps of the production boreholes water quality parameters were used to compute the production boreholes water quality map using the index technique. Therefore, pro-active measures must be taken into consideration to check the levels of pH, chloride, iron, electrical conductivity and temperature to avert severe contamination and to protect production boreholes.

Keywords: Production boreholes, Water quality, Geostatistics, GIS, Namibia

Estimation of groundwater recharge in the Kalahari aquifers of Kavango West and East Regions using the chloride mass balance method and environmental isotopes, Namibia

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Abstract

Sustainable groundwater utilization in parts of hot semi-arid sub-Saharan countries, like Namibia, is constantly a challenge. For the aquifers in the Kavango West and East Regions, the issues to investigate the resource are amplified by the core use of surface water from the perennial Okavango River. This has resulted in the aquifers in the region to be highly understudied, even though they are being utilized. This study focuses on the middle and the lower Kalahari aquifers in the Kavango West and East region. The chloride mass balance method and environmental isotopes were applied in determining the groundwater recharge of the Kalahari aquifers in the Kavango West and East regions. The annual average precipitation in the study area is 570 mm/a. Groundwater, rainwater and surface water samples were collected during the year 2020. The concentration of chloride in precipitation was obtained from a different study conducted in the area. Episodic recharge is observed from $\delta_{18}\text{O}$ and tritium where groundwater from similar sources is recharged over different years at certain areas in the two regions. Modern recharge is observed within the study area of which most is taking place within the Omuramba Omatako ephemeral river. Spatial distribution of chloride in the Kalahari aquifers indicates that recharge is occurring in both the middle and lower Kalahari aquifers at varying rates. An average of 6.03 mm/a (1 % of the annual precipitation) of recharge was determined using the chloride mass balance method for the entire study area. The recharge rates estimated for the Kalahari aquifers can be used in the management of these aquifers.

Keywords: Recharge, Environmental isotopes, Chloride mass balance, Namibia

Baseline concentrations of radionuclides in groundwater of the Namibian Uranium Province, Namib Desert, western Namibia

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Abstract

The Namibian uranium province located in the Namib Desert, derives its name from the local presence of almost ten uranium tenements. The mines conduct monitoring of natural radionuclide concentrations of Ra²²⁶, Ra²²⁸, Pb²¹⁰, U²³⁴, U²³⁸, Th²³² and Po²¹⁰, in local aquifers. This data is useful in mine rehabilitation planning, developing closure criteria and for potable water quality standards, as only radiation doses additional to the natural background are usually considered 'controllable' for radiation protection purposes. The baseline data was collected through quarterly groundwater sampling with submersible pumps and analysed by an accredited laboratory. The uranium deposits are hosted in Damara age granites or as secondary mineralization in Tertiary calcareous palaeochannels. The analysis of the long-term baseline data provides the background radionuclide concentrations of three aquifer types in the province, i.e., the Quaternary saturated alluvium of the Khan and Swakop ephemeral Rivers, the Tertiary palaeochannel sediments, and Proterozoic basement aquifers. The ephemeral rivers are of importance because they supply groundwater for agricultural use downstream the mines. The analysis demonstrated that the alluvial aquifers have the lowest natural radionuclide content, with the U²³⁴ concentrations ranging between 0.03 and 3.4 Bq/l, while palaeochannel and basement aquifers show intermittent U²³⁴ concentrations ranging between 0.25 and 5.1 Bq/l. The groundwater in the immediate ore zones shows the highest U²³⁴ concentrations ranging between 44.8 and 86.3 Bq/l, exceedingly higher than the WHO standards of 1 Bq/l. This study illuminates that radioactivity is a natural phenomenon and that groundwater chemistry baseline data is paramount to groundwater protection.

Keywords: Namib Desert, Uranium province, Baseline, Radionuclides, Groundwater, Namibia

Will the groundwater resources of the Kunene and Omusati regions (northern Namibia) be able to meet water demand in the context of climate change in 2050?

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Abstract

The Kunene and Omusati regions are two contrasted areas in terms of geology, hydrogeology and economic development. The Kunene region extends from the ephemeral Ugab River in the south to the perennial Kunene River, which forms the Angolan border. It is a particularly arid area with rainfall ranging from less than 50 mm in the west to 300 mm in the east, whose landscape is shaped by a rugged geology. Its eastern neighbour, the Omusati region is part of the Cuvelaï-Etосha basin. Getting more precipitation (300-500 mm), it is a flat area covered mostly of Kalahari sediments with detrital material. The border between the two regions is formed by the carbonate rocks of the Otavi fold belt. A recent study by the French Geological Survey has gathered and interpreted local information to issue thematic maps in the field of aquifer recharge and groundwater use. Both regions are facing serious water scarcity. In the Kunene Region, the population is sparse and very rural, and the economy is based on livestock farming (pop. Density 2021: 0.9/km²). The recharge is low (~0.5% of precipitation) and water supply of cities such as Khorixas, Opuwo and Outjo is problematic. In the Omusati Region, the population density is ten times higher (10.1/km²). The region is semi-arid, and the recharge is estimated at 6% of precipitation. However, soil salinity and underground geochemistry degrade the quality of the infiltrated water. In most of the area, groundwater is not suitable for human consumption and water is supplied by a surface canal from the Calueque Dam (Angola). Climate projections from CORDEX Africa were applied to compute the future evolution of potential groundwater recharge. In the mid-term (2041-2070), projections for mean annual precipitation and potential evapo-transpiration would lead to a limited recharge increase (< 2 mm) in the coastal areas, with locally more substantial increase for alluvial formations. The rest of the study area could experience potential recharge decrease of between 0.5 and 4 mm for Omusati and less than 3 mm southeast of the Kunene. In the long term (2071-2100), projected recharge is a general decrease in the two regions. Concomitantly, the water demand will increase in accordance demography (population will be 173 000 in Kunene and 288 000 in Omusati by 2050), urban infrastructure, rural domestic and non-domestic water demand, irrigation, industry and tourism, environment and wildlife requirement. The thematic maps provide an overview of the water resources situation in these two regions at horizon 2050. The comparison of water demand and climate projections is highlighting sectors of tension, mainly in urban areas. Future mining projects also will require quantities of water which cannot be supplied from groundwater resources. This study was financed by the French Agency for Development under an agreement with the Namibian Government.

Keywords: Aquifer potential, Climate change, Water demand, Namibia

Hydrogeochemical characterization of groundwater in the municipality of Caimbambo (Angola)

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Abstract

In regions where water resources are scarce, groundwater is a vital resource. The characterization and assessment of groundwater resources are fundamental for correctly exploiting and maintaining their quantity and quality. The region of the municipality of Caimbambo (Angola) has suffered a devastating drought since 2012 and the aquifers, developed in igneous rocks, constitute, at sometimes of the year, the only source of water supply for the population. The main objective of this study was to characterize the physical-chemical composition of the groundwater in the area of the municipality of Caimbambo, contributing to the identification of areas favourable for its abstraction. The study area has the largest cartographic expression of the regional granitoid units of Eburnean age (about 2.0-2.2 Ga) that are generally biotitic, quartz dioritic, and calco-alkaline granites, sometimes hornblende. In some places the rock outcrops show strong chemical alteration in the uppermost levels, developing porous-type aquifers near the surface, but with fractured-type characteristics towards the depth. They are strongly fractured, following preferential directions NNE-SSW, NNW-SSE, and N-S and E-W, which form the base of the hydrographic network. The morphology is rugged and forms a landscape of valleys and elevations that allow rapid surface water runoff to the lower areas. Precipitation is estimated to be between 400-500 mm/year in the western part of the study area, but at the NNE, E, and SSE extremes, it can reach 1000 mm/year, being concentrated in four to five months of the year. These natural conditions, aggravated by changes in global and regional precipitation models, promote the shortage of water needed for consumption by the populations. The hydrogeochemical characterization of the groundwater was based on the physical-chemical analysis of samples collected in 27 boreholes for human consumption. The analyses were performed at the Laboratory of Analysis of IST-Lisbon (Portugal) and the software Quali Graf 1.17, IBM SPSS Statistics 26, and PHREEQC were used for their interpretation. The groundwater presents a wide range of mineralization, with electrical conductivity ranging from 68 $\mu\text{S}/\text{cm}$ to 1400 $\mu\text{S}/\text{cm}$, from slightly acid to basic pH between 5.93 and 7.72, and alkalinity between 3 and 590 mg/L of CaCO_3 . The results highlight the predominance of mixed bicarbonate facies (Na-Ca, 38%), sodium bicarbonate (24%), and, in less representation, calcium bicarbonate (12%). Although the chloride ion is in concentrations ranging from 4 to 229 mg/L and sulfate between 0.8 and 75.0 mg/L. Some waters show the presence of nitrate ions (reaching up to 187 mg/L of NO_3^-), four of which are above the admissible value of 50 mg/L for human consumption (WHO, 2003). A positive correlation between the concentration of this species and total mineralization is observed, pointing to strong anthropic contamination. The dissolved silica concentration varies between 8.4 and 92.0 mg/L SiO_2 , indicating the dissolution of aluminosilicates and silicates from the crystalline rocks. The hydrochemical composition of the groundwater directly reflects the water-rock interaction processes with granitic rocks and recent covering sediments, under tropical environments, sometimes masked by the impacts of human activities.

Keywords: Hydrochemistry, Hard-rock aquifers, Nitrates, Water-rock interaction, Drinking water

Characterization of the Primary Kalahari Aquifers Using Hydrogeochemistry and Isotope Techniques to Develop a Groundwater Monitoring Network, Kavango East and West Regions, Namibia

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Abstract

The use of groundwater in the Kavango East and Kavango West Regions is becoming increasingly important for both domestic supply and irrigation; whilst aquifer characterization is in shortfall. This study aimed at characterising the primary-porosity aquifers of the Kalahari Group in terms of hydrogeochemistry and isotope hydrology, as well as to develop a groundwater monitoring network. The Kalahari Group aquifers constitute the most important aquifers utilized for bulk water supply in the two regions. A total of 97 surface water and groundwater samples collected in 2 years (2019 and 2020) have been analysed for hydrogeochemistry, stable isotopes, and tritium. All samples examined for physicochemical parameters were analysed according to standard methods. The results illustrated that groundwater was slightly acidic to slightly alkaline with an average pH of 7.6 placing it in the neutral realm. Total hardness observed in the majority of analyses places groundwater in the hard to very hard category. The study found that the major hydrochemical facies for the Primary Kalahari Aquifers are predominantly Ca-Mg-HCO₃ water type > Na-HCO₃ > Ca-Na-HCO₃ > Na-SO₄-Cl > Na-Cl. The aquifers are characterised primarily by water-rock interactions that indicate the chemical alteration of the rock-forming minerals influencing the aquifers through dissolution and ion exchange processes. The cations and anions in the aquifer are principally sourced from rock-weathering rather than evaporation, crystallization, and precipitation mechanisms. The groundwater quality is suitable for human consumption without any treatment, for irrigation and livestock watering according to the World Health Organization guidelines and the Drinking Water Guidelines of the Department of Water Affairs. Groundwater in a few sampling sites, particularly in the north-central Kavango West Region were unsuitable for domestic use and irrigation purposes. $\delta^{18}\text{O}$ and $\delta^2\text{H}$ become progressively depleted in groundwater from the north-east KE to south-west KW. Stable isotopes indicate recharge to the aquifer from meteoric waters. Tritium results suggest that there is infiltration of current precipitation recharging the aquifer. A groundwater quality and quantity monitoring network was designed, outlining clearly the objectives and locations for monitoring to ensure sustainable water resources management.

Keywords: Groundwater quality, Monitoring network, Kalahari aquifer, Kavango East Region, Kavango West Region, Isotope hydrology

Assessment of groundwater potentials and aquifer protective capacity of Abubakar Tatari Ali Polytechnic, Bauchi, Northeast Nigeria, using Dar-Zarrouk parameters

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Abstract

Delineating the aquifer lithologic boundaries and understanding the aquifer protective capacity through the Dar-Zarrouk parameters are necessary to exploit groundwater potentials successfully. The study assessed the Abubakar Tatari Ali Polytechnic's groundwater potential in Bauchi, Northeast Nigeria. With a maximum electrode spacing of 100 m, about fifty-seven (57) Vertical Electrical Sounding (VES) were performed utilizing Schlumberger Array. The IPI2win and Interpex software was used to process the data after it was carried out with the ABEM SAS 4000 Terrameter. Dar Zarrouk characteristics, including longitudinal unit conductance (S), transverse unit resistance (T), coefficient of anisotropy (λ), the formation's resistivity, reflection coefficient (RC), and resistivity contrast (FC), were applied to the processed data. The results show between five and six geologic layers, with aquifers depth of between 20 and 80 meters, with resistivity range from 364.55 to 567.66 Ohm meters. The Dar Zarrouk parameters range from 0.032 to 2.800 Ohm meters for the transverse resistance, 94.500 to 3,456 Ohm meters for the longitudinal unit conductance, and 2.390 to 3.01 for the coefficient of anisotropy. Other parameter values include RC ranging from 0.64 to 0.99 and FC from 10.78 to 81.59, and all evaluations show the area to have good groundwater potential.

Keywords: Schlumberger array, Dar-Zarrouk parameters, Aquifer protective capacity, Groundwater

Assessment of total dissolved solids at the sources and troughs in Etosha National Park, Etosha Heights, and Ongava Private Game Reserve, Namibia

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Abstract

Natural surface water, critical for animals and humans, is scarce in semi-arid and arid climates. In this context it has become imperative to regularly monitor water quality. Water pollution is an acute environmental issue which affects the potability of water sources. Water quality monitoring assesses the existing levels of pollutants, their identification, estimation of potential impacts and prediction of future conditions so as to implement appropriate remedial measures. Data were collected from Etosha National Park, Etosha Heights and Ongava Game Reserve during the beginning of the 2020 rainy season (November – December) and towards the end of the rainy season 2022 (April - May) to allow for spatial and temp comparisons. Measurements were done *in situ* predominantly on boreholes and troughs frequented by animals. Total Dissolved Solids (TDS) were derived from the Electrical conductivity (EC), which was measured *in situ* using a Hach field portable instrument (HQ 14d conductivity meter). 144 and 123 samples were collected during the dry and wet seasons, respectively. Spatial analysis was done in ARGIS 10.8 and interpolated using the Inverse Distance Weighting (IDW) method. The results show that the average TDS levels for the wet and dry season were 1665mg/L and 1488mg/L, respectively, showing that TDS was higher in the wet season. GIS-based Inverse Distance Weighting interpolation was used to create maps depicting areas with high TDS levels during both dry and wet seasons. Identification of boreholes with TDS levels exceeding the acceptable limit in Etosha National Park and Etosha Heights highlights the need for conservation efforts in these areas. Moreover, it is necessary to consider other contaminants besides TDS, such as dust, rust bacteria, cysts and sand. To conserve water resources effectively, future studies should consider to analyse additional parameters. It is essential to monitor water quality and consider the impacts of seasonal variations on groundwater to ensure sustainable access to clean water for wildlife use.

Keywords: Total Dissolved Solids (TDS), Electrical Conductivity (EC), Inverse Distance Weighting (IDW), Wet season, Dry season, Namibia

Trend Analysis of Water Levels of the Namibian Groundwater Monitoring Network for the Period 2008-2022

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Abstract

The Geohydrology division at the Ministry of Agriculture, Water and Forestry, is mandated to assess and manage the groundwater resources of Namibia. The assessment and management of an aquifer system involves the establishment of a network to monitor and evaluate groundwater level dynamics. The Water Resources Management Act, Act No 11 of 2013, requires the establishment of a reliable groundwater resources observation system in order to provide and disseminate sound information. For efficient and effective assessment and management of groundwater resources, the Geohydrology Division has identified a total of 73 master stations out of 630 national monitoring boreholes. These master stations are representative of monitoring boreholes in groundwater potential bodies, country wide. Collection and analysis of water level data is vital in conducting hydrogeologic assessments and quantifying national water resources to aid planning and decision making. In addition, the evaluation of water levels assists in the understanding of groundwater flow and dynamics for predictive water-use scenarios in support of water management policies and decisions. Water level trends in 73 Groundwater Monitoring Master stations for the period 2008 – 2022, were collected in order to assess the fluctuation of water levels and the potential causes thereof. A hydrograph was drawn for each groundwater potential body comprising of water level trends from master stations within that groundwater potential body. The analysis and interpretation of these hydrographs shows a general decline in water levels over the observed timeframe with less reactive responses of water levels during the rainy seasons. A major decline in groundwater levels observed during the 2008-2009 drought period preceded a significant increase in groundwater levels which occurred in 2010-2011 following high rainfall which led to a recharge response in most aquifers. Reduced rainfall over the last 7 years significantly contribute to the general decline in water level trends because groundwater abstraction increases, and recharge is reduced due to longer drought periods.

Keywords: Drought, Water Level, Trend Analysis, Groundwater Monitoring, Namibia

Opportunities and implications for utilisation of a newly discovered aquifer underlying the Windhoek northern industrial area

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Abstract

Despite the negative impacts of climate variability on resources, groundwater is still under-utilised in Southern Africa. While a lack of groundwater resources is often blamed for not developing water supply, evidence indicates that limited understanding of aquifers to support groundwater development is the main constraint. Due to financial constraints resulting in water supply not keeping up with increasing demand and prolonged droughts due to climate change, the Central Area of Namibia (CAN) experiences frequent water scarcity. The area is supplied via a network of surface water dams, strategic aquifers, portable water reuse, pipelines, water treatment facilities and reservoirs. Bulk water supply to CAN is the responsibility of the Namibia Water Corporation Ltd and the City of Windhoek all under the custodian of the Ministry of Agriculture, Water and Land Reform (MAWLR). Windhoek encompasses the biggest industrial water users traditionally supplied via structured reticulation. However, increased water scarcity has seen strict water demand management measures imposed on industrial users. One of the measures in place is reduction of volumes supplied to industry; this affects productivity. In 2017, after a 20% water saving target was implemented, SLR (Namibia) was the lead consultant providing technical advice and overseeing the execution of groundwater supply development through scientific methods whilst following national standards in the Windhoek Basin. Based on this work, this study showcases how groundwater supply from the newly discovered and so-called Windhoek North Aquifer was conducted successfully; remains a relevant option during times of water scarcity. Further, the study identifies risks to groundwater resources (quality and quantity) and opportunities for an industry driven water stewardship initiative, looking beyond establishing infrastructure, towards resource management through scenario-oriented sustainability as well as vulnerability assessments. Development of local groundwater to supplement traditional water supply options for industrial users increased in the Windhoek Basin. It significantly elevated the role of local groundwater in areas where information on aquifers was limited. 2023 has seen a water saving target of 10% being implemented, impact on individual users will vary and so will implications for users outside the CAN. To that effect, continued development of groundwater resources should focus interventions and cooperation between regulators and industry. To succeed, increasing investment into plans that support groundwater resource development through research, application of scientific methods, adherence to national guidelines and standards, addressing resource governance, as well as establishing resource protection will be key.

Keywords: Aquifer, Industry, Groundwater use, Water security, Windhoek Basin, Namibia

A review on groundwater recharge in Namibia

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Abstract

The scarcity of water or absence of permanent or reliable surface water in semi-arid environments like Namibia and the reliance on groundwater for water supply requires groundwater recharge information for water resources management. This study employed secondary data sources to provide a review of groundwater recharge in Namibia. A total of 40 groundwater recharge studies in Namibia were compiled, particularly focusing on those that have estimated recharge values and excluding those that dealt with groundwater recharge mechanisms only. A spatial distribution of groundwater recharge studies in Namibia has shown that most of the studies concentrate on porous aquifers, especially on Kalahari beds. Most of the studies undertaken on porous aquifers mainly covered Cuvelai-Etosha Basin, Kalahari Catchment, western catchments and Stampriet Basin. Studies in the Cuvelai-Etosha Basin indicated that groundwater is recharged through preferential flow paths. Groundwater recharge studies in the Kalahari Catchment of northeastern Namibia have shown that the main recharge mechanism in the area is direct recharge from precipitation. Few recharge studies that have been carried out on alluvial aquifers in the western catchments of Namibia demonstrated that they are usually recharged through infiltration during flash floods. Groundwater recharge in Stampriet Basin within Kalahari was investigated, including the Auob and Nossob aquifers. Auob aquifer is indirectly recharged through the Kalahari aquifer, where no impermeable layers exist. For the Nossob aquifer, water is regarded as fossil water since there is no direct recharge from precipitation. Despite fractured, fissured or karstified aquifers being classified as moderate to high groundwater potential rock bodies in Namibia, only a few studies have been done on these aquifers. The common groundwater recharge estimation method that was used in most studies is the Chloride Mass Balance with the highest recharge rates. Estimation of groundwater recharge rates using groundwater models is also common in Namibia. The studies generally indicated that 5% to 14% of the precipitation becomes groundwater recharge in areas with mean annual precipitation between 150 to 600 mm/a. Although a good number of groundwater recharge studies have been carried out in Namibia, only very few studies have incorporated the effect of vegetation on groundwater recharge. This review has highlighted a gap in information on the scale and spatial distribution of groundwater recharge across Namibia. Hence, there is a need to carry out more groundwater recharge studies in Namibia, especially in fractured, fissured or karstified aquifers that are currently understudied. It is recommended that future groundwater recharge studies incorporate the influence of vegetation, especially in bush-encroached areas, as it is one of the key factors influencing groundwater recharge.

Keywords: Groundwater recharge, aquifer, Namibia

ST06: GEOLOGY IN THE SERVICE OF SOCIETY: APPLIED GEOSCIENCES IN AFRICA**ST06_S01: Engineering geology, geotechnics and geohazards****Sources and pollution assessment of trace elements in soils of the central, Dodoma region, East Africa: Implication for public health monitoring****Mahamuda Abu^{a*}, John Desderius Kalimenze^b, Benatus Norbert Mvile^c**

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Abstract

The study assesses the pollution levels and sources in soils of As, Pb, Cu, Zn, Cd, Mn, Cr, Co, Ni and Se in the central Dodoma region of Tanzania from estimations of CF, EF, Igeo, PLI and RI together with PCA, FA and HCA multivariate techniques. Generally, the capital city's regional area is polluted with these heavy metals with PLI > 1 and EFs > 40. The Igeo also shows concerning concentration levels of As with 60.77% of the study area being moderate to extremely polluted by As and As, Cd and Pb are the heavy metals that require immediate monitoring within the Dodoma region. The multivariate analysis supports a dominant geogenic source of these heavy metals with the mafic ore bearing lithology controlling these elemental concentrations in soils via chemical weathering of pyrites, arsenopyrite and chalcopyrite as the most probable geological process releasing these heavy metals into the soil. The fast-growing industrialization of the region with its associated commercial agriculture activities, also contributes although it may be small for now, to the heavy metals' contents in soils within the area. With the pace of industrialization coupled with the desire of the country to create jobs through small-scale activities, it is appropriate and timely to assess the levels of As, Cd and Pb in surface and groundwater as well as in some cereals like maize or millet which are the mainstay of the people and should be centred at the northern and central parts of the region. This is necessary for effective public health monitoring and to enhance environmental management practices in the region.

Keywords: Heavy elements, Pollution level, Public health, Dodoma region, Tanzania

Production of eco-cement through clinker substitution by mixing calcined clay and limestone, Songololo (DR Congo)

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Abstract

Concrete is an artificial material produced from the mixture of cement, aggregates and water in well-required proportions to which some chemical additives can be added. Cement is cheap, available and easy to use but its production is responsible for high CO₂ emissions (5 to 8% of global anthropogenic emissions, and around 35% of industrial emissions). On average 0.8 to 0.9 ton of CO₂ is emitted to produce one ton of Ordinary Portland Cement (OPC). To reduce these environmental impacts, the substitution of clinker with the calcined clay-limestone mixture, which is abundant in rocks of Neoproterozoic West-Congolian group and widely spread in the Songololo region (DR Congo) is adopted. The eco-cement is called 'Limestone Calcined Clay Cement' (LC3). A partial substitution of the clinker carried out, mechanical/physical tests performed and then the performance of the mortar monitored over a period of 90 days. The WBCSD/WRI 'Greenhouse Gas Protocol' methodology allowed the calculation of CO₂ emissions into the atmosphere. Three types of clay are available in the Songololo Region. The kaolinite is the principal clay mineral and its content vary from 27 to 34%. The sum of kaolinite and amorphous phase which enable clay to react with cement material ranges from 57 to 60%. The SiO₂ content ranges from 33 to 76%, the Alumina content from 12 to 20% so that the ratio Al₂O₃/SiO₂ is on the higher side i.e., 0.17 – 0.53. The calcination window is between 750° and 850°C and the best clay which can act as Supplementary Cementitious Material (SCM) was identified. The partial substitution of clinker by calcined clay – limestone mixture (30 – 35%) has reduced CO₂ emissions by up to 25% from 0.824 tons of CO₂ for one ton of Ordinary Portland Cement (OPC) to 0.640 tons of CO₂ for one ton of 'Limestone Calcined Clay Cement' (LC3). The compressive strengths (R_c) of the Limestone Calcined Clay Cement (LC3) varies from 8.91 to 57.6 MPa from Day 1 to Day 90, and are within the standard, greatly exceed the reference 'Cement 32.5' and are almost similar to 'Cement 42.5' marketed in local markets. In view of the results, the new LC3 can be considered for industrial trials.

Keywords: Eco-cement, Calcined clay, Limestone; Cement; DR Congo

From awareness to ownership: Increasing resilience to geohydrologic hazards in South Africa

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Abstract

Africa's adverse socio-economic atmosphere, characterised by political unrests, poverty and uneven distribution of resources continues to predispose communities (especially the marginalized) to even greater vulnerability to geohydrologic hazards. It is unfortunately within these disadvantaged communities that the smaller, but more frequent hazards occur, and where the costs in terms of loss of lives and property are borne painfully. The ability of at-risk communities to absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner is indispensable for sustainable development. Nonetheless, translation of these inferred benefits into practice remains a major challenge. Failure to develop these intrinsic capabilities may be attributed in part to lack of ownership demonstrated by vulnerable communities or individuals during various phases of the disaster management cycle. In 2022, South Africa experienced the deadliest landslide and flood disaster which resulted in over 400 deaths, destruction of over 12 000 houses and an estimated 40 000 displaced persons in KwaZulu-Natal. Against this backdrop, this study investigated the level disaster risk awareness and readiness to take ownership by landslide-prone communities inhabiting the slopes of the Soutpansberg Mountain (Limpopo Province). The study employed the Modified Protective Motivation Theory (MPMT) to interrogate the readiness of the vulnerable communities in initiating and/or adopting risk reduction measures. The efficacy of threat and coping appraisals as suggested by the Protective Motivation Theory (PMT) was explored through integration of the different elements of ownership appraisal namely, pre-contemplation, contemplation, preparation, action, maintenance, and termination. Through an Interpretative Phenomenological Analysis (IPA), findings indicate that the target community lacks the ability to prepare, and to initiate risk reduction measures despite the awareness of potential risks (80%). Findings also suggest that through capacity building, communities can develop intrinsic capabilities to identify, assess and minimise their own risks. The implications of the MPMT on building resilience to geohydrologic hazards in Africa are discussed. This study further recommends the MPMT as plausible framework for providing impetus to community-based disaster risk management processes in Africa and beyond.

Keywords: Capacity building, Protection Motivation Theory, Resilience, Threat appraisal

Dust characterization around the Uis Tin workings, Namibia (Poster)

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Abstract

Mining of tin-bearing pegmatites near Uis, Namibia, has been ongoing since 1911. The historic operations, however, closed due to a price drop in tin in 1990. The mine remained closed until 2015 when AfriTin Mining decided to redevelop the historic Uis hard-rock tin mine. At the time of this study (2017) AfriTin (AfriTin Mining Ltd rebranded to Andrada Mining Ltd in 2023) was not actively mining. The objective of this project was to investigate the chemical composition of the tin mine tailings and to assess the morphology, chemical characteristics and dispersion of the resulting dust fallout. Dust has the potential to contaminate the surrounding area and pose health risks to the residents of Uis.

Sixty-one surface and tailings samples were collected for analysis. Initial analyses were performed using a handheld XRF device. Additionally, six samples underwent a dry dust separating process to isolate PM10 and PM2.5 components. These PM samples were characterized using SEM, XRD, plasmid scission assay, and ICP-MS. Metal concentrations in the surface samples varied significantly from the source to the surrounding areas. The PM samples were found to contain dominant minerals such as illite, quartz, albite and clinocllore, with varying amounts of calcite and hematite. SEM images showed particulate matter of diverse sizes, mostly sub-angular in shape. Predominant particle size in the fine-grained clay samples was below 5µm. The plasmid scission assay revealed a dose-dependent relationship between sample concentration and DNA damage, with an average damage of 42%. The observed DNA damage in the PM samples may not be solely due to geochemical factors, as the enrichment of metals in the ICP-MS data was low. However, a concentration response was observed, suggesting that higher sample concentrations increased the interaction between plasmid DNA and PM samples. The SiO₂ content in the PM samples, particularly in illite and quartz, may also contribute to the DNA damage. Quartz, consisting of crystalline SiO₂, and illite, a platy clay mineral with a negatively charged upper surface, could react with biological components and cause damage to plasmid DNA.

In conclusion, this study emphasizes the importance of assessing the chemical composition and health implications of tin mine tailings in the Uis area of Namibia. Dust fallout from mining activities has the potential to contaminate the environment and pose health risks to residents. Further research is needed to better understand the mechanisms involved in the observed DNA damage and to develop appropriate mitigation measures for the protection of the local community.

Keywords: Tin mining, Tailings, Dust fallout, Chemical composition of dust, Health implications, Namibia

Geological hazard investigation by the Engineering and Environmental Geology Division, Geological Survey of Namibia

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Abstract

Geo-hazards are adverse geologic conditions capable of causing widespread damage or loss of property and life. They are associated with either long-term or short-term geological processes. Common geological hazards in Namibia include ground instability and failure, erosion associated with seasonal flooding, and seismic activities. The Geological Survey of Namibia, through its Division of Engineering and Environmental Geology, investigates potential geological hazards and their risks to the surrounding natural and built environment; the latter includes buildings, roads, bridges and other installations and structures in urban and rural areas. These investigations involve field observation, data collection, data analysis and compilation of geo-hazard maps, which are useful in hazard risk mitigation. This information is crucial in providing guidance to stakeholders such as local authorities, affected communities, proposed development projects and other forms of land use. Our report focuses on a few case studies of geo-hazards investigated by the Division of Engineering and Environmental Geology. They include a) impact of faults in urban settings, focusing on the Pahl Fault, which traverses the Windhoek city centre and causes structural concerns to a number of residential and commercial buildings, and b) erosional gullies, with an emphasis on gully features that were observed in Rundu, Kavango Region, after the 2021 rainy season. The presentation will highlight the effect of these features on the town infrastructure (built and underground services), on the characterisation of the phenomenon as well as on recommendations to the town councils. Lastly, the investigation will present cases of localised ground crack occurrences in some of the Kalahari-regions of Namibia, i. e. Ohangwena, Omusati and Omaheke. These features predominantly manifest themselves during the rainy season, causing concern among crop and livestock farmers in the area. Investigations carried out by the Geological Survey of Namibia help to establish the origin of these features and the degree of risk they pose to the communities concerned. Geoscientific input like this has a direct impact on the lives of people and helps to lessen anxiety by providing context for geological occurrences and associated potential threats in the affected areas.

Keywords: Geo-hazards, Ground instability, Geological fault, Erosional gullies, Natural and built environment

Risk Assessment of Abandoned Mines in Namibia

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Abstract

The risk assessment of abandoned mines in Namibia is vital for the identification of potential hazards they pose to human health and the environment. This article provides an overview of the risk assessment process conducted by the Geological Survey of Namibia, focusing on the progress achieved thus far. The risk assessment process involves extensive fieldwork, where various components at each mine site are identified and evaluated for potential risks. These features encompass a wide range of elements, such as open pits, shafts, tailings, waste rocks, unstable structures, toxic substances and other potential sources of danger. The assessment aims to systematically identify, analyse and evaluate the risks associated with each component. Eventually each site is classified as a Mining Environmental Liability (MEL) or a non-Mining Environmental Liability. So far, out of the 157 abandoned mines in Namibia, 54% have been assessed using a field-based approach, and out of the assessed sites, 17 have been classified as MELs.

By conducting risk assessments of abandoned mines, the Division of Engineering and Environmental Geology seeks to identify and address potential safety and contamination hazards to safeguard human health and protect the environment. The findings of these assessments will contribute to the Environmental Baseline For Comprehensive Appraisal Of Risk Assessment plans, and facilitate remediation and/or reclamation efforts. Continuous risk assessment of the remaining abandoned mine sites in Namibia is important. This presentation emphasizes the significance of understanding and managing the risks associated with abandoned mines, ultimately contributing to the overall safety and well-being of local communities and ecosystems.

Keywords: Abandoned mines, Risk assessment, Mining environmental liability (MEL)

Seismicity and seismic hazard assessment in West Africa

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Abstract

No in-depth seismic hazard (SH) study for West Africa has ever been conducted, as the regional earthquake catalogues are incomplete. Such lack of a comprehensive SH study has negatively affected planning and development of critical infrastructure and disaster risk management in West Africa. This study aims to bridge the knowledge gap by applying modern techniques to updating the existing catalogues and assessing the seismic hazards for the region. We updated the current catalogue for West Africa from the International Seismological Centre, publications and data from seismic stations in West Africa. Various studies considered the seismotectonic setting of West Africa as stable continental crust and a region of shallow crustal seismicity, respectively. We investigated both schools of thought and compared results. For each scenario, three different ground-motion models (GMMs) were combined to produce hazard maps using logic tree formalism with equal weights. West Africa was divided into five source zones for computation of earthquake recurrence parameters and for the entire West African region. Computed Gutenberg–Richter b-value, activity rates (λ), and regional maximum possible magnitudes (m_{\max}) for the zones ranged from 0.84 to 1.0, 0.3–2.1, and 5.2–7.0, respectively. Calculated b-values, λ , m_{\max} for the region were 0.77, 4.1 and 7.2. The estimated b-value (0.77) falls within the generally accepted range for tectonic seismicity. SH predicted by GMMs for stable continental areas was higher than that predicted for shallow crustal seismicity. Therefore, our results confirmed that West Africa is characterized by stable continental crust. The highest hazard levels were observed in parts of Ghana, Togo and Cameroon, ranging from 0.02 g to 0.03 g.

Keywords: Seismicity, West Africa, Probabilistic seismic hazard assessment, Earthquake recurrence parameters, Peak ground acceleration

Geotechnical Management, Implementation and Monitoring of Southern Coastal Mines Seawalls (Poster)

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Abstract

At Southern Coastal Mines, the mining area and personnel are safeguarded by soil structures designed to stop the ocean from entering the excavated pit where resources are being mined. These structures are referred to as seawalls. Through qualitative experience and analysis, we know that the seawalls are susceptible to two main failure modes: failure in slope stability and failure due to wave overtopping. Building the seawall happens concurrently with mining pit excavations as the material being excavated is also used to build the seawalls and accrete the beach for added protection and future mining areas. Seawalls are built once available mining paddocks are deemed safe by analysis, and vibrating wire piezometers are installed in the seawalls to monitor the pore water pressure subsurface to track the movement of the phreatic surface. Once built these seawalls are monitored and inspected daily with trigger action response plans in place, if any deviations are encountered. Coastal analyses are run quarterly to ensure the seawall can withstand a 1:10 year storm and mitigation strategies are in place in case it is deemed sub-standard. Factor of Safety (FoS) analysis using the pore pressure readings are on an automated system with trigger alarms alerting the relevant personnel when phreatic surfaces rise past the safe threshold dropping the FoS < 1. Seawall surveillance team meetings on a bi-weekly basis review the performance of the seawall. The seawalls at Southern Coastal Mines follow a single design method modelled for FoS of 1.15, which is implemented along the 20 km stretch of the mining area, with continual and close monitoring to ensure the safety of mine workers and safeguard today's mining operations, as well as future projects.

Keywords: Slope stability, Seawall, Geotechnical management, Factor of Safety (FoS), Phreatic surface

Geomorphological and geophysical analysis of the Xade Complex neotectonic fault scarp: Implications for seismic hazards in stable continental regions

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Abstract

Stable Cratonic Regions (SCR) are generally thought to be characterized by low magnitude seismic events. One such SCR is the Kalahari Craton, which covers the majority of Botswana. However, improved instrumental coverage and the 2017 Mw 6.5 Moiyabana earthquake suggest that there is a significant activity within the craton. The factors controlling the localisation of relatively large earthquakes in these settings remain an area of active debate. Geomorphological studies, which can better capture the long-term distribution of faulting, can help to identify the features of such earthquakes and the factors controlling their distribution. In this study, we describe a newly identified apparent fault scarp, the Xade Scarp. We use a combination of the TanDEM-X Digital Elevation Model (DEM) and aeromagnetic data to understand the geometry of the Xade Fault and its relationship with the underlying pre-existing basement structures. The Xade Scarp is an approximately 62 km long curvilinear fault with an average vertical displacement of ~ 2 m with the largest slip values generally found close to the centre of the fault. According to earthquake scaling relationships, a scarp this long could fail in an earthquake as large as Mw 7.2. The average slip observed is towards the lower end of what is expected for a fault of this length suggesting that this may represent a single event. The scarp closely follows a prominent aeromagnetic low within the southern lobe of the Xade Complex. The scarp ends shortly after this low is interrupted by a fault which crosscuts the complex. The Xade Complex is a 1,109 Ma mafic magmatic complex which is buried beneath several hundred metres of the sediments of the Kalahari Group and Karoo Supergroup. The aeromagnetic low that the scarp follows has been associated with layering within the complex. These results support the importance of pre-existing rheological anisotropy in controlling moderate-large magnitude seismicity in SCR regions. The association with internal structure within an igneous complex is however unusual. Faulting in this region generally follows structures within mobile belts, and in general intrusions are often associated with less anisotropy and reduced fault slip. It has been suggested that the Xade Complex may have economic potential, and one of the worrying aspects of recent studies exploring this and similar SCR neotectonic fault scarps is that they suggest faulting may be concentrated in areas, such as cratonic margins, where various forms of mineral reserves are also concentrated.

Keywords: Stable Cratonic Regions, Seismic hazards, Xade Complex, Pre-existing basement structures, Fault scarp

Assessment of the basalt fiber composite materials potential in South Africa

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Abstract

Most of the volcanic igneous rocks found in South Africa covers the Precambrian through the Early Cretaceous epoch. Some of the mafic rocks have a variety of chemical compositions, ranging from basic (tholeiitic) to acidic (alkali). Several of those volcanic rocks can produce basalt fibers. As part of the Paris Climate accord, which was signed in 2016 and focuses on lowering carbon footprints and increasing environmental awareness worldwide, the usage of naturally existing basalt materials is expanding and evolving at a rapid rate. Since they are more affordable, with exceptional toughness, and can be utilized as a substitute for carbon and glass fiber in countries such as the Russian federation. In order to find possible sources of basalt materials suited for basalt fibers in a developing nation like South Africa, regional geochemistry was conducted and used for analyses in this study. The mafic volcanics such as dolerites, dacites, basaltic gabbros, and amphibolites are some of the rocks, which were included in the collected geochemistry data set. Modeling was conducted to zone into areas that fall within the specific geochemical compositions of basalt fibers ranges. Preliminary results of this study suggest that analyzed samples from the Eastern Cape, Northern Cape, KwaZulu-Natal, and Free State have a higher potential for basalt fiber development. Further technical specialized work will be conducted in the laboratory in order to determine the quality of South Africa basalt rock and specific fibers applications based on physical properties and characteristics such as melting temperature and viscosity.

Keywords: Viscosity, Basalt fibers, Geochemistry, Climate change, Composite materials

Review of the seismicity, seismotectonic and earthquake characterization of the northwest-southeast trending fault zones in the East African Region

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Abstract

The East African region is traversed by the East African Rift System (EARS), a 3000 km long north-south trending major active tectonic feature of Cenozoic age characterized by continental rifting. The East African Rift System extends from the Afar triple junction, between the horn of Africa and the Middle East, to western Mozambique including Madagascar. EARS is a zone of active deformation characterized by volcanism and faulting which have been an ongoing phenomenon since the Eocene (~45 Ma) and a moderate level of seismicity. In spite of the moderate level of seismicity, a number of strong earthquakes have been reported in recent and historical times. These earthquakes have caused loss of life due to the ever-increasing population that exacerbate earthquake risk and a significant level of damage to infrastructure attributed to the high vulnerability of the local buildings and other structures. The East African Rift System is traversed by northwest-southeast trending Muglad-Anza-Lamu fault zone (MALFZ) and Aswa-Nyangia fault zone (ANFZ). Unlike the EARS, these NW-SE trending fault zones are characterized by left lateral (sinistral) strike slip movements and extend from South Sudan through central and southern Kenya to Lamu embayment (basin) in the southeast Kenya, cutting across the eastern branch of the East African Rift System. The ANFZ passes through the northernmost extremity of the western branch of the East African Rift System in the Lake Albert and Albert (West) Nile in the north and northeastern Uganda. A review of the seismicity, seismotectonic and earthquake characteristics in the East Africa region is herein presented. The results of this review show that, where else the East African Rift System is characterized by shallow (< 40 km), mainly normal fault, small magnitude and volcano-tectonic earthquakes, moderate to large magnitude earthquakes characterize the Muglad-Anza-Lamu and the Aswa Nyangia fault zones. These fault zones have been the epicenters of major earthquakes in the eastern African region. These earthquakes include the M_w 7.2 South Sudan earthquake of May 20, 1990 and aftershocks of M_w 6.5 and 7.1 on 24 May 1990, the 1937 M_s 6.2 earthquake north of Lake Turkana close to the Kenya-Ethiopian border, the January 6, 1928 M_s 6.9 and aftershock M_s 6.0 of January 10, 1928 in the central Kenya rift valley, the 1924 M_s 5.6 Suguta valley earthquake, the 1913 M_s 6.0 Turkana earthquake, and the 1912 M_s 6.2 Lake Albert earthquake. Recent earthquakes include the January 22, 2012 mb 5.2, March 20, 2014 mb 5.3 and May 3, 2020 mb 4.8 in Turkana region; July 17, 2015 mb 3.9, November 25, 2015 mb 4.0 and May 3, 2020 mb 3.7 in South Sudan and April 18, 2020 mb 4.1 in central Kenya. These historical as well as recent earthquakes demonstrate that the NW-SE trending fault zones are seismically active, and characterized by moderate to large earthquakes which exhibit a combination of normal and strike slip faulting mechanism.

Keywords: Seismicity, Seismotectonics, Muglad-Anza-Lamu fault zone, Aswa-Nyangia fault zone, East Africa

Dust and Radiation Assessment for the Uranium Mines in the Erongo Region, Namibia

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Abstract

The Geological Survey of Namibia through the Division of Engineering and Environmental Geology conducted an air quality and radiation assessment for the uranium mines in the Erongo Region, central Namibia. The main aim of the exercise, which is part of the division's mandate to monitor the impacts of mining on the environment, was to evaluate the contribution of the mines to the background dust concentration in the region, especially at the major towns or receptors. The main pollutants of concern are particulate matter (PM; dust) and radon, with the radionuclide content within the dust being important for the radiation dose assessment. The impact of dust on human health is largely dependent on particle characteristics, particularly size and chemical composition, as well as duration, frequency and magnitude of exposure. To achieve the objectives, an ambient Air Quality Monitoring network was established to measure fine particulate matter and radon, together with meteorological parameters. Monitoring locations were chosen based on population density in the region. Dispersion modelling was conducted using the U.S. EPA's CALMET/CALPUFF dispersion modelling suite to identify the main contributing sources to the measured PM concentrations. The radiation-related public exposure doses due to the inhalation of radon, radon progeny and radioactive dust were quantified using real-time empirical results for ambient atmospheric radon concentrations, and radionuclide concentrations from selected PM₁₀ samples. The modelling results, simulated at the various air quality sensitive receptors, indicated mining and quarrying operations to be the main contributors to the central receptors at Arandis, Palmenhorst and Jakkalswater. The radiation exposure doses associated with the inhalation of atmospheric dust and radon were found to be well-below the world-wide average inhalation doses provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Based on the findings of the assessment, it is recommended to undertake an improved emissions inventory and re-run the dispersion model with the updated emissions inventory to get a better understanding of the significance of local sources.

Keywords: Air Quality, Particulate Matter (PM), Radon, Exposure dose, Dispersion modelling

The characteristics of m_b 4.9 Turkana rift mainshock-aftershocks sequence, East Africa

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Abstract

The volcanically and seismically active Main Ethiopian and East African (Kenya) rifts are linked in a complex zone within the Turkana Depression bounded by the Ethiopian Plateau to the north and East African Plateau to the south. Subsurface imaging beneath Lake Turkana and surrounding sub-parallel basins reveal multiple half-graben basins bounded by N-S striking normal faults. Lake Turkana includes at least three Quaternary volcanoes within the central rift basins. The objectives of this study are to use the mainshock-aftershocks spatial distribution and focal mechanisms of the mainshock and large aftershocks to determine the main rupture fault plane and surrounding minor rupture planes, develop an improved statistical model for assessing earthquake hazards in the Kerio Basin and to compare the M_b 4.9 Turkana and M_w 5.2 Karonga mainshock-aftershocks sequences. 32 stations of the Turkana Rift Array to Investigate Lithospheric Structure (TRAILS) project and a permanent GEOFON station (LODK) recorded on May 3, 2020, the M_b 4.9 event and its aftershocks. The origin times, locations, magnitudes and fault plane solutions of the earthquakes are determined by the SEISAN programme. The absolute locations of the events are improved using the double difference method. Four maximum likelihood estimates (MLEs) parameter values (c , p & K_0) describing Omori's law of decay rate are determined by the AFTPOI programme, while five parameter values (c , p , K_0 & α) describing the statistical model MLEs are determined by the ETAS programme; both programmes are written in Fortran language. A cut-off magnitude, M_c , of 1.62 and b -value = 1.33 ± 0.24 for the M_b 4.9 Turkana mainshock-aftershocks sequence are determined. The mainshock is located on the borderline of Lake Turkana, while most of the aftershocks occurred onshore triggered on an NNW-SSE oriented main rupture plane. There are no notable foreshocks, hence no background seismicity is used in the analysis. The main rupture plane is a normal fault with a oblique strike-slip component. Two fault plane solutions for the aftershocks are determined; one coincides with the main rupture plane geometry while the other is an oblique strike-slip solution. The ETAS model parameter values are $c=0.0007$, $p=0.7071$, $K(0)=1.5361$ and $\alpha=1.217$. The spatial distribution of the M_w 5.2 Karonga sequence exhibits an intersection of faults caused by both seismic and aseismic slip deformation. Further investigations, such as joints measurement around the Kerio region and waveform inversion, can be undertaken to improve the fault plane solution of the main rupture plane. Additionally, fault plane solutions for other large aftershocks can be determined.

Keywords: Main Ethiopian Rift, East African Rift, Half-graben basins, Mainshock, Aftershocks, Omori's law of decay rate, Statistical model, ETAS model

The influence of anthropogenic activities on geohazards: insights from Namibian case studies

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Abstract

Geohazards are generally defined as natural events that pose risk to human lives, infrastructure and the environment. Traditionally, geohazards such as landslides, tsunamis and earthquakes are believed to be solely natural phenomena, driven by natural processes. However, the question of whether human activities are contributing to the occurrence and severity of geohazards remains a subject of debate. This study explores anthropogenic activities with the potential to trigger or exacerbate geohazard events, focusing on Namibian examples. It examines anthropogenic factors, such as the removal of vegetation cover, which destabilises slopes, compromises the integrity of the soil and increases the likelihood of landslides and erosion as found in the case of Rundu Town. The aspects of urbanization and inadequate stormwater management practices prevalent in northern Namibian urban areas are also highlighted. These practices often lead to disruption of natural drainage patterns and increased run-off, subsequently intensifying the magnitude of floods. Other aspects include excessive groundwater abstraction in the face of prolonged droughts due to climate change (as during 2020/2021 in the Omaheke and Otjozondjupa Regions, Namibia), which result in ground subsidence and other instabilities. Exploring these intricate connections between human activities and the natural environment, this study seeks to highlight the contribution of human beings and human activities to the occurrence of geohazards. It also encourages efforts to be directed towards safe development practices, minimising anthropogenic contributions, and ultimately towards safeguarding and protecting ecosystems and communities in Namibia.

Keywords: Geohazards, Natural processes, Anthropogenic, Climate, Namibia

Geotechnical Considerations for Wind Farms: A Case Study of Deep Kalahari Sands, Namibia

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Abstract

Utilization of wind energy as an alternative energy source has been growing in Southern Africa including Namibia due to global warming, environmental pollution and limited fuel resources. Turbine structures themselves are unique due to the nature of the loading they impart into the foundations and supporting soils/ rock in terms of type, magnitude and variation. Wind turbines are often subjected to strong static and dynamic loads and are generally placed too far apart to consider any relationship between ground conditions from one turbine to another. Such conditions result in increased geotechnical risks that require specially adapted geotechnical investigation that are designed to manage risks at different stages of project development. The site is overlain by approximately 30 m of poorly consolidated Kalahari Group deposits consisting of fine-grained aeolian sand, alluvium, and varying degrees of pedogenic soils. The use of geophysical methods, such as multi-channel analysis surface waves (MASW) and 2D Electrical Resistivity Tomography (ERT), in addition to traditional invasive geotechnical techniques (test pitting, rotary core borehole drilling, standard penetration test, dynamic probe super heavy testing) were undertaken to collect critical design data. This paper outlines the investigative approach undertaken and laboratory testing programmes adopted that is optimized for efficiency and risk. This paper also discusses key geotechnical parameters for wind turbine foundation design are discussed. By analyzing and interpreting the collected data, it is clear that an understanding of the geotechnical conditions is vital during the early stages of project development, which can prove advantageous for finalization of wind farm layout and preliminary foundation design.

Keywords: Geotechnical investigation, Kalahari sands, Stiffness, Foundations

ST06_S02: Agrogeology, Medical Geology**The Hidden Dangers to Health as a breach of Human Health Rights within Mining Districts: Measures to address the menace emanating from Small-Scale Mining Activities****Emmanuel Arhin^{a*} Jeff Dacosta Osei^a, Prosper M. Nude^b**^a*University of Energy and Natural Resources, School of Geosciences*^b*University of Ghana, Department of Earth Science, Legon***Corresponding author: pmnude@gmail.com***Abstract**

The small-scale mining industry (ASGM) in Ghana contributes over 40% of the country's gold production and serves as a significant source of wealth creation and livelihood for millions of families. However, current mining operations by the artisanal miners have disregarded responsible mining attitudes, leading to ecosystem pollution, and resulting in several health issues. The current data focuses on some indirect environmental health diseases emanating from the contaminated ecosystem due to human activities (e.g., mining. Agriculture). The study appraised 3344 soil samples, collected at a depth of 40 cm in a mine district in Ghana. The samples were sieved to < 2mm size fraction and analyzed for all the elements present in the samples using ICP-MS. contained elements. The concentrations of four out of the 51 multi-elements (arsenic (As), lead (Pb), copper (Cu), and zinc (Zn)), known to have an association with gold mineralization in Birimian terrain were determined. The levels of concentrations and distributions of the elements were used to predict the possible health implications geo-spatially. The results found some areas to be enriched in the potentially harmful elements which may present environmental health problems. For the safety and health of populations living in the ASGM communities, the paper advocates a periodic assessment and monitoring of the pollution status of the mine to ensure that the health and safety of lives is assured for sustainability in line with SDG 13 (ensuring sustainable consumption and production patterns).

Keywords: Small-scale mining, Wealth, Potentially harmful elements, Health risk, Ghana

Geophagy and Potential Health Risks in Pregnant Women: The Case Study of Maputo City (Mozambique)

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Abstract

Geophagy is the practice of the voluntary consumption of sediment, soil and/or clay. The practice is prevalent among pregnant women and children. This research aims to analyze and characterize geophagic materials sold in the main markets of Maputo city (Zimpeto, Xipamanine and Xiquelene) and assess the potential risks for pregnant women. Fractions < 2 mm (total material consumed) and < 63 µm were analysed to determine pH, EC, OM, chemical composition (XRF), and mineral phases present (XRD). The results revealed pH from slightly acidic to slightly alkaline, electrical conductivity between 264 - 465 µS/cm. Textural analysis revealed that sand-sized particles were most representative in all samples (57.2 - 93.02%). Mineralogical phases identified in the consumed sample were classified as quartz (> 60%) > Fe oxides/hydroxides > phyllosilicates (micas and kaolinite) > feldspars, suggesting a risk of dental enamel damage, perforation of sigmoid colon, inhibition of antibiotic absorption. The high concentrations of some PTEs was higher than the recommended daily intake for pregnant women, possibly inducing risks of spontaneous abortions and including neurological disorders for the fetus. The study suggests the need for improved geophagic materials and education about the health risks associated with pregnant women.

Keywords: Geophagy, Pregnancy, Health risk assessment, Maputo, Mozambique

Crushed nepheline syenite: an alternative fertiliser source for maize plant growth in Malawi

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Abstract

The high costs of imported chemical fertilizer and the geopolitical situation in the Ukraine has resulted in fertiliser market prices that cannot be sustained by resource-poor smallholder farmers in Africa. Due to low use of fertilisers, there is increased declining soil fertility leading to food insecurity due to inadequate domestic food production at household and community levels. This is especially the case in developing and less developed countries with little capacity to import food and chemical fertilisers. Chemical fertilizers are conventionally used to supply N, P and K, in products that are suitable for temperate conditions, but may be less effective in tropical areas where the climatic, agro-ecological, soil mineralogical and socio-economic conditions are very different. The value of chemical fertilizers is reduced through rapid dissolution and loss in deeply leached tropical soils. Weathering of silicate minerals produces clay or micaceous mineral products, and releases K unidirectionally to the exchangeable pool. There is increased confidence to support the use of these rocks more widely as sources of K, especially in poorer parts of the world. We, therefore, used plastic plant columns with maize to assess the availability of potassium (K) from nepheline syenite rocks as alternative fertilizer sources for maize production. The study used crushed nepheline syenite rocks collected from three districts in Malawi. Potassium (K) is essential for the healthy growth of plants. In tropical environments, K is the major nutrient that is most deficient compared with N and P. Four application rates (equivalent to 100, 330, 660 and 1200 mg K kg⁻¹ soil) were used for each crushed rock and a Muriate of Potash (MOP) positive control, each of which was applied to 60kg of soil in which the only source of K was the added treatment. After setting, each column was filled with a mixture of the nepheline syenite and 60 kg of soil with each application rate replicated four times. The application rates were independently randomized within each K source. After filling all the columns with the soil and necessary application rate of both the nepheline syenite and MOP, maize was sown in the columns. Growth yield and nutrient uptake of maize plants, fruit quality showed that crop growth, yield and nutrient uptake were positive for the added treatments. Nepheline syenite application at a rate of 1200 mg K kg⁻¹ soil resulted in almost equal growth yield when compared to maize of MOP treatment. In addition, the application of nepheline syenite enhanced maize resistance to pests. Therefore, this study shows that K availability for plant growth can be enhanced through application of nepheline-bearing rocks, which at the same time can enhance maize plant resistance to pests.

Keywords: Fertiliser, Maize, Silicate minerals, Nepheline syenite, Weathering, Malawi

Influence of slag particle size, pH and time of contact to mobility of harmful elements of copper slag from the Nkana smelter (black mountain) slag dump, Zambia, Copperbelt Province, Kitwe District

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Abstract

This study aims to investigate the leaching behaviour of copper and cobalt from the Nkana smelter (black mountain) dumped copper slag in different conditions. The variables and parameters affecting the leachate's copper and cobalt concentration was also identified. Research focuses on evaluating the influence of slag particle size, extraction fluid (leaching agent) pH and length of time during which slag is in contact with extraction fluid (time of contact) to release potentially harmful elements (copper and cobalt) from the Nkana smelter. Slag samples of <0.075 mm, (0.075-0.15) mm, (0.25-0.25) mm, (0.425-0.71) mm, and (0.71-1.18) mm were individually treated with adjusted distilled water with varied pH (2,3,5,7,8) in propylene bottles for one month. The toxicity characteristic leaching procedures (TCPL), synthetic precipitation leaching procedures (SPLP) and leachate extraction procedures (LEP) protocols were employed to assess the quantities of metal leached in various environmental circumstances; release of copper and cobalt was entirely affected by the pH of leaching agent > the time of contact > particle size. Metals show extreme release in an acidic environment. The highest metal released was copper: 460 ppm in (pH=2, <0.075mm), whereas cobalt was only 130 ppm in (pH=2, 0.15-0.25) mm). pH shows extreme influence on the release of metals where its p_ values to the metals release influence is much lower than 0.05; time of contact shows great influence on the release of copper and cobalt, where p_ values are < 0.05. The results from this study show that managing the pH of the leaching agent according to particle size of slag waste and the contact duration of the slag with the leaching fluid are crucial in preventing the release of copper and cobalt from the Nkana smelter damped copper slag.

Keywords: Mobility, Time of contact, Leaching agent, Leachate, Harmful elements

Geophagy prevalence and its potential health effects on pregnant women: the case study of Onangama village, Namibia

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Abstract

Geophagy is the voluntary consumption of earthy materials such as clay. The relationship between geophagic materials' composition and related potential health effects on geophagic individuals is inferential. Geophagy is recognised and reported as a common practice in Namibia especially among pregnant women. However, its aetiology, prevalence and potential health effects are not documented. This case study aimed to establish Geophagy in Pregnancy (GiP) occurrences, define the geochemical and mineralogical compositions of the geophagic materials consumed, and identify the potential health effects on pregnant women in Onangama village, northern Namibia. This was achieved through geochemical and mineralogical studies of geophagic materials and a health surveillance on pregnant women from the study area. Mineralogical and geochemical investigations of materials were determined using X-ray Powder Diffraction (XRD), Scanning Electron Microscope (SEM), X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Other parameters such as pH, and soil organic matter (SOM) were also considered. The health risk index was estimated for a better understanding and evaluation of the potential health risk. Furthermore, a survey on geophagy within the study area as well as an assessment of health data on pregnant women acquired from the regional hospital (Engela State Hospital) were conducted. The geochemical analysis revealed high concentrations of Al, Ca, Fe, Mg, Mn, K, Na, and Si. Trace elements including As, Cr, Hg, Ni and V, as well as SO_4^{2-} , NO_3^- , and NO_2^- anions, also presented high content when compared to the recommended daily allowance for pregnant women. Ingestion of these geophagic materials might present a potential health risk to pregnant women including concomitant detrimental maternal and foetal effects. The mineralogical phases identified conspicuous dominant quartz (SiO_2) with minor calcite (CaCO_3), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), kaolinite ($\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$), illite ($\text{KAl}_2[\text{AlSi}_3\text{O}_{10}](\text{OH})_2$), illite-montmorillonite in some materials. Majority of quartz particles were angular to sub angular with sharp edges while kaolinite morphologies depicted flaky and fluffy structures. Quartz morphologies might generate health issues during and after consumption. However, kaolinite particles shapes could be beneficial to the consumers as they are used in the production of gastrointestinal medicines such as kapectate. The pH of geophagic materials ranged from 3.77 – 8.17, which is greater than the gastrointestinal (GI) tract pH ($\text{pH} < 2$). Alkaline pH for some of the geophagic materials can increase the GI tract pH and retard the availability of elements. SOM content (0.16 – 1.32%) indicated the potential of materials to retain pathogenic micro-organisms. The prevalence of geophagy in the study area was high (88.2%). The most common health issues reported during the survey was gastrointestinal related illnesses. The health data collected from Engela State Hospital on pregnant women revealed limited prenatal, antenatal and postnatal complications, low birth weight, and other parturition related health issues. Although the prevalence of geophagy among pregnant women was high, reproduction-related health issues revealed from the health data is minimal to suggest direct danger from the consumption of the studied geophagic materials.

Keywords: Geophagy, Pregnancy, Onangama village, Namibia

Agricultural Geology in Kunene Region: Unlocking Sustainable Crop Growth Potential (Poster)

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Abstract

The Kunene Region, nestled in the arid landscapes of northwestern Namibia, presents a delicate balance between a unique ecosystem and the mounting threat of climate change, with diverse geographical features, cultural heritage, and desert-adapted wildlife. However, the escalating impacts of climate change have brought unprecedented challenges, compounding the vulnerabilities faced by the region's fragile ecosystem and local communities. Rising global temperatures, shifting precipitation patterns, and the increasing frequency of extreme weather events have transformed distant concerns into stark realities that necessitate urgent attention and a comprehensive response. In this paper we adopted an interdisciplinary approach, where we seek to untangle the intricate web of climatic, ecological, social, and economic factors that collectively shape the region's vulnerability landscape. The Kunene Region which is characterized by vast landscapes, diverse ecosystems, and a robust agricultural foundation, faces challenges of crop growth limitations, soil fertility constraints, and sustainability concerns. In light of these challenges, the concept of agricultural geology has emerged as a potential solution, harnessing the untapped potential of rocks to enhance crop production while simultaneously addressing critical Sustainable Development Goals (SDGs) such as zero hunger, good health and well-being, and climate action. Agricultural geology holds immense promise by utilizing rocks as abundant natural resources containing essential minerals, such as phosphate and nitrogen, pivotal for plant nutrition and health. Integration of geological insights into agricultural practices presents a promising avenue to address and elevate crop productivity in the Kunene Region. By mitigating climate change through sustainable land use practices, the region can actively contribute to environmental preservation and ensure agricultural resources for future generations. However, despite its potential, practical implementation of agricultural geology in Kunene faces significant barriers, notably the complex issue of land tenure that directly influences the adoption of agro-mineral resource management principles. The study underscores the potential of agricultural geology as a sustainable solution to bolster crop productivity and enhance climate resilience in the Kunene Region.

Keywords: Climate change, Vulnerability, Land tenure, Geosphere, Agriculture

Examining Public Health Risks Related to Potentially Harmful Elements in Soils and Vegetables within a Gold Mining Region: A Case Study in Migori County, Kenya

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Abstract

The objective of this study was to evaluate the levels of specific heavy metals, namely mercury, arsenic, cadmium, chromium, lead, nickel, selenium, and zinc, in soil and vegetable samples collected from the gold mining areas of Migori County, Kenya. Soil and locally available cabbages, kales, and amaranths were gathered from the study site. To prepare the samples, they were treated with freshly prepared solutions of HNO₃ and HCl (aqua regia) in a 1:3 volume ratio. Subsequently, the acid-digested samples were analyzed using ICP-MS at Bureau Veritas Laboratories Company in Vancouver, Canada. The findings revealed varying concentrations of the selected heavy metals in the examined samples. The dissimilarities observed in the levels of these elements in the soil and vegetables were likely attributed to mining practices and the proximity of the sampling locations to the mines. The investigated vegetables exhibited significant soil-to-plant transfer coefficients for the studied heavy metals. *Brassica oleracea* var. *capitata* (cabbage) demonstrated the highest absorption potential, while *Amaranthus hybridus* L. (smooth pigweed) showed the lowest. The data indicated that arsenic (As) had higher transferability compared to the other heavy metals, and *Brassica oleracea* var. *capitata* (cabbage) had the greatest capability for heavy metal absorption, followed by *Brassica oleracea* (collard greens/Sukuma). The results of the average daily intake (ADI), hazard quotient (HQ), and hazard index (HI) analyses highlighted that the consumption of *B. oleracea* var. *capitata*, *A. hybridus*, *S. nigrum*, and *B. oleracea* (collard greens) could pose significant carcinogenic risks to humans. This study concludes that the main source of these metals is associated with the geological composition of the area and mining activities. Further studies are recommended to assess the impact of these metals on human health through the consumption of vegetables and other edible plants. Additionally, regular monitoring of heavy metal presence in soil and foodstuffs is essential to enhance food safety and mitigate heavy metal exposure in the region.

Keywords: Heavy metals, Essential metals, Health risks, Soil, Vegetables

ST07: GEOPARKS, GEOTOURISM AND GEO-ETHICS FOR PROMOTING EARTH HERITAGE**ST07_S01: Geoheritage, Geotourism and Geoparks in Africa****African Contribution to the IUGS First 100 Geological Heritage Sites****Asfawossen Asrat^{a,b,*}, Asier Hilario^{c,d}, Juana Vegas^{e,d}**

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Abstract

As defined by the International Union of Geological Sciences (IUGS), “An IUGS Geological Heritage Site is a key locality exhibiting geological elements and/or processes of international scientific relevance, used as a reference, and/or with a substantial contribution to the development of geological sciences through history”. Taking this into consideration, the IUGS International Commission on Geoheritage, through its flagship IGCP 731 Project embarked on identifying the First 100 IUGS Geological Heritage Sites in 2021-2022. Through an open, participatory process involving more than 400 geoscientists from more than 50 countries, IUGS announced the first 100 Geological Heritage Sites on October 28, 2022 during the 60th Anniversary meeting of the IUGS held in Zumaia, Spain, and published a book on these geological heritage sites (www.iugs-geoheritage.org). African contribution to this process has been very significant. Among the 181 candidate sites from 56 countries in the world, 23 candidates were from 14 African countries. Fifteen sites from Africa have been included in the IUGS First 100 Geological Heritage Sites. These include the iconic sites of the Archaean Barberton Greenstone Belt in South Africa, the Glacial Record of the Marinoan Snowball Earth in Namibia, the Okavango Delta in Botswana, the Richat structure in Mauritania, the Danakil Depression in Ethiopia and Eritrea, the Tsingy of Bemaraha in Madagascar and the Mosi-Oa-Tunya (Victoria Falls) in Zambia and Zimbabwe. 45 experts from African universities and geological surveys, in collaboration with experts from international organizations, participated in the African proposals. The IUGS Geological Heritage Sites have been selected because of their high scientific value at international level. They are sites that served to develop the science of geology with significant discoveries leading to important scientific debates and ideas. The recognition of these Geological Heritage Sites by IUGS will increase their visibility. In addition, this recognition will help to promote the sites as the best demonstration of geological processes, to enhance geotourism and their appreciation by the public, and to ensure their preservation and protection. These African Geological Heritage Sites are also closely linked to the traditions and narratives of the respective indigenous populations. Considering Africa’s geodiversity, the selected sites are only the few among the multitude of Geological Heritage Sites on the continent. Many more sites can be recognized in future similar programmes such as the upcoming “the Second 100 IUGS sites”, which will be announced in 2024 during the 37th International Geological Congress in Busan, Republic of Korea.

Keywords: IUGS, Geological Heritage Site, Africa, Scientific value, Geodiversity

Main Threats to the Integrity of Geological Sites of Heritage Interest: The Matsequenha Columnar Basalts, Namaacha District, Mozambique

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Abstract

The Matsequenha columnar basalts are the only known example of columnar disjunction in the country. Located northeast of the administrative village of the Namaacha District, the region is characterized by geosites of scientific, touristic and cultural interests. In order to understand the scientific relevance of the geosite and the degree of preservation of the Matsequenha columnar basalts, an inventory and quantification of the elements that occur at the site was made, followed by an analysis of the main threats that put its integrity at risk. It was found that the columnar basalts of Matsequenha present regular columns, with a disjunction pattern mostly pentagonal and sometimes hexagonal; the average diameter varies from 21 to 35 cm and the average relative length of the columns is four metres. The studied columns show banding striations that follow their deformation into Chevron folds and present vesicles filled by a cryptocrystalline material of carbonatic composition. From the point of view of valuation, the data obtained shows that the Matsequenha columnar basalts have considerable scientific and educational relevance, calculated at $[A = 0.56]$, associated with the morphological, petrographic, and structural characteristics. With a vulnerability, calculated at $[V = 0.66]$, the geosite is at risk of destruction due to its exploitation for construction material. Based on this qualitative and quantitative assessment, it was concluded that the columnar basalts present a heritage interest, given their rarity and morphological features, which make the geosite an ideal site for petrological, mineralogical, tectonic and structural studies. Consequently, there is an urgent need to protect this site in order to ensure its preservation for scientific research, training of geoscientists and geotourism.

Keywords: Columnar basalts, Geo-conservation, Geosite, Quantification, Matsequenha, Mozambique

Geoheritage and Geopark potentials in Northeastern Nigeria (Poster)

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Abstract

Preliminary assessment of the geodiversity of Northeastern Nigeria, which constitutes approximately 30% of the Nigerian landscape of 923,768 km² is presented here within the scope of an ongoing comprehensive study of the country. The study aims at educating, sensitizing and redressing government's unintended but undue policy bias in favor of conservation of biotic nature to the neglect of abiotic elements. The continued exclusion of geodiversity conservation action as seen in the operation of National Parks is not only detrimental to an integrated and sustainable management of national space and its environmental resources; it is contradictory to the balanced ecosystem services approach which recognizes the continental crust as the natural capital of water, oil and gas and minerals in addition to being source of food security from soil formed by the breakdown of rocks and minerals. The study is based on geological data, including maps, SRTM models, and satellite images acquired over the last four decades. Nigeria encompasses important geological records with several geosites that give insight to Precambrian Earth evolution from the Archaean to the Neoproterozoic Brazilian/Pan-African West Gondwana amalgamation and a Phanerozoic plutonic-sedimentary cycle spanning the Mesozoic, Cenozoic and Quaternary to Recent peneplanation. Within the scope of a nation-wide study, we present a broad assessment of fifteen selected geosites in the expansive (268,580 km²) Northeastern Nigeria terrain which geosites range from small to large scale with geoheritage values (GV) of remarkable scientific/educational, aesthetic, recreational, cultural/historical and economic values having state/provincial, national and international levels of significance (LS). They consist of geosites characterized by unique geomorphosites, highlands and plateaux (1800 - 2400m) formed from sub-horizontal basalt flows, volcanic cones and plugs as well as dissected plains of variegated metatexite/diatexite metamorphic complexes and sedimentary lithologic picturesque endowed with lakes, warm springs, waterfalls, columnar basalts, quarries, caves and oasis in sand dune terrains. Some of the sites are under increasing risk of deterioration from anthropic activities due to non-existence of legislative geoconservation guideline and systematic inventory; thereby endangering non-renewable geological and geomorphologic evidence that have supported decades of studies and research, involving enormous public expenditure {Nigerian Geological Survey Agency (NGSA) and the universities}. We have adopted a three-step qualitative inventory selection, quantification and evaluation using a five-point evaluation system based on systematic characterization and classification of well-known geoheritage values. SWOT analysis and ranking place the Yankari Warm Springs/Games Reserve and the Mambilla Plateau/Gashaka-Gumti National Parks in the first and second ranking, due to their high (qualitative and quantitative) geodiversity, geoheritage criteria and level of significance. The investigation has resulted in a first-order inventory of geosites and geodiversity sites which require a unifying national geoconservation effort, legislative support and public enlightenment involving the National Parks Authority, the NGSA and the recommended Consortium for Geoheritage and Geoparks in Nigeria (COGGEN) in order to receive UNESCO attention.

Keywords: Geoheritage, Geopark, Geosite, Nigeria

Promoting geoconservation in Africa through technical training on geological heritage of the PanAfGeo project

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Abstract

PanAfGeo is an international co-operation project which supports the training of geoscientific staff from African geological surveys. It is co-funded by the European Union and a consortium of 12 European geological surveys. PanAfGeo is an unprecedented programme led by African and European experts that aims to reinforce the skills of African geoscientists and improve the governance and sustainable use of African geological resources and related infrastructure, including proper management of geohazards and geological heritage. Through its work packages, PanAfGeo allows to instill knowledge and skills in the geoscientific fields where geological surveys contribute to society, such as geological mapping, mineral resources assessment, artisanal and small-scale mining, environmental management of mines, geological hazards, geological heritage, and geological data management. We herein summarize the key aspects of the PanAfGeo project as it relates to capacity building on geological heritage. The first phase of the PanAfGeo project (2016-2019) included Work Package 6 on Geoheritage, led by IGME-CSIC and with five training sessions: two in French (Morocco and Madagascar), two in English (Namibia and Tanzania) and one in Portuguese (Mozambique), with a total of 141 participants from 26 African countries. The second phase of the project (2021-2024) includes Geoheritage in Work Package D (New Frontiers in Geosciences), led by PGI and with three training sessions: one in French (Congo), one in Portuguese (Angola) and one in English (Botswana). One important outcome from the first phase was the “Declaration of Antananarivo on geological heritage and its conservation in Africa” (2019; <https://bit.ly/3pwP2bh>) and a booklet explaining the basic concepts related with “Geoheritage and Geodiversity” (2019). The training lasts 6 days, oriented at geoconservation concepts, geoheritage inventory methodologies and their practical application. At least 3 of those days consist on fieldwork related with the identification of geological heritage sites and the assessment of their value through the diverse parameters related with the potential use of sites (scientific, educational and touristic), as well as calculation of fragility, vulnerability, susceptibility to degradation and risk of degradation (based on the methodology developed by IGME since the 1970s. Practical examples for the training are based on local geology and trainees’ own home country, and include suggestions for potential touristic development. Specific attention is given to the identification of the international scientific relevance of geosites, as it is one of the prerequisites set by UNESCO to consider applications for Global Geopark recognition. The successive training sessions have identified a common demand from government institutions and non-governmental organizations, both related with nature conservation and tourism, towards the identification and proper inventory of geological heritage. This way, geological heritage can be sustainably used by local and regional stakeholders as a resource for socioeconomic development and be preserved for future generations.

Keywords: Geoconservation, Africa, Geological heritage, Training, Co-operation

Project Inventory, Evaluation and Valorization of geosites throughout the Senegalese territory through the National Geological Service of Senegal

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Abstract

In Senegal, most of the classified sites are historical or biosphere sites. Rarely has attention been paid to the geodiversity that conditions the value of biodiversity. The creation by Presidential Decree No. 2022-1358 of the National Geological Service of Senegal (NGSS) whose main mission is to establish an efficient system for the acquisition, processing, interpretation and dissemination of geoscientific data will play a role fundamental in the identification of geosites which makes it possible to contribute to developing, among the Senegalese population, a scientific and tourist interest through education and awareness on the importance of geological characteristics in Senegal. Thus, in 2020, the Ministry of Mines and Geology through the Directorate of Prospecting and Mining Promotion (DPPM) and the National Geological Service of Senegal (SGNS) has implemented a geovalorization strategy for exceptional geosites, aimed at enhancing, with the objective of conservation and valorization, Senegal's geological heritage. The pilot area of the project as a potential Geopark is the Dindéfélo Community Nature Reserve in the Kedougou region. The first phase focused on inventory and identification was completed in 2020. In the same vein, the second phase started in 2021 and focuses on the evaluation of geosites and the enhancement of the Dindéfélo Community Nature Reserve (DCNR) created in 2010 (Bassari Country), to be declared a UNESCO World Heritage Cultural Landscape. In collaboration with the Cheikh Anta Diop University of Dakar, the Chouaïb Doukkali University, El Jadida, Morocco and the University of Huelva of Spain, many activities and achievements have been carried out in the DCNR, such as an exhaustive census and mapping of geosites, documentaries for the public, a reception centre with local management committee, library, directional and indicative signs, construction of roads and access trails, awareness campaigns through the local community, training of tourist guides and teachers and many more.

Keywords: Nation Geological Service of Senega, Dindéfélo Community Nature Reserve, Kédougou, Geological Heritage, Geopark, Senegal

IUGS Geological Heritage Sites: historical context, criteria and methodology of a new IUGS international programme

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Abstract

The scientific community has long demanded the establishment of a global programme with global standards for the recognition of geological heritage sites of high international relevance. This programme is developed under IGCP-731 Project 'IUGS Geological Heritage Sites' (IUGS-GHS), 2021-2023, that continues the efforts of the 'Global Geosites Project' promoted by the European Association for the Conservation of Geological Heritage (ProGEO) and the International Union of Geological Sciences (IUGS) with the co-sponsorship of UNESCO during 1995-2008. In this new era starting with the IGCP-731 project, which is led by the Commission on Geoheritage (IUGS), the global inventory is based on international collaboration between institutions and specialists, which is providing high social and institutional visibility to the geosciences. IUGS-GHS brings together 500 experts from all disciplines from 56 countries and 16 international scientific organizations affiliated to IUGS. An IUGS-GHS is a key place with geological elements and/or processes of scientific international relevance, uses as a reference, and /or with substantial contribution to the development of geological sciences through history. Recognition of the IUGS-GHS is achieved through the following phases: i) definition of the IUGS-GHS and the standards they must meet; ii) design of an easy and reproducible assessment methodology and selection of experts from all disciplines of the Earth Sciences as voting members for the selection process; iii) transfer and training sessions of the methodology in a two-track process: specialists elected as voting members; and to national delegates (national geological surveys, universities and other institutions) together all scientific organizations affiliated to IUGS; iv) evaluation phase and analysis of the results; v) final proposal of 100 IUGS-GHS and submission to the IUGS Executive Committee for ratification; vi) official presentation at an international event and vii) audit of the process by the IUGS-ICG and start of the process for the following 100 IUGS-GHS. At this moment, IGCP-731 Project has selected the First 100 IUGS-GHS according to the higher scoring, with a wide and balanced geographical distribution (33 America; 28 Europe; 15 Africa; 1 Antarctica and 23 Asia-Pacific-Middle East) and by types of main geological interest (History of Geosciences; Stratigraphy and Sedimentology; Palaeontology; Igneous and Metamorphic Petrology; Volcanology; Tectonics; Mineralogy; Geomorphology and Active Geological Processes and Impact Structures and Extra-terrestrial Rocks). Every two years, 100 IUGS-GHS will be recognised following the protocol established and coordinated by the Geological Heritage Sites (ICG) Sub-Commission. The recognition of the Second 100 IUGS-GHS will be during a special session at the International Geology Congress in Busan (Korea) in 2024.

Keywords: IUGS, Geological Heritage Site, Geoheritage inventory, Methodology, IGCP-731

Promotion of Geoheritage sites in Ghana: Opportunities for Geo-tourism and Geo-education

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Abstract

“Geoheritage” is a generic but descriptive term applied to sites or areas of geologic features with significant scientific, educational, cultural, and/or aesthetic value. Geoheritage sites are preserved sites of geoscience importance related to Earth processes, Earth history, and the concept of geologic time. Geoheritage sites are one of the practical ways of demonstrating the relevance and importance of geoscience to the public. Geoheritage sites also provide opportunities for geotourism. Geoheritage sites serve the public interest in many ways: (1) educate about geologic hazards, (2) educate about geologic resources and the environmental consequences associated with their exploitation, (3) advance knowledge about climate and environmental changes, and (4) educate about the evolution of life and the evolution of the Earth. Such sites can also be used as outdoor geoscience classrooms and recreational centres and can provide economic support to local and regional communities by enhancing tourism. Ghana is endowed with many heritage, scenic and recreational sites which have geologic features or landscapes that are visually appealing and inspire a sense of awe and wonder. All these sites can be turned into geoheritage sites or geoparks to enhance tourism, improve public geoscience literacy, and connect the public to the landscape. These sites include Ghana’s only natural lake, Lake Bosomtwi, Boti, Akaa, Kintampo, Fuller and Wli waterfalls and the beauty of the Akwapim Mountain Range. The landscapes of the Neoproterozoic Voltaian Basin which include the Gambaga massif to the north, the Damongo and Kintampo massifs to the west, and the Kwahu plateau to the south of the Basin are also of interest. Other scenic spots include Mount Afadja and Atiwa Range. This study identifies this heritage, scenic and recreational sites and discusses how they may be developed into Geoheritage sites by describing the special and distinct geologic features and geologic history of the associated landscapes and making recommendations to decision-makers and other stakeholders on how to establish and manage these potential Geoheritage sites to conserve their special and distinct geologic features for future generations.

Keywords: Geoheritage, Geotourism, Geo-education, Ghana

Tete Fossil Forest, Mozambique: A world class geoheritage site

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Abstract

The Tete Fossil Forest (TFF) contains petrified wood within the terrains of the Karoo Vulcano sedimentary Province (Upper Carboniferous-Upper Jurassic) in Mozambique. These are very extensive deposits within the Matinde Formation (Late Permian) and four fossil forests (geosites) have been recognized, namely: Carangache, Cadzewe, Mapembera, Nhambando sites and are all part of the same continuous forest along the margin of the Zambezi River. These fossil forests were identified since the 19th century, however, little work has been done. Our work recognizes conifer trees that flourished in the region more than 250 Ma, before the End-Permian Mass Extinction. Recent ongoing studies point to the existence of at least five different genera including new wood species. The scattered fossil trunks in the TFF reach up to 20 m in height and 2m in diameter, covering an area of more than 1000km², thus being the most extensive fossil forest yet found in Africa and probably in the world. Some of the trunks found in the TFF are in their original position and have not been transported. Many of them are in a very well-preserved state. Many features attest to the uniqueness and outstanding universal value of the TFF in Mozambique: (1) the autochthonous nature of the forests (trees preserved in situ), (2) the high density of scattered petrified trees, (3) the excellent preservation of plant features, including internal structures of the fossilized trees, thus allowing their detailed identification, (4) the morphology and morphometrics of the growth rings, which is a palaeoclimatic indicator, and (5) the presence of taphonomical features and structures for understanding palaeoecological aspects of ancient ecosystems. Due to these characteristics, the TFF has a high scientific value and has been proposed as a geological site with national and international relevance. Its legal and physical preservation is crucial for future research into the palaeoecology of Permian ecosystems in Gondwana. The TFF is not an isolated occurrence: similar fossilized woods and even forests may occur in some southern African countries within the rocks of the Karoo Province. Nevertheless, the dimensions, preservation state, types of wood, accessibility and other factors lead us to conclude that no other areas in Africa and probably in the world have such large exposed petrified woods as the ones in the TFF. It is crucial to highlight the uniqueness of the TFF considering its global relevance so that the national and regional governments value their significance and proceed with its legal protection in order to guarantee research, education and public use of this outstanding Permian fossil forest.

Keywords: Fossil forest, Geoconservation, Inventory, Mozambique, Permian

4GEON Project as a Tool for Sharing Playful Geoscience Knowledge

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Abstract

A typical part of the activities of geoparks is the creation, sharing, interpretation and transmission of knowledge about their territory, geological phenomena and their connection with local biota and culture and the history of people's lives. The IGCP-751 4GEON project is aimed at supporting the transfer of geoscience knowledge in geoparks of four continents. This project launched in 2022 connects five diverse geoparks (The Barrandian National Geopark; Rio Coco UNESCO Global Geopark (UGGp); Colca y Volcanes de Andagua UGGp; Ngorongoro Lengai UGGp and Bohol Island UGGp) defined by their unique (hi)story, geological and geomorphological phenomena, culture and local community makeup. The aim is to present the main activities and results to date of the Project, as well as the tools used in its implementation. The most important event of the project was the Eastern Partnership conference and workshops, which took place in Příbram, Czechia, between August 29 and September 7, 2022. In several places in the Czech Republic (Barrandian National Geopark, Bohemian Paradise UGGp, etc.), project participants became familiar with the Czech concepts of geoscience research, Earth heritage interpretation, the use of virtual reality, the geoschool, mining tourism, palaeontological sites, and geotourism products as well as shared experiences from other geoparks and protected areas of the Eastern Partnership countries. As the first planned output of the project, a geoportal has been launched, several online workshops were also held, a project portal was created and the project was intensively promoted among local residents and regional administrations from all involved geoparks. During the first year of the project implementation, several diverse activities were implemented, briefly described in the article "*Report of 4GEON: A Project of Four Continents Connected Through Playful Geoeducation*". In 2023, an online workshop was held, micro-projects are being created at partner geoparks and opportunities for financing them are being sought, geoeducation and geobuses are running, a webpage, Pinterest and FC accounts were created promoting the project and all the geoparks involved in it. The next project team meeting will be held at the University of Hradec Králové and Barrandian National Geopark at the turn of September and October. At this meeting, it is planned, among other things, to familiarize participants with the way of working on joint activities related to the geoportal, the project web portal, the use of Pinterest and other social media platforms for this purpose. Palaeo-art as an effective educational instrument will also be introduced. Specific activities will be agreed which will lead to further development of geoschools, geobus, and tools of interpretation of Earth's heritage.

Keywords: Earth heritage interpretation, Geopark, Geoportal, Geoschool, IGCP project

Baringo Great Rift Valley Aspiring Geopark: Unveiling Geological Wonders

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Abstract

The Baringo Great Rift Valley Geopark, situated within the East African rift and formed during the Miocene epoch, stands out as a region of exceptional geological, natural, and cultural significance. It has emerged as a prime candidate for UNESCO's prestigious global geopark designation. In this article, we explore the transformative potential that the Baringo Great Rift Valley aspiring geopark holds, not only for Kenya but also for the broader African region and the world. We emphasize its pivotal role as a catalyst for sustainable development, promotion of peace, and community cohesion. Moreover, we highlight the significance of science, global partnerships, and alternative livelihood opportunities in realizing these aspirations. The methodology employed to characterize the geopark includes mapping (geological, palaeontological, biological, and cultural aspects), community awareness programmes, stakeholder workshops, and field visits. Through this process, we identified 40 distinctive geosites, utilizing a selection criterion that took into account factors such as the site's significance, condition of road infrastructure, and site safety. Subsequently, we narrowed down the list to 16 geosites that epitomize the exceptional features and formations in this area. These selected sites show case geological wonders of both international and regional importance, palaeontological heritage, geological structures, volcanic peaks, faulted scarps, waterfalls, soda lakes, hot springs, geysers, and areas of cultural significance for worship, initiation, and peace treaties. The geopark also holds great potential for geotourism and ecotourism activities, including high-altitude sports, mountain climbing, long-distance hiking, and more. The Geopark concept, which emphasizes sustainable practices and community involvement, paves the way for enhancing livelihoods and boosting the local economy. This is achieved through initiatives like geotourism and ecotourism, driven by the unique geological, natural, and cultural features of the area. The UNESCO Geopark designation opens doors to global partnerships, offering valuable support and collaboration opportunities. In conclusion, the journey of the Baringo Great Rift Valley towards UNESCO Global Geopark status represents a remarkable opportunity for community engagement. This engagement aims to achieve the triple helix functions of the geopark, namely conservation, development, and education, and holds the potential to leave a lasting positive impact on the region and beyond.

Keywords: Baringo, Geopark, Geosite, Sustainable development, Peace promotion

Geotouristic potentialities of Guéra and vicinities (Central Chadian Massif, Chad): Case of Granite Geomorphosites

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Abstract

Chad is located in a vast Pan-African mobile domain, formed during the Pan-African orogeny (750-550 Ma). It contains Precambrian geological features located in central part of the country; precisely in Guéra. The geological features are dominated by plutonic rocks namely granites. Granite outcrops constitute paramount geological heritage in the study plot that is yet to be studied. The study the outcrop for geotouristic purposes is the suitable way to promote and exploit them for the sustainable development of Guéra. Thus, to reach this objective, several field and laboratory works have been conducted through specific tools. It emerges that granite geomorphosites in Guéra include inselbergs and slabs of varying shapes and sizes. Inselbergs are made up of certain vertical monuments including pedestal rocks, tors, boulders, and shelters mainly found on their top and piedmont. Pedestal rocks are spheric and disc in shape, 300 cm to 2 m in diameters are above 2 m high. Boulders vary in shape and some can reach 3x7 m size. Shelters are heterogenous in shape; their entrance is narrow and they are several meters deep. Slabs are several sq. meters in area and present numerous centimetric circular tafones. *La Reine de Guéra* is an inselberg, with a high scenic value whose overall shape is similar to that of a woman lying down on her back. Even if it is the main touristic attraction of the locality, other inselbergs and their geomorphological features constitute fascinating geotouristic assets through their exceptional aesthetic, educative, recreative, and cultural values. The development of geotourism will be an interesting way for the exploitation of the Guéra geomorphosites while improving the living conditions of Guéra and its vicinities.

Keywords: Guéra, Granite, Pedestals rocks, Tors, Geotourism, Chad

Developing geotourism as a sustainable development vehicle: the case of the Lake Tana region, Ethiopia

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Abstract

Sustainable development is a critical issue for the world. It is a concern at all levels: global, national and local, and for developed and developing countries. Geotourism, if sustainably planned and managed, has the potential to contribute to sustainable development. Sustainable geotourism helps to raise the awareness of the local communities and tourists about the values and importance of geosites, thereby contributing for geoconservation and for enhancing visitor experience. In addition, it has the potential to contribute to the socio-economic development of local communities. Despite the potential role of geotourism for sustainable development, there is a lack of comprehensive study on how sustainable geotourism can be developed. Against this backdrop, the main objective of this study is to understand how geotourism can be developed as a sustainable development vehicle. More specifically, this study explored an inventory of geosites and an assessment of their potential for geotourism development, with a case study in the (eastern and southeastern) Lake Tana region of Ethiopia. A number of methods were used to make an inventory of geosites, such as consulting experts, reviewing documents, using Google Earth and conducting fieldwork to assess their geotouristic potential. The criteria used for the assessment of geosites consisted of scientific, educational, scenic, recreational, protection, added (cultural and/or ecological), and functional (accessibility and proximity to tourist facilities and services) values. The inventory and assessment methods allowed to identify the potential geosites for geotourism development. A first list of 120 geosites has been inventoried. Further screening and clustering resulted in 61 geosites, of which 44 were geosites with and without viewpoints while the rest 17 were viewpoints. Among the major geosites are waterfalls, a lake with islands and island monasteries, a flood plain, caves and cave churches, lava tubes, a mountain (shield volcano), volcanic plugs, volcanic cones, rock-hewn churches, and viewpoints. The geotourism potential of the 44 geosites was assessed using the criteria mentioned above. In addition, the scenic beauty of the 17 viewpoints was also assessed. The results demonstrated that the region has diverse geosites with a potential for geotourism development.

Keywords: Geoheritage, Geotourism, Geotouristic valorization, Sustainable development, Volcanic features, Lakes, Waterfalls

Essaouira aspiring Geopark (Morocco): Effective capitalization of (Geo)heritage resources

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Abstract

With 5 international and 3 national designations (*UNESCO World Heritage Site, UNESCO Cultural Intangible Heritage, Man and Biosphere UNESCO Programme, Ramsar Site and Site of Biological and Ecological Interest*), Essaouira province is without any doubt the best territory in which to establish a geopark. Indeed, all the heritage features are represented (cultural, natural and human heritage, etc.). If the key component is the geological heritage, then it is worth highlighting that the geological history of Essaouira province, as part of both Atlantic margin and Atlasic domain, spans over 250 million years. The present work aims to inventory, assess and promote the major occurrences of geodiversity in Essaouira province, which are still unrecognized, fully unrevealed and unexploited, for conservation and development purposes. The inventory allows us to select the most significant geosites that are assessed through an adaptation of the method proposed by Reynard et al. (2016), based on the scientific and the additional criteria. Our new approach consists of the identification of the potential geosites according to a spatial hierarchy (primary, secondary, tertiary and individual geosites), while keeping the original metrics. This procedure has enabled us to assess geosites in terms of their scientific, cultural, recreational and aesthetic values: (i) Jbel Amsittene primary geosite (6 secondary and 15 tertiary geosites); (ii) Tidzi Diapir primary geosite (14 secondary geosites); (iii) Jbel Hadid primary geosite (14 secondary geosites). The remaining geosites in the province have been considered as individual geosites (21 scientific and 16 cultural). A database has been created by GIS-based implementation and the outcomes that highlights the most relevant geosites are plotted on synthetic maps that integrate all data pertaining to the basic infrastructures. This work provides a contribution to the Moroccan geoheritage inventory and promotion. Therefore, we suggest activities to be developed, mainly in the fields of geotourism and geo- education. Indeed, these activities will allow to outreach Earth Sciences and to catalyze sustainable socio-economic development in rural areas while keeping and promoting their local identity. Consequently, it is important to integrate geoheritage in the region's development- related priorities and strategies and to set up a Geopark in Essaouira Province, supported by an already existing ecosystem services of cultural and natural character.

Keywords: Geosite, Inventory, Assessment, Essaouira, Morocco

ST08: THE ROLE OF MINERALS AND FOSSIL FUEL INDUSTRIES IN AFRICA'S ENERGY TRANSITION TO CARBON NEUTRAL AND GREEN HYDROGEN ENERGY ECONOMIES**ST08_S01: The role of Minerals and Fossil Fuel industries in Africa's Energy Transition to Carbon Neutral and Green Hydrogen Energy Economies****Dynamic simulation of CO₂ storage in a saline aquifer, Bredasdorp Basin, South Africa****Blessing Ayotomiwa Afolayan^{a*}, Eric Mackay^b, Mimonitu Opuwari^a**^a*Petroleum Geosciences Research Group, Department of Earth Sciences, University of the Western Cape, Bellville, 7535, South Africa*^b*Institute of Petroleum Engineering, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS, UK*^{*}*Corresponding author: 3993275@myuwc.ac.za***Abstract**

With more than 70% of South Africa's energy needs satisfied by coal-fired power plants, underground carbon storage offers a technological solution that can drastically mitigate carbon dioxide discharges in South Africa and aid in attaining the government's net zero carbon emissions by 2050. Dynamic simulation of a saline aquifer for carbon dioxide storage was conducted with particular focus on the effect of boundary constraints (closed and open aquifer) on injectivity and storage. Injection into the aquifer was at the rate of 762,000 m³/day for 20 years (2030 – 2050), and a further 20 years for plume containment studies. For the closed aquifer, there was a rapid pressure buildup with average reservoir pressure rising from 26,145 kPa in 2030 to 56,100 kPa (2050 – 2070), well block pressure also increased from 28,000 kPa in 2030 to 58,880 kPa in 2050 and aligned with average reservoir pressure in 2051 to 2070, bottom-hole pressure rose to 62,465 kPa in 2050 and dropped to 56,100 kPa in 2051 to 2070. Plume migration was not rapid due to the pressure buildup in the aquifer and CO₂ did not migrate to the reservoir flanks. Gravity segregation was active, but the system was largely viscous dominated as CO₂ movement was mainly horizontal. CO₂ dissolution in formation water was active, but the confined boundary condition made formation water highly concentrated with CO₂. Solubility trapping, dissolution and residual trapping were the active trapping mechanisms in the closed aquifer; 74% of the total injected CO₂ (236 billion moles) was still in the supercritical phase in 2070, 18% had dissolved in brine, and 8% was residually trapped. For the open aquifer, there was pressure dissipation in the system even with the same injection rate of 762,000 m³/day as in the closed aquifer. Average reservoir pressure was constant at 24,900 kPa from 2030 to 2070, well block pressure was reasonably maintained at 28,000 kPa in 2030 to 2050, dropping to a little below the average reservoir pressure from 2051 to 2070, well bottom-hole pressure was 32,000 kPa in 2030, maintained at 31,000 kPa from 2031 to 2050, and further came down to the well block pressure at 23,000 kPa from 2051 to 2070. Injected CO₂ contacted the overlying seal due to buoyancy and migrated to the reservoir flanks due to low pressure in the aquifer. The system was also viscous-dominated, gravity segregation was present, and brine invasion was very active, accompanied with active dissolution of CO₂ in brine. However, with open boundary settings, brine invasion and non-confining pressure in the reservoir, more formation water was available to dissolve injected CO₂, resulting in low CO₂ concentration and density variation in the reservoir. A large amount of the gas existed as supercritical mobile CO₂, and the primary trapping mechanism was structural trapping under the seal. Dissolution and residual trapping were also in play. In 2070, of the 236 billion moles of CO₂ injected, 56% was in the mobile phase, dissolved CO₂ was 36% and residually trapped was 6.8%. The reservoir therefore offers good prospects as a CO₂ sink.

Keywords: Carbon dioxide storage, Simulation, Saline aquifer, Pressure build-up, Plume migration, Active trapping mechanisms

Fault Seal Analysis for Carbon Dioxide Storage within the Offshore Pletmos Basin, South Africa

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Abstract

Carbon Capture and Storage (CCS) is a growing technology intended to decrease anthropogenic carbon dioxide discharges, thus assisting in the fight against climate change. Geological sequestration of CO₂ via CCS involves the injection of supercritical CO₂ at high pressure from large industrial sites like coal-fired power plants into the subsurface layer of rock, typically at depths of 800 - 3000 m, so that the fluid is held underground and trapped by the surrounding rocks. Saline aquifers, found all over the world, are capable of trapping and securely storing large quantities of CO₂, potentially amounting to hundreds of years' worth of human-generated emissions. Various opportunities exist to permanently lock away CO₂ in subsurface geological formations, with the most viable option being within depleted oil and gas reserves. From a South African perspective, the majority of CO₂ storage work has focused on the Zululand Basin, located south-east of the country. For this reason, it is essential to gain a broader understanding of the capacity of South Africa to store CO₂ by looking into the unfamiliar Pletmos Basin. This basin known for its extensive fracturing and sizable sandstone deposits within a saline formation, could provide insights for improved CO₂ storage. The main objective of the study was to examine whether faults would seal or act as conduits for CO₂ storage in the Pletmos Basin. This study harnessed well log, core, and 3D seismic data to construct a geological model illustrating the placement of faults in the Pletmos Basin, which featured qualities such as lithofacies, porosity, permeability, proportion of shale, and fluid flow regimes. The results of juxtaposition analysis were used to determine the probability of occurrence for seals, while Shale Gouge Ratio (SGR) and Clay Smear Potential (CSP) calculations verified the seal capacity and integrity. Based on the analysis carried out, the main reservoir section and possible CO₂ injection unit was identified between horizons 13At1 and 1At1 (~ 1700 m). Reservoir porosity and permeability ranged between 10 – 20% and 1 – 15mD respectively. In addition, the SGR (>0.4) calculated within the study area indicated a high possibility of faults to seal. This was based on an algorithm by Yielding *et al.* (1997).

Keywords: Fault seal, Carbon dioxide storage, Juxtaposition, Shale gouge ratio

Critical Minerals for Energy Transition in Uganda: Unlocking the Potential for Sustainable Development

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Abstract

Worldwide there is increasing focus on clean energy transition mainly to curb carbon emission to reduce greenhouse gases in the atmosphere. Critical minerals are minerals that are essential for the functioning of modern technologies, economies or national security, with a risk of disrupted supply chains. The importance of these minerals arises from their significance in modern technologies, scarcity and therefore high economic value. In the case of Uganda, key critical minerals for energy transition include lithium, manganese, cobalt, copper, rare earth elements, uranium and graphite. These minerals are vital for the production of batteries, wind turbines, electric vehicles and solar panels. Uganda possesses significant deposits of these critical minerals, particularly in the Kigezi, Rwenzori, Buganda, Busoga and Acholi Regions. However, the country currently lacks the infrastructure, expertise and tools required to explore, extract and process these minerals efficiently. In order to unlock the potential of critical minerals in Uganda, a strategic approach is required. This involves building local human capacity, establishing mineral resources, improving infrastructure, enhancing mining regulations, promoting responsible mining practices and partnerships between the government, private sector and international organizations. Furthermore, Uganda must invest in research and development to develop innovative and more efficient methods for mineral extraction and processing. Therefore, Uganda must strategically position itself to play a key role in the global supply chain of critical minerals in order to harness potential economic benefits and resilient energy systems, considering the global focus on energy transition. By diversifying its energy sources and strategically leveraging its mineral resources, Uganda can accelerate the transition towards a low-carbon economy, enhance energy security and foster economic growth as well as contribute to SDGs. However, it is essential to address the above-mentioned challenges to ensure a successful energy transition.

Keywords: Energy transition, Critical minerals, Sustainable development, Uganda

Assessment of the Potential for Underground Green Hydrogen (H₂) Storage in Namibia

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Abstract

The drive towards a carbon-free economy has accelerated research for renewable energy sources. Green hydrogen continues to gain considerable attention as a viable alternative source of energy. The climate change imperative has been the main driver of the renewed policy focus on green hydrogen, globally. It is simulated that clean hydrogen could meet up to 12% of final energy consumption by the year 2050. At standard conditions, hydrogen gas (H₂) has a low density of 0.089 kg/M³ as an energy carrier and consequently, larger scale volumes of H₂ are required to store energy at the scale of GWhr to TWhr. Underground hydrogen storage is a promising route in addressing the demand – supply gap caused by characteristic fluctuations of renewable energy. Large scale volumes can be stored effectively in geological formations such as aquifers, salt caverns and abandoned mines, etc. Namibia, has a high potential in generating renewable power (e. g. solar, wind) and could become a producer of green hydrogen, with commensurate geo-economic benefits. Considering Namibia's on-going efforts to develop the green hydrogen industry, this study investigates suitable sites for underground green hydrogen storage. The potential for storing H₂ in depleted aquifers, porous rocks, abandoned mines and salt caverns is presented and storage sites are ranked according to the following criteria: 1) reservoir geometry (depth, thickness, trap, etc.), 2) seismicity, 3) accessibility, 4) geological structure (faults, folds) and 5) petrophysics (porosity and permeability).

Keywords: Green hydrogen, Underground hydrogen storage, Renewable energy, Climate change

Methane Emission Reduction Extractive Industry

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Abstract

Greenhouse gases carbon dioxide, methane, ozone, nitrous oxide, hydrochlorofluorocarbon, etc. reduction is essential with a view to global warming mitigation and climate changes. Methane production from natural gas LNG liquefied natural gas, shale gas, gas hydrate, coal bed methane, blue methane hydropower, bio methane agriculture, etc. Greenhouse effect of methane is twenty-eight times more potential than carbon dioxide. Increasing methane emissions are a major contributor to the rising concentration of greenhouse gases in Earth's atmosphere. Global Methane Initiative (GMI), Oil & Gas Methane Partnership (OGMP), Oil and Gas climate initiative (OGCI) United nations UNECE organizations play a pivotal role for reduction of greenhouse gases emission for saving our green Planet Earth. GMI focuses on three key sectors: Oil and Gas, Biogas, and Coal Mines. Methane emissions from oil and natural gas systems result from both normal operations and system disruptions. Removing fugitive methane gas from underground coal mines, tailing dams mining sector are important task. UNECE.ORG International Centre for excellence Coal Mine methane – Poland and China are integral part of task force for methane emission reduction. Global gas flaring reduction GGFR in hydrocarbon sector petroleum production operations release methane into the atmosphere through the wasteful practices of intentional flaring and venting, as well as through unintentional releases such as fugitive methane emissions or venting during unexpected incidents. During crude oil production, a sudden or dramatic increase in pressure could cause an explosion. . Gas flaring allows producers to de-pressurize their equipment and manage unpredictable and large pressure variations by burning any excess gas. Associated gas is used for productive purposes faring, totally unproductive and can be avoided far more easily than many other sources of greenhouse gas (GHG) emissions. Shale gas production hydraulic fracturing emits methane gas. Seafloor geomorphology and ocean floor mapping - by sub bottom profiling detects Pockmarks- concave, crater-like depressions on seabeds that are caused by seabed fluids (liquids and gasses) seepage methane gas escaping and erupting through the seafloor. Prospecting exploration of gashydrate/methanehydrate/ clathrate in ocean and permafrost region, seismic imaging detects pockmarks on the oceanfloor. Continental slope instability failure during production of gas hydrate leads to geohazards huge amount of methane emission in atmosphere. Glaciers also releases methane gas. Methane slip occurs LNG liquefied natural gas escapes to atmosphere from shipping tankers.

Keywords: Greenhouse gas, Methane emission reduction, Natural gas methane, Coal mine methane, Global gas flaring

Balancing sustainable mining: Is carbon neutral energy production feasible for development and climate change mitigation?

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Abstract

Energy production is one of the main drivers of climate change through burning of fossil fuels, especially coal for electricity production and the steel industry. According to current inventories, the amount of coal used to manufacture steel would need to decrease by 80%, while metallurgical and coal used in thermal power stations would need to be reduced by 50% by 2050 in order to achieve a 1.5°C decrease in global temperature. Without such interventions, climate forecasts indicate that droughts, floods, and increased heat in summer months will become more frequent and intense, with the likelihood of upsetting rural subsistence livelihoods and increasing poverty levels. The mining industry can play a significant role in decarbonization by investing in renewable energy systems such as geothermal, hydroelectric, solar, wind, green hydrogen, biomass, including the electric battery and fuel cell technologies. As of 2022, hydroelectric power accounts for 15.3% of the world total energy production; wind energy accounts for 6.6%, solar for a mere 3.7%, biomass for only 2.3% and geothermal for under 1%. Nuclear energy will become a major energy source in the future, as technologies improve and become more efficient; currently nuclear energy accounts for 9.8% and is poised to reach 14% by 2050. Thus, the remaining 61.3% of world energy production are accounted for by fossil fuels. The costs of renewable energies vary drastically, except for green hydrogen: they are not prohibitive but more expensive than fossil fuels. For example, wind energy costs US\$38/MWh, geothermal US\$75/MWh, solar US\$36/MWh, hydropower US\$64/MWh and biomass US\$114/MWh. Green hydrogen will need an infrastructure to be put in place first, with investments in millions of US\$. However, once the infrastructure is in place, it will cost about US\$42/MWh. The identification of key minerals required in the renewable energy economy is at the basis of achieving decarbonization targets by 2050. A new investment pattern must be considered, i. e. the mining industry has to invest in minerals required in the electric vehicle battery and in fuel cells vehicles, such as Li, Na, V, Cu, Ni, Co, P, F, Al and graphite. Investment in Cu, Ni and Al is critical in the renewable energy industry across all types of renewable energy systems. REEs and PGEs will be required by wind energy and also for electric vehicles as ever smaller but more powerful magnets will be needed. These commodities also are critical in the electronics industry for laptops, tablets, cell phones and other touch screen technologies. Current energy demand is fueled by population growth and the industrialization of the developing world. As of 2021, China was the leading producer of greenhouse gases (GHG) per capita, followed by the USA, Russia, India, Japan, Western Europe, Australia, Brazil, Canada, Mexico, Saudi Arabia, Iran, Turkey and South Africa. Africa as a continent is the least producer of GHG but suffers the most from extreme climate events such as floods and droughts. In more ways than one, mining has the solution to climate change, with a gradual decarbonization as industries shift from fossil fuels based to renewable energy systems.

Keywords: Renewable energy, Green hydrogen, Decarbonization, Fossil fuels

Ecological Management in the Metallurgical value recovery during electric vehicle conversion

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Abstract

The conversion of internal combustion engine vehicles to electric vehicles is pushed by a huge desire for clean energy transportation and reduction in greenhouse gas emissions. This is an unstoppable global upward trend toward the development and manufacture of eco-friendly and energy efficient vehicles. The fast-approaching depletion of basic materials for liquid fuel and natural gas, as well as global warming and environmental pollution brought on by the avalanche consumption of these raw materials, all serve to continuously accelerate this trend. Extraction, separation, and refinement are some of the resource-intensive steps in the raw material sourcing process. Large amounts of water, energy, as well as other materials like ammonia, are consumed. This makes the process of extracting raw materials and turning them into usable forms a substantial contributor to energy utilization and consequently GHG emissions. Furthermore, with the process of converting the internal combustion engines vehicles to electrical vehicles an environmental issue of waste pile up will be created. This necessitates the need for a sustainable developmental method for repurposing and recycling the waste to create profit and a circular economy. The metallurgical aspect in this circular economy is the processing of the metallic and non-metallic waste components that will be generated during the conversion process. The research paper will discuss sustainable and efficient methods to extract/recover the valuable metals through metallurgical routes (Pyrometallurgy and Hydrometallurgy). The current processing routes for these valuable metals are Pederson process, Hall heroult-Bayer process and Carbothermic reduction process which is more theoretical and has no practical application yet. Lastly, the economical implications, profitability, related circular economy and industry applications will be presented.

Keywords: Circular economy, Electric vehicle conversion, Sustainability, Repurposing, Metal recovery

Finding a balance between hydrocarbons and green energy in the face of the energy crisis

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Abstract

Sustainable energy production has become a priority around the world, as a first pass response to the looming need to mitigate global warming. The world is progressively positioning itself for the proclaimed energy transition. The challenge faced by major oil producers includes implementation of operations and business models which safeguards net zero carbon and ensure the contributions can reduce greenhouse gas emissions in concordance with the Paris Agreement. Today, we recognize that the usage of fossil fuels by humanity has a negative impact on the environment and has a long-term negative impact on the planet's climate. Nevertheless, it has been exceedingly challenging to significantly alter our behaviour. However, the COVID-19 epidemic altered the situation and all but halted trade, travel, and consumer spending. This caused us to re-evaluate the need for and cost of hydrocarbons. When the pandemic was at its worst, producers across the world suffered, but the war between Russia and Ukraine is showing that hydrocarbons are difficult to replace. We are yet to find a good substitute for oil, in terms of cost, availability and fitness for purpose. The energy industry is confronted with the question of whether to reinvent itself and venture more into renewable businesses avenues. The rising cost of hydrocarbon extraction creates incentives for accelerating the energy transition away from hydrocarbons towards progressively more affordable renewable energy resources. The transition away from hydrocarbons encompasses more than energy production, it also involves finding alternatives (green hydrogen, solar power, biogas, wind power, etc.) for industrial processes. When approaching this transition, leaders should consider all different possible alternatives and their potential impacts on energy consumption. Many alternative energy sources are available, each with its own pros and cons. How do we manage with minimal damage to the world's economy with this transition? The transition from oil and gas to renewables has involved complicated technological research. The transition is slow, but the technological advancements are promising. This study explores how we can navigate away from hydrocarbons without causing too much societal upheavals. We must explore the progressive Gradual Phasing-out of Fossil Fuels option, by planning for a gradual phase-out of hydrocarbons while ensuring a just transition for workers and communities heavily reliant on fossil fuel industries. This will require social support programmes and retraining opportunities for affected workers transition to new industries and careers. To facilitate the transition, significant investments in renewable energy infrastructure and technologies are necessary. Government support, incentives, and subsidies can encourage private sector involvement in renewable energy projects. By employing these strategies and considering the interests of the affected workers, communities and the environment, the transition away from fossil fuels can be managed responsibly, ensuring a sustainable and equitable future for all.

Keywords: Hydrocarbon, Energy transition, World economy, Energy crisis

‘Circular economy’ can start from the first stages of exploration geology

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Abstract

Creating a more circular economy is an important part of achieving materials sustainability and lowering carbon emissions, especially in the industrialised and more wasteful countries of the world. The term ‘circular economy’ (CE for short) is often used to describe the reverse loops in the materials cycle (e. g. recycling, re-use and repair) but CE thinking needs to cover the whole value chain right from the beginning. Important actions to ensure circularity take place in the production and manufacturing ‘inbound’ steps of the materials cycle – and the very first of these inbound steps are geology and mining. The Ellen MacArthur Foundation defines three key CE principles: ‘designing out waste and pollution’, ‘keeping products and materials in use (at highest value)’, and ‘regenerating natural systems’. All of these are applicable to geological exploration and planning for mining¹, including important activity in Africa. These core value chain steps are significant contributors to the ‘emission-rucksack of materials’. CE thinking in exploration includes, for example, early consideration of by- and co-products as well as the main commodity of interest; designing resource efficient mining and extraction processes; using techniques such as life-cycle assessment to test mine design and extraction technology; re-use of mine waste and capture of ‘other’ value streams; biodiversity and ecology regeneration and enhancement; joining primary production with recyclers as materials solutions providers; and taking part in activities to ensure onwards good materials stewardship and participation into future CE value capture through each step in the value chain. In our UKRI Interdisciplinary Circular Economy Centre for Technology Metals (Met4Tech) we are carrying out research across the full value chains for the specialist technology metals (rare earths, lithium, cobalt, tin and tungsten) defined as critical minerals in many countries, and vital for the strategic technologies needed for the energy transition and net zero aims. We will give some case study examples from this research to illustrate how CE can be applied in geological exploration and regional development. We will also set this CE thinking in the context of the new UN Resource Management System and consider how best to visualise the important point that we need to bring more raw materials into circulation but, as we do so, ensure they are brought into a much more sustainable and circular economy.

Keywords: Circular economy, Critical minerals, Resource management, Responsible sourcing

Reference:

¹<https://geoscientist.online/sections/features/the-circular-economy-a-view-from-the-front>

ST09: AFRICA'S NUCLEAR FUEL RESOURCES**ST09_S01: Africa's Nuclear Fuel Resources****Primary-hosted uranium resources, geology, and mineralization in the Damara Orogen, Namibia**Guy Freemantle^{a*}, Judith Kinnaird^b^aThe MSA Group, South Africa,^bCIMERA, School of Geosciences, University of the Witwatersrand, Johannesburg, 2050 South Africa*Corresponding author: guyf@msagroupservices.com**Abstract**

The bulk of Namibian uranium deposits occur in the Erongo Region, where two categories of deposits host the nation's 386 kt indicated U resources: 77 % in primary-hosted deposits of the Rössing type; and 23 % in carnotite-dominant surficial deposits of the Langer Heinrich type. The primary-hosted deposits are those in which U occurs in the sheeted leucogranites (SLG) that are commonly referred to as alaskite. Namibia is a globally significant producer of uranium with the first mine at Rössing (a primary deposit) producing continuously since 1976, and the second primary deposit at Husab producing since 2016. Presently ~130 kt U indicated resources are hosted in at least four unexploited alaskite deposits within a 50 km-radius of Rössing. The major primary deposits are products of the Pan African Damara Orogeny, in which the highest-grade metamorphism, and consequently the greatest density of successively leucocratic, episodes of granitic intrusions occur in the high-T°/low-P southern Central Zone (sCZ) of the orogen. All the sCZ primary deposits are similar, having formed in structurally prepared sites in granulite facies Neoproterozoic metasediments of the lower Damara Supergroup, which are spatially proximal to basement-cored domes and inliers, and tectonically proximal to regional peak metamorphism. Potentially economic deposits occur on the southwest edge of the Khan Inlier at Etango, on the south eastern margins of the Ida Dome at Omahola, and on the eastern edge of a basement inlier at Valencia. Contemporary interpretations for the formation of these large, low-grade deposits favour models of low-percentage partial melt of weakly-uraniferous source material. The uranium repositories in the source rocks likely include common accessory minerals, such as zircon, monazite, biotite, and apatite, that retain or release U, Th, lanthanides, and other incompatible elements into the silicate melt and magmatic fluids. The bulk of U mineralization in the primary-hosted deposits occurs as uraninite [$U^{4+}U^{6+}O_2$], coffinite [$U(SiO_4)_{1-x}(OH)_{4x}$], and minor secondary hydrate minerals, predominantly uranophane [$Ca(UO_2)_2SiO_3(OH)_2 \cdot 5(H_2O)$]. A relatively low proportion of U (~5 %) is hosted in the refractory minerals betafite [$(Ca,U)_2(Ti,Nb,Ta)_2O_6(OH)$] and/or brannerite [UTi_2O_6]. The varying proportions of the major host minerals and the refractory phases essentially reflect local formation conditions within the deposits, as well as the broader region. The primary driver for uraninite crystallisation within the SLG's is REDOX buffering of dissolved U^{6+} -complexes by reductants in the reactive Damaran metasediments. Mineral analysis, by EPMA show that calculated $U^{4+}:U^{6+}$ and U:Th for uraninite populations have deposit-specific compositional variation. This variation in U valence appears to be a function of primary (unaltered uraninite) and secondary controls on U valence states (altered uraninite), as well as oxidising conditions in the near surface, where alteration of the uraninite is evident. In addition, many of the uraninites contain detectable REE and Y, which provide a fingerprint for identifying the ore of the deposits. In order to facilitate an understanding of a projects potential viability the distribution controls on refractory uranium minerals is a particularly useful tool at the various stages of exploration, while the composition of uraninite has useful implications for the metallurgical aspects of primary uranium mining.

Keywords: Uranium, Alaskite, Resources, Mineralogy, Exploration

Determining Uranium Mineral Compositions by Electron Probe Micro Analysis

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Abstract

Uraninite is one of the most abundant uranium ore minerals; it occurs in west central Namibia in the world's largest mineable granite-hosted deposits. It is the primary ore mineral in late- to post-orogenic sheeted leucogranites (SLGs) that intruded in multiple generations into structurally prepared granulite-facies Neoproterozoic metasediments. Contemporary interpretations for the ore genesis favour models of oxidised, low-% partial melt of weekly uraniferous source material intruding and reacting with reducing units of the metasedimentary sequence. The primary driver for uraninite crystallisation within the SLG's is REDOX buffering of dissolved U⁶⁺-complexes by reductants in the reactive Damaran metasediments. Resultant insoluble U⁴⁺ has combined with available impurities and U⁶⁺ to bond with O²⁻ and crystallise impure uraninite. The uranium repositories in the source rocks likely included common accessory minerals such as zircon, monazite, biotite, and apatite that retain or release U, Th, lanthanides, and other incompatible elements into the silicate melt and magmatic fluids. Variable proportions of the uranium-bearing refractory minerals betafite and brannerite reflect diverse local conditions within deposits during-, and subsequent to ore genesis.

Keywords: Uranium, Ore deposit, Mineralogy, EPMA, Mineralization

Uranium mineral compositions of the primary-hosted uranium deposits of the Central Damara Orogen, Namibia

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Abstract

Uraninite is the most abundant mineral prospected for-, mined and processed for the supply of raw uranium compounds to the global nuclear industry. It occurs in a wide variety of geological settings, and in central Namibia the largest, mineable granite-hosted deposits are forecast to provide a significant proportion of future U₃O₈ supply. The granite-hosted uraninite occurs in relative abundance in late- to post-orogenic, sheeted leucogranites that preferentially invade as pegmatitic sills and dykes. These invade structurally prepared sites within deformed, Neoproterozoic metasediments of the Damara Supergroup. The metasedimentary sequence unconformably overlies folded Palaeoproterozoic basement inliers and domes predominantly comprising metasedimentary and igneous assemblages of the Abbabis Metamorphic Complex. The primary driver for uraninite crystallisation is the REDOX buffering by reductants in the reactive Damaran metasediments that donate e⁻ to soluble U⁶⁺ complexes. Insoluble U⁴⁺ and U⁶⁺ bond with O and crystallise impure uraninite with UO₃ and impurity components. While variable proportions of the refractory betafite and brannerite reflect diverse local conditions within deposits during ore genesis. Sites of sufficiently large granite volumes that have interacted with reactive Damaran metasediments occur at the Rössing and Husab mines, and the Etango and Valencia deposits at the Farms Goanikontes and Valencia, respectively. There are two popular mechanisms for the concentration of uranium into peraluminous granitic melts: one is incompatible element partitioning into partial melts; and the other magma fractionation. Contemporary interpretations favour the former, describing models of low-% partial melt of the basement and lower-Damara units as the sources of the silicate melt, and therefore also the uranium. The uranium repositories in the source rocks likely include common accessory minerals such as zircon, monazite, biotite, and apatite that retain or release U, Th, lanthanides and other incompatible elements into the silicate melt and magmatic fluids. Element partitioning is determined primarily by trace element compatibility and solubility within melt and fluids, respectively. Mineral formulae determination of data from EPMA analyses of 42 uraninite specimens, from the Husab, Etango, and Valencia deposits, are based on standard stoichiometry and charge balance recalculation. The calculated compositions of the uraninite specimens show that UO₂/UO₃ and U_{tot}/Th is varied, but plot in deposit-specific populations. Stoichiometry calculations of betafite and brannerite analysis results, at Husab, confirm that uranium valence is required in the oxidised state to maintain charge balance, suggesting late crystallisation, potentially from the residual fluid phase that hosts the remaining soluble U complexes. Calculation of the primary mineral compositions serves two objectives: One is to quantify the ratio of oxidised and reduced uranium during deposit genesis, and to assess and quantify the degree of coffinitisation and alteration of uraninite subsequent to crystallisation. The second is to quantify the variable proportions of contaminant phases and elements, and U⁴⁺/U⁶⁺ that are expected in naturally occurring uraninite for process and metallurgical design. Recent work has for example, assessed the effect of Pb on the behaviour of uraninite in the leaching environment. Accurate quantification of uraninite compositions may be an important contributor to designing efficient, environmentally friendly low-grade uranium leach process.

Keywords: Uraninite, EPMA, Mineralogy, Uranium

The Karoo sandstone-hosted uranium deposits in the Sutherland area, Northern Cape Province, South Africa

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Abstract

The occurrence of the Karoo-age sandstone-hosted uranium deposits in South Africa was officially announced in Parliament in 1973 although the first discovery was made in 1969. This led to much exploration activity in the Northern and Western Cape provinces and resulted in the discovery of several thousand uranium occurrences (Cole, 1998) that delineated the Karoo uranium province. Exploration ceased by the mid-1980s when the fall in the uranium price rendered most of the occurrences sub-economic. Nonetheless four of the deposits underwent pre-feasibility studies, with the largest one at Rystkuil, 45 km southeast of Beaufort West, having a resource of 6 791 tonnes of U (Cole, *op cit.*). To date, none of the deposits has been mined, although they have been re-investigated several times over the past two decades during periods when the uranium price rose. The author was employed by Esso Mineral Africa as an exploration geologist in the Sutherland area in the late 1970s and this is a summary of the findings about the occurrence of the uranium deposits. The latter are hosted by the Poortje Member sandstone of the Teekloof Formation (Adelaide Subgroup, Beaufort Group, Karoo Supergroup). Although this member attains a maximum thickness of about 200 m, it is generally less than 40 m thick in the cliff exposures along the escarpment about 40 km east of Sutherland town. The sandstones are coarse- to fine-grained and fine upwards into siltstones and mudstones. They are interpreted as fluvial channel deposits of a meandering river system, with the siltstones and mudstones representing overbank deposits. Individual fining-upward beds are 3 to 5 m thick and amalgamate to form the thick packages. The uranium orebodies occur at the base of the sandstone beds as thalweg deposits that are less than one metre thick and elongated along the palaeochannel. They are dark coloured due to the presence of abundant organic material and contain some bone fossils and intraformational mud clasts. The most abundant ore mineral is coffinite, with associated uraninite, molybdenite, pyrite, arsenopyrite and chalcopyrite (Cole, *op cit.*). The best-developed mineralization is at the base of the thickest sandstone package. Although the initial Esso model for the uranium ore deposits was that of a roll-front type, as found in the western USA, research has indicated that this is not so. The origin has been ascribed to oxidised uranium carried by ore fluids that encountered localised reducing conditions in the sandstone channel thalwegs, causing the uranium to precipitate out (Cole, *op cit.*). The source of the uranium is inferred to be the mudstones that contain volcanic detritus from a source situated to the south. With the current renewed interest in uranium as a “green” alternative to carbon-sourced energy, there is again the possibility that the Karoo deposits will attract investment.

Keywords: Karoo uranium, Sandstone-hosted, Coffinite

Reference:

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Africa's Nuclear Fuel Resources: Potential Benefits and Challenges

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Abstract

Africa possesses a wealth of uranium, an essential resource for nuclear energy initiatives. Namibia and Niger rank among the world's leading uranium producers, while South Africa and several other countries contribute to the production of this valuable commodity in smaller quantities. Presently, South Africa stands as the sole nuclear operator in Africa, operating two reactors at the Koeberg Nuclear Power Plant, which collectively generate nearly 2000MWe of power. However, South Africa is contemplating the possibility of extending the lifespan of its existing plants and expanding its nuclear power programme. In terms of progress, Egypt has already commenced its nuclear programme and is in the process of constructing four 1200MWe reactors at El-Dabaa, situated on the Mediterranean coast. Several other nations, including Ghana, Uganda, Nigeria, Kenya and Niger, have received support from the International Atomic Energy Agency (IAEA) to develop their respective nuclear power programmes. Potential benefits of nuclear power plants are recognized for their ability to generate clean energy, devoid of air pollution, and serve as a dependable source of zero-carbon power. Nuclear power programmes offer opportunities for technology transfer and knowledge acquisition. Collaboration with experienced international partners can facilitate the transfer of expertise, training and education in nuclear science and engineering. Nuclear power programmes require significant upfront investments that need to be sustained over a long period of time until the savings from fuel outweigh the initial capital costs. This applies not only to financial investments but also to the energy invested in nuclear facilities and the supporting fuel infrastructure, which initially require more resources compared to conventional energy programmes. Strengthening nuclear security measures is also essential to prevent unauthorized access to nuclear materials and safeguard against proliferation risks. The lack of skilled workers can be attributed to various factors. Limited educational and training programmes specific to the nuclear industry are available in Africa, leading to a scarcity of qualified professionals. Additionally, brain drain, where skilled individuals seek employment opportunities abroad, further exacerbates the shortage of expertise within the continent.

Keywords: Nuclear power, Clean energy, Greenhouse emissions

Different styles of uranium deposits in Africa

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Abstract

A need to reduce the use of fossil fuels for a low carbon future, will mean that generation of electricity by nuclear power is likely to increase. Currently, there are 440 nuclear reactors around the world, dominantly in the northern hemisphere, and as numbers potentially increase a consistent supply of uranium will be required. Africa is a significant uranium producer. Uranium may occur in primary or secondary deposits. Primary deposits are characterised by mineralization in granites and pegmatites, minor vein deposits, carbonatite-hosted enrichments and IOCG related associations. Production of uranium from primary deposits accounts for ~18% of the world's resources. Secondary deposits of uranium can occur as unconformity-related, sandstone-hosted, quartz-pebble-hosted, phosphate deposits and surficial deposits and a number of very minor sources. The major unconformity-related uranium deposits in the Athabasca Basin in Canada, where uranium was deposited from circulating groundwater at a major geochemical boundary, produce around a third of the world's uranium supply. Such deposits in Africa are very minor. The most notable primary deposits in Africa are the uranium-bearing granites of the Damara Central Zone in Namibia. The pegmatitic uraninite-bearing leucogranite sheets may occur as large masses or in narrow sheets interbanded with metasedimentary rocks, intruded late in the Damara orogenic cycle ca. 510 Ma ago. Grades are extremely variable but typically ~350 ppm dependent on world uranium price. Secondary quartz-pebble-hosted uranium deposits occur in the Archaean Witwatersrand Basin in South Africa. Detrital uraninite, gold, pyrite and other heavy minerals were preserved in conglomerates deposited in the basin in an anoxic atmosphere. Uranium and gold were remobilised during hydrothermal fluid flow through the basin and authigenic pyrite developed. These fluids carried a primitive hydrocarbon oil that transformed into bitumen when it encountered uranium-bearing minerals. Uraninite is commonly associated with carbon nodules and veins, in association with pyrite and minor gersdorffite, pyrophyllite and brannerite, a refractory uranium-bearing titanium oxide. South Africa is now the tenth biggest world uranium producer. Secondary deposits of importance are the Palaeozoic to Mesozoic sandstone- and arkose-hosted deposits in Niger and Malawi where uranium-derived from an older source has been carried by ground or river water and deposited in roll-front and tabular deposits in medium- to coarse-clastic sedimentary rocks. Highest grades are associated with stacked deposits in multiple sandstone horizons. Coffinite is the main U-phase accompanied by minor uraninite and secondary U phases near surface. Pleistocene to Recent channel-hosted surficial deposits formed within the last 60 million years as near-surface valley-fill sands and gravels in semi-arid to arid areas, with uranium derived from a primary source somewhere in the hinterland. Such deposits provide ~4% world uranium resources. Klein Trekkoppie and Langer Heinrich in Namibia are characterised by carnotite in association with calcrete, carbonates, gypsum and halite, and form a series of concentrations locally along a buried riverbed, or as overbank deposits. The combined uranium production from primary sheeted leucogranites together with that sourced from surficial deposits has resulted in Namibia being the third biggest world producer after Kazakhstan and Canada.

Keywords: Uranium, Damara Central Zone, Primary deposits, Secondary deposits

A late Holocene palaeotsunami deposit at Cape St Francis, Eastern Cape, South Africa: implications for the siting of a nuclear power station at the nearby Thyspunt locality

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Abstract

In this study we report the discovery of a late Holocene quartzite boulder deposit at Seal Point, at Cape St Francis, in the Eastern Cape Province of South Africa, some 50 m inland from the coast. On the basis of hydrodynamic calculations, the deposit is interpreted as a palaeo-tsunami deposit, produced by huge waves, moving at a minimum velocity of 7.1 m/s, which overturned large blocks of quartzite which are piled on top of each other in an imbricate fashion, and which rest directly on broken sea shells of a shell midden. South African power utility parastatal ESKOM has identified a potential site for a nuclear power station at Thyspunt, some 10 km WNW of Seal Point. In the aftermath of the Fukushima disaster in Japan in 2011, the safety of coastal nuclear power stations is of paramount importance and is an issue of great societal concern and relevance. The implications of this discovery are discussed, with respect to the siting of a nuclear power station nearby. The geology of the area around Seal Point is dominated by prominent outcrops of trough cross-bedded quartzites of the Ordovician Table Mountain Group of the Cape Supergroup. The boulder deposit is found 50 m inland from a small gap in a ridge of quartzites, through which large waves were focussed. The path leading from the gap to the boulder deposit is strewn with other very large quartzite boulders that have been transported and deposited there. In the boulder deposit the largest boulder clast has dimensions of 5.6 by 2.6 by 1.5 m (with a mass of around 55 tons, using a density of 2.61 t/m³), and is overturned, with truncated cross-bedding facing downwards. Several other large boulders are piled up adjacent to the largest boulder, in an imbricate fashion. Hydrodynamic calculations were made for the largest boulder, using the modified Nott equations. The minimum velocity required to transport the largest boulder in rolling mode, is calculated to have been 7.1 m/s. This is consistent with a tsunami wave. The boulders rest on a shell midden, consisting of an accumulation of broken seashells (fragments of *Patella*, *Choromytilus* and other genera). The shells were dated radiometrically using ¹⁴C (radiocarbon) AMS dating, to about 1470 ± 50 C.E. This gives a *maximum* age for the boulder deposit which rests directly upon the midden; the prehistoric deposit must *predate* the establishment of a Dutch East India Company (VOC) post at Algoa Bay in the 1720s. This discovery, together with the presence of megaboulder beds situated upon outcrops at Thyspunt itself, indicates that this region experienced large waves, most likely of tsunami origin, within the past 500 years, with an unknown recurrence interval. Bombardment during tsunamis or storms by huge boulders of the size recorded here (effectively, 50 tonne missiles propelled at 7 m/s) would pose a major safety risk for any infrastructure built along the shoreline, and this brings into question the desirability of siting a nuclear power station there.

Keywords: Palaeo-tsunami deposit, Coastal nuclear, Power shoreline

Uranium detection in the Beaufort West area, South Africa using remote sensing techniques (Poster)

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Abstract

The main Karoo Basin of South Africa is well known for its thick glacial deposits, sedimentary sequences, terrestrial vertebrate fossils, plant assemblages and extensive flood basalts with their associated dolerite sills and dykes. The basin is also known for various commodities, uranium being one of them. Uranium is a highly dense metal that is mostly used as fuel for nuclear energy power plants and occurs within sandstone bodies of the Adelaide Subgroup. Most of these sandstone bodies form part of the Middleton Formation. Remote sensing techniques were used to assist uranium detection in the Beaufort West area by delineating target areas for uranium exploration. Remote sensing was successful in distinguishing various lithologies using various techniques including band ratios and Principal Component Analysis (PCA). ASTER band ratios (12/13, 11/12, 14/12) were used to highlight silica, Sentinel 2 (11/12, 4/2, 12/8+3/4) and Landsat 8 (6/7, 6/5, 4/2) band ratios were used to detect alteration, iron oxide and ferrous iron. These ratios were used to distinguish between sandstone bodies, dolerite sills and dykes. Band ratios were the best technique to highlight target uranium areas in the Poortjie Member of the Middleton Formation. This was corroborated by uranium anomalies mapped from ground and airborne radiometric data. Additional field work, drilling of boreholes and geochemical analysis are required together with the remote sensing data to refine new target areas. Discovery of such potential targets for mineral exploration areas can assist in reviving mining activities in underexplored mineral reserves in poverty node areas such as Beaufort West.

Keywords: Uranium, Remote sensing, Main Karoo Basin, Beaufort West, Mineral exploration

Overview of Uranium Activities in Namibia and the African Continent

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Abstract

After years of low uranium prices, the improving climate of positive supply and demand fundamentals has put the Namibian uranium sector into a phase of resurgence. The Rössing Uranium Mine has been in operation for 46 years, it is the largest and longest operating uranium open cast mine in the World. The extension of the life-of-mine to 2036 has been approved, and the Ministry of Mines and Energy consequently extended the Mining License to 2036. New investment in pit and TSF extension, plant refurbishment and infrastructure upgrades will be part of the increased life of mine. At full production, Swakop Uranium's Husab Mine has a designed annual mining capacity of more than 100 million tonnes. The ore is fed to a processing plant with a nameplate capacity of 15 million t of ore per year, and an annual output of 6 000 t U₃O₈. Total uranium production in 2022 was 3 960 t of U₃O₈, extracted from just over 97 million t of ore mined. At the Langer Heinrich Mine, based on the improved market conditions, a restart project to the tune of about N\$ 1.25 billion has commenced in 2021 with target production for the 1st quarter of 2024. Bannerman Energy released the results from the Definitive Feasibility Study completed on its Etango-8 uranium project in December 2022. It confirms the strong technical and economic viability of a conventional open pit mining and heap leach processing operation with a throughput of 8 million tons per annum. Reptile Mineral Resources and Exploration completed a Definitive Feasibility Study for its Tumas project, which targets an annual production rate of up to 3 million pounds of uranium underpinned by a mine life of more than 20 years. A mining license has been approved conditional to receiving environmental clearance. The company also undertakes exploration activities on other Namibian tenements, which include joint ventures with the Japanese Organisation for Metals and Energy Security. Elevate Uranium is the largest uranium exploration tenement holder in Namibia. The company's primary projects in Namibia are the Koppies, Hirabeb, Marenica and Namib IV uranium projects, which are included in 10 active tenements, containing mineral resources of 81.6 Mlb U₃O₈. Zhonghe, Forsys, and Headspring have exploration projects in advanced stages. In addition, there are a number of new exploration companies who have taken over nuclear fuel EPLs in Namibia and are busy with exploration. The Namibian Uranium Association is supporting all these activities by ensuring best practice environmental, social and governance performance and hence the sustainability and public acceptance of the sector. Besides the established mining activities in Niger and South Africa, the African continent has exploration activities in Algeria, Botswana, Burundi, Cameroon, CAR, Chad, Djibouti, Egypt, Equatorial Guinea, Ethiopia, Guinea, Kenya, Libya, Madagascar, Mali, Mauretania, Morocco, Nigeria, Senegal, Sudan, Tanzania, Tunisia, Zambia, and Zimbabwe.

Keywords: Uranium, Namibia, Africa, Mining, Exploration

ST10: HYDROCARBON POTENTIAL IN AFRICA**ST10_S01: Hydrocarbon potential in Africa****Mineralogy and Pore System Characterisation of the Maastrichtian-Palaeocene Shales from the OMA-1 Well, Offshore Dahomey Basin, Nigeria: Implications for Shale Gas****Olubunmi C. Adeigbe^{*}, A. I. Agunsoye, O. A. Ehinola***Department of Geology, University of Ibadan, Ibadan, Nigeria***Corresponding author: olukris2009@gmail.com***Abstract**

X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Nitrogen adsorption isotherm analyses were carried out to determine the mineral composition; micro-structures and pore geometry; pore volume (PV), surface area (SA), and the Pore Size Distribution (PSD) of the shale samples of Maastrichtian-Palaeocene, Dahomey Basin for possible gas fracking and subsequent increase in gas production as transition fuel. Isolated and connected inter-granular, intra-particle, and organic pores were observed, and fair permeability was inferred from the SEM images. The presence of over 50% quartz including feldspars and significant carbonate minerals as compared to other clay minerals which is predominantly kaolinite, also denoted the brittleness nature of the shales. The PSD ranges within the 2nm-50nm interval of mesopore classification by IUPAC and the average pore volume and surface area are 0.11cc/g and 298m²/g respectively inferring a macropore system, thus, the Intragranular pores and microfractures dominates the pore structures which are easy network path for free gas. Th values obtained for PSD are well above many producing shales in the USA (Barnett, 0.04cc/g), including the lower limit pore size of 20nm for shale gas in some China shales. Therefore, the Maastrichtian-Palaeocene shales of the Dahomey Basin are highly porous for gas storage and they have the ability to release the gas upon fracking.

Keywords: Pore size distribution, Pore geometry, Brittleness, Nitrogen isotherm

Palaeo-environmental characteristics of the bitumen deposits of the eastern Dahomey Basin: Indications from the steranes and terpanes finger printing

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Abstract

The enormous deposit of bitumen which occurs across the East-West belt of the eastern Dahomey Basin has been gaining a lot of attention in recent times. However, the degree of biodegradation of the bitumens has greatly reduced the quality of the initial oils and also altered the inherited attributes from the source rocks, the knowledge of which is sparingly understood. The asphaltene contents of the bitumen samples were pyrolyzed by flash pyrolysis and the asphaltene pyrolysates containing biomarkers possessing characteristics of the initial oils were analyzed for sterane and terpane distributions and these were used to characterize the initial oils. The sterane and terpane fingerprints showed similar distribution patterns indicating similarities in source input attributes. The source attributes as revealed by the regular steranes (C_{27} , C_{28} , and C_{29}) indicate a combination of marine and terrestrial organic matter inputs (with values ranging from 48.62 to 60.65%, 19.58 to 29.38% and 14.64 to 23.23% respectively). The predominance of C_{27} regular steranes and high C_{27}/C_{29} sterane ratios (>2.0) confirms abundance of organic matter of marine origin. More so, the high abundance of C_{30} steranes in all analysed samples indicate that the initial oils were generated from marine source rock. The samples are found to be genetically related and are products of a reducing open marine environment that received abundance of plankton and algae. Gammacerane occurs in low to moderate concentration, with gammacerane index ratios (0.32 to 0.46) indicating a highly reducing hypersaline condition for the source rock. Oleanane, a biomarker from higher plants found in Late Cretaceous or younger sediments was present in low to moderate proportion with oleanane index ranges from 0.38 to 0.57 which is greater than 0.2. Thus, it shows that the oils are from Tertiary (Palaeogene to Neogene) source rocks. The C_{30} $\beta\alpha/(\beta\alpha+\alpha\beta)$ ratio (0.25 to 0.47) suggest low to early thermal maturity of the initial oils of the bitumen samples.

Keywords: Flash pyrolysis, Organic matter, Environment, Gammacerane, Oleanane

Sedimentological and mineralogical assessments of the Afowo oil sand deposits, southwestern Nigeria

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Abstract

Determination of reservoir properties of tar sand deposits of the Campano-Maastrichtian Afowo Formation through textural parameters as well as mineralogical components, formed the focus of this research work. The study was carried out with detailed field and laboratory techniques, which involved bitumen saturation analysis, textural analysis, petrographic study and X-ray diffractometry. A total of fifteen (15) outcrop samples of tar sand deposits were collected at six (6) different locations in Ondo and Ogun States, respectively. From the textural analysis, the sediments were found to be of three different lithofacies, i. e. fine-, medium- and coarse-grained. These sediments ranged from poorly sorted to very well sorted. Average percentage bitumen impregnation was estimated to be 25.7%. Petrological studies showed the sediments consist predominantly of quartz, which constitutes over 90% of the total mineralogical components. Feldspar constitutes <1% of the entire components, which is indicative of textural maturity of the studied Afowo sediments. Results of XRD analysis tallied with the petrological study revealing quartz as the dominant mineral; kaolinite was also observed in the majority of the samples. Other minerals such as calcite, siderite, anatase, gypsum and gibbsite occur in minor amounts across the selected samples. The majority of the samples can be grouped into good and excellent reservoir classes. However, the Trianga sample exhibited unconventional textural properties, which made it impossible to determine its particle size distribution and other attributes. Consequently, its reservoir quality could not be determined.

Keywords: Reservoir, Sedimentology, X-ray diffractometry, Mineralogy, Tar sands

Gas chromatography and geo-electric characterisation of the black shale associated with the Upper Cretaceous Afowo Formation of the Eastern Dahomey Basin, Southwestern Nigeria

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Abstract

The Dahomey Basin is a trans-frontier transform basin that straddles the boundaries of West Africa countries Nigeria, Ghana, Togo, and Benin. The Basin overlies the Precambrian Basement complex in an unconformable manner, with a varying sedimentary sequence, more than 3 km thickness particularly towards the proximal offshore province. In the offshore, there are proven hydrocarbon fields and an enormous bituminous deposit on the onshore of the Eastern Dahomey Basin. However, there is paucity of information on shale gas potential in the basin. As such, this study characterises the black shale of the study area using a gas chromatography (GC-MS) and geo-electric approach. For the GC-MS, 0.5g of eighteen pulverised borehole samples were weighed into a test tube and 2 mL of 2:1 hexane: methylene chloride was added. Sample was sonicated for 30 minutes then centrifuged for one minute. The extract was then subjected to a further 1:100 dilution without fractionation. An electrical resistivity imaging (ERI) technique was employed for subsurface investigation in the study area using the dipole – dipole array due to its high sensitivity to vertical and/or inclined anomalies. Vertical and lateral changes in subsurface resistivity were combined to produce a two-dimensional image of the subsurface. A five hundred metre profile line comprising of 51 electrode system was designed for the survey using a minimum separation of 10m. Results show that the biomarker ratio indices of n-C17/Pr is 0.9 which is <3, suggesting the hydrocarbons emanate from a biogenic origin. The diagnostic ratio of Dibenzothiophene (DBT) /Phenanthrene (PHEN) is 1.03 which is >1, indicating the shale as a source rock lithology. Furthermore, the pristane/phytane ratios <1 indicates a marine depositional environment under anoxic redox conditions. Gammacerane/ Hopane shows a low value of 1, suggesting a shale-type source rock. For geo-electric result, Profile 1 revealed three substrata which range from 985 – 1500 Ωm, 200 – 900 Ωm and 985 – 3000 Ωm for sandstone, carbonaceous shale sequence and ferruginised sandstone respectively. Thickness of these components range from 5 – 12 m for sandstone, 10 – 15 m for the carbonaceous shale sequence and 10 – 18.5 m for the ferruginised sandstone unit. Profile 2 showed that the subsurface section is sequenced into two geo-electric units, with a resistivity value of 200 – 299 Ωm and 401 – 572 Ωm, indicative of lithologic transition from shale to sandstone from top to bottom. Thickness of the carbonaceous shale is 25 m near the end of the profile. Profile 3 shows that the mid stratum is a 50 m – 55 m thick geo-electric layer with a resistivity range of 190 – 533 Ωm which corresponds to carbonaceous shale. Between the 70 – 120 m distance-mark, it is impregnated by an anomalous resistive body of 1350 Ωm delineated as bituminous sand. The black shale associated with the Dahomey Basin indicates potential for shale gas generation, however, a rock-eval pyrolysis should be conducted to ascertain the dominant kerogen type in the basin.

Keywords: Black shale, Dahomey Basin, Biomarkers, Nigeria

Assessment of Hydrocarbon Generative Potential of the Sokor 1 Formation Source Rock, Fana Low Uplift Tectonic Unit, Termit Basin

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Abstract

The West and Central African Rift System is a typical intracontinental Cretaceous-Palaeogene rift system with prominent hydrocarbon reserves. The Termit Basin is an extensional asymmetric rift, which is divided into ten tectonic units, including the Fana low uplift (study area). In this basin, although oil is mainly derived from the Upper Cretaceous marine shales, 70% of the proven reserves have been discovered in the reservoir units of the Sokor1 Formation, which is a deltaic to lacustrine deposit. This paper aims to analyse the hydrocarbon generative potential of the Sokor1 Formation source rock. Thirty-five selected cutting shale/mudstone samples from this formation were investigated with Rock-Eval pyrolysis and eight crude oil samples were examined through various biomarker parameters using GC and GC-MS techniques. The source rocks samples analyzed have total organic carbon (TOC) values ranging from 0.31 wt% to 4.66 wt% averaging 1.37 wt%. The hydrogen index (HI) ranges from 69 mg HC/g to 698 mg HC/g and S₂ values extend from 0.49 mg/g to 30.62 mg/g. T_{max} values ranged from 302°C to 444°C with an average of 426°C. The cross plot of HI versus T_{max} revealed type I, and II, grading to mix II-III and III kerogens. The organic matter content of the analyzed samples ranges from poor (M-5D) to excellent (M-5I). 80% of these samples have TOC values above 0.5 wt%, which is the threshold value for a hydrocarbon-generating source rock. The oil-prone kerogen is in the oil window, while the gas-prone and oil/gas-prone kerogens appear immature based on the HI versus T_{max} and HI versus TOC plots. The hydrocarbon production potential values ranged from 0.58 mg/g to 30.96 mg/g, showing that these source rocks are ranked from poor to excellent. Maturity biomarker parameters, such as the C₂₉ 20S/20R steranes and methylphenanthrene ratios, indicate that the oils analyzed derived from mature source rocks with the early to mid-phase of the oil generation window. Based on steranes (C₂₇, C₂₈, and C₂₉), the oils studied fall into the category of typical source rocks deposited in a deltaic environment. The T₂₆/T₂₅ versus steranes/hopanes diagram indicates a deltaic to marine depositional environment. The extended hopanes, which addresses anoxia, show that the source rocks for the oils studied were deposited in a dysoxic environment. The Sokor1 Formation source rocks are mainly composed of mature oil-prone kerogen with TOC values above the hydrocarbon generation threshold, indicating good to excellent petroleum potential. They are thermally matured and are at the early to middle generation of the oil stage. Biomarker analysis of crude oil samples indicates that oils are generated from the deltaic/marine deposited source rock, indicating the contribution of Sokor1 Formation source rock to the oil accumulated in this area.

Keywords: Total organic carbon, Thermal maturity, Biomarkers, Depositional environment, Termit Basin

Tele-petrography in the quantitative evaluation of petrophysical characteristics of reservoir rocks with the terra package: the case of sandstones

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Abstract

In the present work, the cement and/or matrix, pores and grains present in sandstones were quantified by tele-petrography. The selected sandstones come from the superficial formations of the Ivorian onshore basin and the deep formations of the offshore basin. A total of six sandstones, three from each part of Ivorian basin, were analyzed. The tele-petrographic analysis consisted of processing the images of these sandstones taken under the natural light from petrographic microscope to the "R" software using the "Terra" package. Results show that the quantification of sandstone components depends on the magnification of the microscope image, the grain size and the sorting. At low and medium magnifications, a small number of images per rock is sufficient to evaluate the proportions of the components. At high magnifications, however, a larger number of images is required as they tend to overestimate the proportions of grains at the expense of other components (porosity, cement, matrix), if the grains are poorly sorted. The presence of phenocrysts accentuates these variations. However, in well-sorted sandstones the proportions of components hardly vary from one image to another, at whatever magnification. Density curves and histograms reveal that the number of components on these curves depends on the proportions, i. e. the higher the proportion of a component the better it is represented, while low proportions remain invisible on the density curves. Remote sensing is therefore promising for the evaluation of the petrophysical properties of reservoir rocks.

Keywords: Tele-petrography, R software, Terra package, Sandstone, Porosity, Côte d'Ivoire

Seismic stratigraphic analysis for the characterisation of petroleum system elements, Walvis Basin, offshore Namibia

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Abstract

Seismic stratigraphy emerged in the 1970s and has evolved to sequence stratigraphy with the incorporation of outcrop and well data. Recognition of seismic stratigraphic units and their seismic facies, such as reflection configuration, frequency, and amplitudes, allow for prediction of lithofacies intervals that may contain source, seal, and reservoir lithologies. Namibia has four offshore basins, namely, the Orange Basin, which is down South of Namibia, bordering with South Africa; the Lüderitz Basin, the Walvis Basin and Namibe Basin. These basins were formed during the Late Jurassic to Early Cretaceous breakup of Gondwana. The Walvis Basin is under-explored. There is limited information on the lithofacies in the northern part of Walvis Basin. Seismic stratigraphic analysis of the post-rift mega sequence of the Namibian passive continental margin has enabled depositional features to be interpreted in terms of the likely controls on their formation. Seven wells have been drilled in Walvis Basin: Norsk Hydro (1911/10-1, 1911/15-1), Sasol (2012/13-1), Ranger (2213/6-1), HRT (Wingat-1, Murombe-1), Shell (Shark well-2313/5-1), Tullow (Cormorant-1) and Chariot (Prospect-S (2312/7-1)). These wells penetrate the post-rift succession from approximately 130Ma to recent and only well 2313/5-1 which is in the south of the basin penetrates older clastic syn-rift sediments. Therefore, the question of mature source and reservoir lithofacies presence and their preservation in northern Walvis Basin presents itself. The study aims to identify and delineate the key seismic sequences of the basin; establish the various seismic facies; and predict the major petroleum system elements within the basin (source, reservoir, traps etc). The advance understanding of the seismic stratigraphy and of source and reservoir lithologies in the northern Walvis Basin will resuscitate interest in exploring the Basin further and may potentially encourage new dataset acquisition and further drilling campaigns in the Basin. Quantitative methods will be used in this study. A Schlumberger Petrel E&P modelling software will be used for mapping seismic horizons, seismic lithofacies and seismic facies. Seismic sequence analysis; seismic facies analysis and prediction of the major petroleum system elements will be carried out on the seismic data by picking major unconformities choosing significant boundaries from well data and to generate facies maps.

Keywords: Seismic stratigraphy, Seismic facies, Lithofacies, Petroleum system

Petrographical Evaluation of sandstone reservoirs of selected wells in the Orange Basin, South Africa (Poster)

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Abstract

The primary aim of this study is to examine the sandstone reservoir rocks of four wells in the Orange Basin, South Africa, by referring to their textural maturity, mineralogical classification, and sediment provenance that will help to understand the effect of mineralogy on the quality of rocks. Thirty samples were used for petrographic analysis, and twenty-six were collected for modal count data. The results reveal that the sandstones of the lower Cretaceous sequence in the Orange Basin are composed of quartz (monocrystalline quartz more abundant than polycrystalline quartz), feldspars (plagioclase more abundant but subequal in some samples to K-feldspars) and lithic fragments (dominantly sedimentary lithic fragments with subordinate rank one and rank three metamorphic grains). The abundance or occurrence of non-undulatory quartz, rare polycrystalline quartz (welded), feldspars, and plagioclase feldspar twins indicate a dominantly igneous and subordinate metamorphic source. The occurrence of sedimentary lithic fragments with additional slate fragments also indicates a sedimentary origin that is partially metamorphosed. The occurrence of palaeovolcanic lithic fragments and the absence of no volcanic or plutonic rock fragments supports a recycled source terrain. The abundance of feldspars over plutonic rock fragments is likely a result of weathering and transport since the former is relatively unstable. A continental block and recycled provenance terrain were determined, showing the occurrence of a sutured belt provenance as a contributor to sediments into the basin based on its low content of volcanic detritus and high amounts of sedimentary lithics and slate fragments. A plutonic igneous provenance is not ruled out based on the occurrence of monocrystalline quartz with unit extinction and the feldspar content with its characteristics. This is further enhanced by the decrease in volcanic detritus with increased sedimentary lithic fragments, indicating that a sutured belt was involved in shedding sediments in the source area. The inter-sample variability (decrease in feldspar content) between the wells results from different depositional environments. The lower energy environments (prodelta, inter distributary bay and intertidal sandstones) have a lower feldspar content and a trend towards the quartz apex. The results from this study can be used as a diagnostic tool to determine the deposition of the environment and understand what factors will influence the reservoir quality.

Keywords: Petrography, Provenance, Reservoir quality, Orange Basin, South Africa

Giant Fields in Libya: A Review of Petroleum Systems, Reserves, and Future Prospectivity

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Abstract

Giant fields in Libya are in four main basins; Sirt Basin, Ghadames Basin, Murzuq Basin and Sebratah offshore Basin. The aims of this work are the following, 1-Reviewing the Petroleum Systems of the Giant Fields in Libya, 2: Reviewing the reserve of the giant fields in Libya, 3: Focusing on Future Prospectivity in Libyan Basins. Most of these giant fields are in Sirt Basin with 72 Billion barrels of original oil in place, 27 Billion barrels oil recovery, and 9.7 TCF gas recovery. The recoverable reserves of the giant fields are exceeding the billion-barrel amount of recovered oil, and henceforth classified as Billion Barrel Fields. The Maastrichtian/Campanian Late Cretaceous marine Sirt Shale is the main source rock in Sirt Basin's giant fields. This source rock is charging the underlain and overlain Early/Late Cretaceous clastic/carbonate reservoir. The second basin is Murzuq Basin, which contains two main fields; Al Shararah Field and the Elephant field, both fields produce from the Palaeozoic plays, with 5.2 Billion Barrels of original oil in place, and 1.8 of oil recovery. The main source rock in the area is the Silurian Tanezzuft Shale, while the reservoir is either the Ordovician Memouniat or the Silurian Acacus, besides the Awaynat wanin, and Mrar clastic reservoirs. The Ghadames Basin is like the Murzuq Basin, but it is younger in terms of the sediment infill. The basin consists of Al Wafa giant field west of the basin with 4 TCF recovered gas, which is produced from the Awaynat wanin F3 Sand and sourced from the Fransnian shale. The Sebratah Offshore Basin is also considered as one of important oil fields in Libya, it consists of Bouri Giant Field with 5.2 billion barrels of original oil in place, and 640 Million oil recovery, whereas, the gas recovery is 14 TCF. The main oil reservoir in this field is the Eocene Numulitic bank and the gas reservoir is Jdeir carbonates. New studies revealed that the stratigraphic traps and deep plays in many areas of Sirt Basin have possessed valuable amount of hydrocarbon still not explored yet. These areas considered as targeting areas for new prospectivity in the future, as all the necessary elements of petroleum system exist. There are also chance to discover more fields especially in the underexplored other Libyan basins e.g. Cyrenaica, Al- kufra, and offshore Sirt basins, hence can adding extra amount of hydrocarbon to Libyan reserve. The National Oil Corporation of Libya believes that the remaining prospectivity of the sedimentary basins of Libya will be driven fit-for-purpose G & G technologies. A strategic shift is underway to invite, test, employ and adopt these technologies soon. This will help to find the new major fields in deeper plays as well as stratigraphic targets.

Keywords: Giant Fields, Prospectivity, Petroleum system, Libya

Characterization of the reservoir and depositional environment of the Owambo Formation (Mulden Group) in the Owambo Basin, Namibia (Poster)

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Abstract

Reservoir characterization is the study of reservoir properties using geological, geophysical, petrophysical and engineering analysis, including uncertainty analysis of geologic and engineering data and spatial variations. The reconstruction of the depositional environment, defined as the environment that existed at the time of sediment deposition, and the understanding of earth processes and history are vital in the identification of possible exploration targets. This study will focus on the Owambo Basin, Northern Namibia, which is located between ~14° to 18°E and ~17 to 19°S, encompassing an area of approximately 80 000 square kilometres. Sandstones from the Nosib Group, carbonates from the Otavi Group and carbonates (limestones and dolostones) from the Owambo Formation (Mulden Group) have been identified as potential reservoir rocks. To date, five exploration wells (Strat Test-1, Etosha 1-1, Etosha 2-1, Etosha 5-1A and OPO-1) have been drilled, and three 2D-seismic acquisition campaigns plus numerous aerogravi-magnetic surveys have been conducted in the basin. No data on permeability and volume of shale or water saturation are available, but a literature study records the following: 1) soil gas surveys showed the presence of anomalous levels of methane, ethane, propane and butane, 2) 2D seismic data identified the ramp anticlines, stratigraphic traps and antiformal traps, 3) porosity in Otavi carbonates ranges from 15% in logs and 21-37% in outcrops, while in the upper Owambo Formation porosity is recorded as about 20% in outcrops. The overall objective of the study is to determine characteristics of reservoirs and the depositional environment of the Owambo Basin, which will be achieved by the study of wireline logs to delineate lithologies of potential reservoirs, analysis of petrophysical characteristics (porosity, permeability, volume of shale, water saturation) of the reservoir rocks and prediction of the Environment of Deposition (EOD). This study will utilize quantitative and qualitative methods to analyze data obtained from the National Petroleum Corporation of Namibia (NAMCOR). The Interactive Petrophysical Software (Petrel) will be applied to quantitatively determine petrophysical properties of reservoirs, while a qualitative approach will be applied to wireline log data (gamma ray, resistivity, neutron, etc.) to delineate and examine different reservoir lithologies as well as determine their depositional environments.

Keywords: Reservoir, Depositional environment, Owambo Formation, Wireline logs

Characterization of the reservoir potential of the H-T Field, Offshore Walvis Basin, Namibia

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Abstract

Reservoir characterization is a process that includes integrating, analyzing and understanding all available data from the well. Understanding the reservoir characteristics plays a pivotal role in optimizing the well performance. The two fundamental properties that govern the quality of reservoir rocks are porosity and permeability. In contrast, clay minerals have a significant influence on reservoir quality. Clay minerals include pore spaces, coat grain surfaces, and swell in the presence of water. Thus, petroleum drilling operations and reservoir management also become affected. The Walvis Basin is significantly under-explored, with only eight wells drilled to date. Some of these wells have confirmed the presence of Lower Cretaceous clastic and carbonate reservoirs and have proven oil-based working petroleum system with two thick, rich mature source rocks within the Aptian interval. Good-quality reservoirs are confirmed to be present at the Cenomanian and Santonian formations. The main aim of this study is to characterize the potential reservoirs intersected by three wells within the Walvis Basin. The results of graphical techniques and conventional formation evaluation workflow identify potential reservoir zones and reveal the reservoir properties of the wells through the integration of well logs and core analysis datasets. This study's expected outcomes include the identification of thin-bedded-sandy reservoirs saturated by oil, possible oil-water contact (OWC), good reservoir quality with up to 25% porosity, showing fair to good permeability values and high net-to-gross ratios of up to 0.75.

Keywords: Reservoir characterization, Offshore, Walvis Basin, Well performance, Well-log interpretation, Potential reservoir

Petroleum Potential of Part of the Deep Offshore, Niger Delta Basin, Nigeria: Insights from Palynofacies and Sequence Stratigraphic Studies (Poster)

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Abstract

Palynofacies and sequence stratigraphic study of the strata penetrated by wells D-1 and BL-1X was carried out. This research aims at studying sedimentary successions penetrated by the above wells in order to determine the ages and environment of deposition, establish the sequence stratigraphic framework of the analyzed sections and correlate them to make geological inferences. A total of two hundred and thirteen (213) ditch cutting samples (D-1= 109 and BL-1X= 104) within the interval 8060-16860 ft and 7900-13000 ft composited at 60 ft intervals were analyzed. The standard acid method of sample preparation for palynofacies study was followed. The lithology consists of alternating shale and sandstone units. The sandstones are fine- to medium-grained (occasionally coarse-grained), mostly subangular to subrounded, but occasionally rounded, and generally moderately sorted. Accessories include a few records of ferruginous material, shell fragments, and abundant records of mica flakes, glauconite and pyrite. The lithologic and textural characteristics indicate that the studied intervals in the D-1 and BL-1X wells belong to the Agbada Formation. The palynofacies analysis yielded low to moderate recovery of palynomorphs, abundant small-size palynomacerals 1 and 2, and moderate records of palynomacerals 3 and 4 at various intervals. Based on the international stratigraphic guide for the establishment of biozones, five (5) palynostratigraphic zones were established in well D-1 and three (3) in well BL-1X. In well D-1 these are a *Pachydermites diederixi* - *Magnastriatites howardii* zone, a *Crassoretitriletes vanraadshoveni* - *Pachydermites diederixi* zone, a *Belskipollis elegans* - *Crassoretitriletes vanraadshoveni* zone, a *Verrutricolporites rotundiporus* - *Belskipollis elegans* zone and a *Nymphaepollis clarus* zone, while in well BL-1X a *Pachydermites diederixi* - *Magnastriatites howardii* zone, a *Crassoretitriletes vanraadshoveni* - *Pachydermites diederixi* zone and a *Cyperaceapollis sp.* - *Crassoretitriletes vanraadshoveni* zone were differentiated. The studied intervals were dated early Miocene to late Miocene based on the stratigraphic age range of marker species, with the D(oro)-1 well spanning up to Early Pliocene. System tracts and chronostratigraphic surfaces dated accordingly. The shales of the maximum flooding surfaces are potential source rocks, while the sandstone and shale units of the systems tracts are potential hydrocarbon reservoirs and seal rocks, respectively.

Keywords: Sediments, Agbada Formation, Miocene, System tracts, Hydrocarbon

An Outcrop Analogue Study of the Potential Unconventional Hydrocarbon Reservoirs of the Whitehill Formation, Ecça Group, Within the Karasburg Basin, southern Namibia (Poster)

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Abstract

The Whitehill and Collingham formations of the Ecça Group in the main Karoo Basin, South Africa are thought to have a huge potential for unconventional shale gas. Formations in the Main Karoo Basin of South Africa have been correlated to those in the Karoo Basins of Namibia mainly through radiometric dating and stratigraphy. The stratigraphy and radiometric dating also correlate the rocks between the Karoo Basins in Namibia and South Africa. The shale in the Karoo Basin within South Africa has a high reservoir potential for unconventional shale gas. Therefore, the shale within the Karasburg Basin in Namibia will be investigated to assess the reservoir potential, given that the shale in the Karasburg Basin forms part of the Whitehill Formation. The evaluation of potential unconventional shale gas reservoirs in the Karasburg Basin is beneficial as only limited studies have been conducted in the basin and this is mainly due to the lack of exploration leading to scarcity of existing drill core data. In order to overcome this problem, this research aims to conduct an outcrop analogue study focusing on characterizing potential reservoirs in the Whitehill Formation, Ecça Group within the Karasburg Basin, southern Namibia. Detailed outcrop logging and facies analysis will be conducted to create a stratigraphic sequence column and samples will be taken for petrographic analyses. Samples will be analysed for mineralogy, porosity, permeability, and total organic carbon content (TOC). To sum up, the results will verify potential unconventional hydrocarbons within the Karasburg Basin.

Keywords: Karasburg Basin, Whitehill Formation, Reservoir, Shale, Total Organic Carbon

Litho- and organic geochemical characterisation of the Umutu-2 and Umutu-5 wells, northwestern Onshore Niger Delta: Implications for hydro-carbon potential and maturation

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Abstract

The Niger Delta on the Gulf of Guinea continental margin, equatorial West Africa has an area of about 300 00km² and a sediment thickness of over 10km in the basin depocenter. Geochemical evaluation of cutting samples from the Umutu-2 and Umutu-5 wells in Oil Mining Lease (OML) Block 38, Onshore Niger Delta, was carried out to identify the provenance, tectonic history, palaeoclimatic and palaeo-depositional environment conditions of the source rock, and to determine the hydrocarbon potential, type, maturity and functional groups of the organic matter. The geochemical analytical techniques employed for this study are Lithium Borate Fusion Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Total Organic Carbon (TOC), Rock-Eval pyrolysis, and Fourier Transform Infrared Spectroscopy (FTIR). The lithology of the wells comprises shale, shaley sand, sandy shale, and sand. The litho-geochemical results indicate the abundance of SiO₂ (av. 87.02%), Al₂O₃ (av. 4.07%), Fe₂O₃ (av. 1.97%), and CaO (av. 2.20%), suggesting mineralogically matured sediments. The sediments are classified chemically as sub-litharenite, Fe-rich sandstone, subarkose and litharenite. The AKF plot revealed that the sediments were deposited in continental to marine environments, with palaeoclimatic conditions indicating semi-humid and humid palaeoclimatic conditions. The Discriminant Function diagram revealed the provenance of the sediments to be felsic igneous, intermediate igneous, and mafic igneous. The Tectonic Discriminant Function diagram revealed that the sediments were deposited in Passive Margin, Active Continental Margin, and Island arc tectonic settings. The TOC ranged from 0.89 wt. % - 26.00 wt. %, exceeding the threshold (0.5 wt. %) needed for petroleum generation. The plot of the Hydrogen Index (HI) versus Oxygen Index (OI) revealed that the organic matter is of kerogen type II, III, and IV, capable of generating oil and gas. The T_{max} values ranged from 384°C- 421°C. The calculated Vitrinite Reflectance range of 0.18% - 0.42% indicates that the source rock is thermally immature. The FTIR application for kerogen typing revealed that the organic matter is of Type I and II, which marginally supports the Rock-Eval results. The Vitrinite Reflectance equivalent from the A-factor versus C-factor plot was identified between 0.2 and 0.5, indicating an immature source rock, further substantiating the thermal maturity deduction from the Rock-Eval result. The major functional groups observed from the IR spectrum have wavelengths ranging from 450 - 3700 cm⁻¹. Overall, the sediments are mainly mineralogically mature sublitharenite and Fe-rich sandstone sourced from felsic igneous, intermediate igneous, and mafic igneous rocks, deposited in continental to marine environments of Passive Margin, Active Continental Margin, and Island arc tectonic settings. The prominent functional groups are alcohol, secondary amine, alkane, methyl group, alkene, benzene, and halo compounds. The source rock has the potential to generate oil and gas at appropriate maturity.

Keywords: Lithology, Provenance, Total Organic Carbon, Fourier Transform Infrared Spectroscopy, Functional groups

Hydrocarbon Potential of the Nigerian Sector of the Cretaceous Mamfe Basin, Southeastern Nigeria: Insight from Geochemistry, Sedimentology and Aeromagnetic Analysis

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Abstract

An integrated approach involving petroleum geochemistry, sedimentology and aeromagnetic studies was used to evaluate the hydrocarbon potential of the Nigerian sector of the Cretaceous Mamfe Basin. Twenty-five (25) outcrop samples comprising of shales, mudstones, and siltstones were subjected to organic geochemical analyses involving total organic carbon content (TOC), Rock-Eval pyrolysis, vitrinite reflectance (VR), and Visual kerogen analysis (VKA) to provide insight on the quantity, quality and thermal maturity of the organic matter in the sediments. Thin section petrography, X-ray diffraction (XRD) and scanning electron microscope (SEM) were carried out on the sandstone samples, to characterize the reservoir quality. Structural elements in the basin were studied using aeromagnetic data. Results show that the TOC values range from 0.06-3.08 wt.% with average value of 0.56 wt.%. S₁ values range from 0.03 –0.70 mg HC/g rock, with average value of 0.12 mg HC/g rock, S₂ values range from 0.03 –1.14 mg HC/g rock, averaging 0.17mg HC/g rock, and HI values range from 6 – 53 mg HC/g TOC, averaging 32mg HC/g TOC. T_{max} and Vitrinite reflectance values ranged from 340°C- 514°C and 0.00- 2.09% respectively. VKA shows abundance of phytoclasts (vitrinite) and pyrobitumen. Petrography, X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses revealed that the reservoirs are coarse-fine grained, poor-well sorted, and angular-rounded subarkose sandstones. The sandstones have undergone a wide range of diagenetic alterations, with the primary and secondary pore spaces predominantly occluded by clay mineral cement. Mechanical compaction and cementation are the main pore reducing processes identified. The pore-spaces are randomly distributed and largely disconnected from one another. Aeromagnetic interpretation revealed that the basin is intensely fractured with major regional faults trending in the NE-SW direction; thus, aligning with the Benue Trough trend. The TOC and Rock-Eval parameters generally indicate poor-fair hydrocarbon generative potential, with mainly humic type III and reworked/oxidized type IV kerogens. The maceral results which indicate low organic matter and large amounts of non-fluorescent organic matter and pyrobitumen, is also consistent with the above assessment. The dominance of Type III organic matter suggests gas prone source rock. The T_{max} and vitrinite reflectance indicate the organic matter are generally immature, and overcooked. Although the source rock parameters suggest poor-fair hydrocarbon potential, with the occurrence of adequate sediment thickness, reservoir quality rocks, potential traps and seals, the Nigeria sector of the Mamfe Basin deserves a more detailed assessment to unravel its prospectivity. Mature quality source rocks may occur in the more deeply buried sections of the basin.

Keywords: Mamfe Basin, Petroleum geochemistry, Hydrocarbon potential, Sedimentology, Aeromagnetic analysis, Nigeria

A three-dimensional geological model of the Main Karoo Basin of southern South Africa (Poster)

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Abstract

A regional three-dimensional (3D) stratigraphic model of the main Karoo Basin of southern South Africa has been produced using Leapfrog© software. Currently, there has been no regional 3D geological model to characterise and assist with shale gas resource estimation of the target Whitehill Formation in the southern Main Karoo Basin. Data used was obtained from the Council for Geoscience (CGS) and included Southern Oil Exploration Corporation (SOEKOR) borehole records, which were the principal data source, supplemented by the Karoo Research Initiative (KARIN) deep boreholes (up to 2400 m) drilled in 2016, seismic profiles and a 3000 m deep borehole, KDD-01, completed in 2021. A hundred and seventy-six additional control points were created to better constrain the 3D model and to improve layer extrapolation beneath the surface. This model is at regional scale compared to the local scaled model completed in 2016. The model encompasses the entire Ecca and Dwyka Group successions of the Karoo Supergroup consisting of up to 3000 metres of sedimentary rock and covering an area of 191008.92 km². The underlying basement is represented by the Precambrian Namaqua-Natal metamorphic province, while the Cape Supergroup overlies the Karoo strata. The successfully created model provides a realistic rendering of the intricate Jurassic-age dolerite system at depth and a more accurate correlation of the topography and geology of the Main Karoo Basin. Features added to the model include regional and local faults, airborne data, shallow percussion boreholes and magnetic data captured for the Karoo Deep Drilling programme of the CGS. The 3D model is expected to continuously evolve with the collection/incorporation of new data, thus allowing the characterisation of the southern part of the Main Karoo Basin as a potential area for shale gas exploration; the model format can readily support shale gas resource estimates of the target Whitehill Formation.

Keywords: 3D model, Main Karoo Basin, Boreholes, Shale gas exploration

Review of the Hydrocarbon Potential of the Permian Karoo Deposits, Mid-Zambezi Basin, Zambia, based on Palaeontological and Geochemical Data

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Abstract

Hydrocarbon prospectivity and scholarly research has centered around three basins; the Barotse, Luangwa and Mid-Zambezi Rift. So far, a suite of data has been generated including MPOG (Microbial Prospection of Oil and Gas) (unpublished), 2D Seismic surveys, two (2) wildcat wells and eighty (8) shallow Boreholes by Zambia Geological Survey Department. Research work has so far been reliant on exposed sedimentary outcrops. However, Basin correlation is challenging as relatively little work has been conducted to constrain the depositional ages of the Karoo Basin that outcrops in Zambia, despite their rich palaeontological records. One such basin; the Mid-Zambezi Basin (MZB), contains Karoo-aged sediments of late Carboniferous–Middle Jurassic age that have been studied since the 1970s; and it has been observed that the Madumabisa mudstone fluvial sequence within the lacustrine origin, gradationally overlies the substantial coal-bearing sequence, the Permian Gwembe coal. The Permian rock suites in the Mid-Zambezi Basin are yet to be fully studied. Studies have been done to fully characterize the petroleum system elements and processes in this part of the basin, a few thermal alteration index (TAI) values ranging within -2 to +2 have been presented. There was little attention to non-coal bearing sequences during the 1960s subsurface investigations, in addition to small sampled area for palynological studies. Therefore, studies ended up suggesting that pollens and pores were not sufficiently abundant for quantitative analysis. Samples from previous work were thus far only subjected to standard palynological processing techniques. The occurrence of macrofossils and microfossils in this basin gives considerable interest to further conduct micropalaeontological studies; for significant microfossil distribution and frequency, and TOC values especially on Carbonaceous Mudstones of the Gwembe Formation. Geochemical analysis will further contribute in drawing quantitative and qualitative conclusions on hydrocarbon potential of the Permian Mid-Zambezi Basin.

Keywords: Source rock, Coal formation, Carbonaceous material, Microfossils, Distribution

Assessing Source Rock Potential and Hydrocarbon Generation in the Cretaceous Strata of the Mamfe Basin, Southwest Cameroon (Poster)

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Abstract

study focuses on the characterization of shale samples from the Cretaceous strata in the Mamfe Basin, located in southwestern Cameroon. The main objective was to determine the source of organic matter input, evaluate thermal maturity, determine palaeo-environmental conditions, and assess the hydrocarbon generative potential of the shale. Sixteen samples were collected and analyzed for total organic carbon (TOC) content and Rock Eval parameters. Organic petrographic analysis was performed to identify the maceral composition of the organic matter. Seven samples with enough TOC content were selected for further analysis, including fractionation, gas chromatography-flame ionization detection (GC-FID) and GC-mass spectrometry. The TOC content of the shale ranged from 0.17 to 4.53 wt.%, indicating poor to good source rock generative potential. The range of volatile hydrocarbon content (S1) in the rocks was observed to vary from 0.04 to 1.25 mg HC/g, while the remaining hydrocarbon generative potential (S2) ranged from 0.04 to 12.75 mg HC/g. These values indicate a spectrum of source rock generative potential, spanning from poor to good quality. The hydrogen index (HI) exhibited a range of 10-281 mg HC/TOC. Cross plots analyzing S2 vs. TOC, and HI versus oxygen index revealed that the kerogen falls under type III and IV, implying the presence of organic matter prone to gas formation. The thermal maturity parameters, such as Tmax (ranging from 451 to 549°C) and vitrinite reflectance values (0.55 to 0.82 %Ro), provide insights into the degree of heat exposure. The cross plot displaying the production index versus Tmax suggests that the organic matter has undergone transformation, resulting in the creation of condensate wet gas and dry gas. These findings indicate the influence of post-Cretaceous igneous activities in the basin on hydrocarbon formation. Analysis of organic petrography in the shales revealed the presence of vitrinite (4.9%) and inertinite (3.4%) macerals, indicating that the organic matter is gas-prone and originated from terrestrial sources. The Carbon Preference Index of 1.0, Trisnorneohopane/Trisnorhopane (Ts/Tm) ratio ranging from 0.33 to 0.63, and moretane/hopane (M/H) ratio ranging from 0.16 to 0.27 suggest that the shales have reached maturity for hydrocarbon generation. The Pristane/Phytane (Pr/Ph) ratio values varying from 0.60 to 1.71, along with the higher abundance of regular C₂₉ steranes (32.0 – 43.0%) compared to C₂₇ (30.0 – 39.0%) and C₂₈ (27.0 – 33.0%), indicate a predominantly terrestrial plant source for the organic matter, with some minor influences from lacustrine and marine sources. The oleanane index ranged from 0.10 to 0.23, further supporting the dominance of terrigenous organic matter in the sediments. The gammacerane index of 0.07 to 0.23 suggests that the organic matter has been preserved under sub-oxic to relatively anoxic conditions. The hydrocarbon generative potential of the Mamfe basin is considered fair, with a predominance of gas-prone kerogen. The shales have reached thermal maturity up to post-mature levels, possibly due to the igneous activities that occurred after the Cretaceous period within the basin.

Keywords: Shale, Organic matter, Thermal maturity, Palaeo-environmental conditions

Characterization of particulate organic matter from outcrops in the Maniamba Basin, Mozambique, as an aid for petroleum exploration

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Abstract

Studies of petroleum prospecting in the Maniamba Basin in Mozambique do not exist, however, inferences of gas potential have been postulated theoretically. Here, the palynofacies and thermal maturity techniques are investigated in order to determine the quality, quantity, thermal maturation, palaeoenvironments and potential for hydrocarbon generation in the Basin. In this regard, 21 samples consisting of dark and less oxidized siltstones, claystones and carbonaceous shales from four Permian outcrops were collected in the Maniamba Basin, Karoo sites in Mozambique. The samples were prepared following the standard techniques used in palynology and palynofacies analyses. Later on, the particulate organic matter was identified and quantified under transmitted light microscopy. Two Ternary diagrams for palaeoenvironment reconstruction consisting of the proportion of Phytoclast (opaque and non-opaque), Palynomorphs and Amorphous Organic matter, were applied. To achieve a feasible quantitative analysis 300 organic particulate matter were counted per slide. The variation of the colour of selected sporomorphs *Laevigatosporites plicatus* was used to infer the preliminary thermal maturation as Rock eval data are not available yet. It was observed that the phytoclast group is the most dominant particulate organic matter, followed by palynomorphs and lastly by the small amounts of amorphous organic matter (AOM). As a result, three palynofacies were established namely Palynofacies A, dominated by phytoclast and palynomorphs, Palynofacies B, dominated by phytoclasts and AOM and Palynofacies C, dominated by phytoclasts and palynomorphs. The identified proportions of organic matter suggest a highly proximal Basin with notable oxic to anoxic conditions typical of fluvio-lacustrine deposits. Additionally, oxidized and forest swamps were also identified in the area. The Spore colour Index (SCI) integrated with the Thermal Maturation Index (TAI) of the sediments indicates maturation stages of organic matter ranging from immature to supermature, suggesting a window for the generation of gas rather than oil.

Finally, kerogen types II, III and IV were observed for most of the outcrops pointing to the potential for generation of wet gas, condensate and dry gas in the Maniamba Basin, thus corroborating with the thermal maturation data.

Keywords: Maniamba Basin, Organic matter, Palynofacies, Hydrocarbon

Preliminary Investigation on the Occurrence and Petrographic Characteristics of Agbaja Coals, Southern Bida Basin, Nigeria

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Abstract

The Bida Basin is one of the frontier basins in Nigeria with largely clastic sedimentary fill of late Cretaceous age. In recent time, understanding the stratigraphic evolution, depositional styles and fossil fuel resource potential of the Bida Basin, Nigeria have been the focus of research activities for reasons not unconnected with efforts at boosting the nation's economy through development of inland sedimentary basins. In this paper, we examined the occurrence of coal deposits at Agbaja Plateau near the Niger and Benue rivers confluence and their compositional characteristics. Representative samples of the coals which occur interbedded with shales, siltstone and sandstones in a coarsening upward mode, were obtained and subjected to organic petrologic, proximate and ultimate analyses. The results show that Vitrinite **V** is the dominant maceral group ranging from 52 to 80% by volume, Inertinite **I** (12.0 to 44.0%) and Liptinite **L** (0.7 to 9.5%). Alginite is absent in all the samples tested. Mineral matter is represented dominantly by clays while pyrite is rare. The reflectance **R_o** of vitrinite ranges from 0.44 to 0.46%. These reflectance values and fluorescence of liptinite indicate that the coal is of sub-bituminous rank. The coals have calorific values ranging from 6.67 to 21.96 MJ/Kg and Fixed Carbon from 1.52 to 42.71%. Values of C, H and S obtained from the Ultimate analysis ranges from 10.02 to 65.77%, 3.7 to 5.99% and 15.81 to 17.65% respectively. The results of this study suggest that the coal seams occur in association with coastal to non-marine shales, siltstones and sandstones at Agbaja Plateau, Bida Basin. They are thermally immature and of sub-bituminous rank. Absence of alginite and high amount of vitrinite indicate derivation from terrestrial source and gaseous hydrocarbon potential. This contribution is significant because it presents the first scientific report of occurrence of coal deposits and their characteristics in the southern Bida Basin. Its implication on the origin and stratigraphy of the basin is also underscored.

Keywords: Agbaja, Bbituminous, Coal, Maastrichtian, Vitrinite

The Hydrocarbon Potential of the Eastern Caprivi-Kafue Basin, Onshore Namibia

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Abstract

Eastern Caprivi-Kafue basin is part of the southwestern branch of East African Rift System (EARS) that extends further southwest to the Okavango delta. The basin has not been drilled deep enough to fully assess its hydrocarbon potential. The presence of a prominent gravity low in Caprivi that extends to Kafue trough in Zambia -where seismic and well data proof the occurrence of Karoo system sediments-, support the existence of a deep permo-cretaceous basin that could hold all elements and processes of an active petroleum system. The analysis of the structure, stratigraphy, and hydrocarbon source potential of surrounding basins (Mid-Zambezi, Luangwa, Cabora Bassa) of SARS has shown similarities, which motivate the execution of more exploration work in the basin: Invictus Energy Ltd, license holder of block SG4571 within the Permo-Cretaceous Cabora Bassa basin has encountered indications of presence of active hydrocarbon systems in its recently drilled the Mukuyu well. On the other hand, within the Mid-Zambezi basin that represents the closest rift basin analogue to the Caprivi-Kafue basin, breccia oil occurrence has been documented, possibly generated from swampy lacustrine or lacustrine influenced source rock. For this study, gravity, and magnetic data, as well as other public domain geological and geophysical information were used. Filters and transformation on the magnetic and gravity data revealed a thick Permian to Cretaceous basin (average depth to basement is 4000m but some areas up to 7000m). High resolution magnetic data (50X50mgrid) shows a potential kitchen zone with favorable structures representing an attractive scenario for exploration. TOC-rich shales and coals in the Permian could provide hydrocarbons generation (e.g. Madumabisa Mudstone, Black shale and coal Group). Clastic reservoirs expected throughout Karoo section (e.g. Wankie Sandstone, Escarpment grit). Low risk of seal presence, several intervals with thick claystone and shales, variety of stratigraphic, structural, and combined traps are expected.

Keywords: East African Rift System (EARS), Hydrocarbon potential, Structural, Stratigraphic and combined traps

Fluid replacement effects on reservoir properties during hydrocarbon production in X-Field, Onshore Niger Delta, Nigeria

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Abstract

During hydrocarbon production, fluid replacement occurs in reservoirs and this has an impact on the reservoir properties and consequently, alters production forecast and models. This study is aimed at producing geological model that can serve as a predictive tool for reservoir monitoring and field development. The properties were harnessed to constrain fluid replacement modeling (FRM) at different reservoir conditions. The FRM was carried out using petrophysical and well-based rock-physics analyses of the wells A1, A2 and A3 of X-field, onshore Niger Delta. Petrophysical analysis was done to determine the fluid saturations, porosity, net-gross ratio (NGR) and shale volume (V_{sh}) while rock-physics analysis was employed to dynamically characterise the reservoirs and estimate its responses to fluid substitution during production. Lithological identification, V_{sh} , brine and hydrocarbon bearing sands and fluid contacts were determined using Gamma ray (GR), Neutron-Density combination and resistivity logs respectively. The reservoir mechanical properties such as Young (E), Bulk (K) and Shear moduli (G), Unconfined compressive strength (UCS) and Compressibility (Cb) were derived from elastic properties (compressional (V_p) and shear wave (V_s) velocities and density, ρ). Five hydrocarbon reservoirs (A-D) were delineated with average values of 67%, 69%, 69% and 70% hydrocarbon saturation (S_h) across the wells. The NGR values reduces from proximal to distal due to reduction in depositional energy. The reservoirs were relatively clean with shale volume less than 15% threshold. V_{sh} Increased in the direction of lower hydrodynamic flow due to reduction in depositional energy. The FRM involving forward modeling showed a steady increase in ρ due to gradual increase in G and K as brine replaced hydrocarbon. Unconventional attenuation of V_p from 3.09-3.04, 3.13-3.08, 3.92-3.86, 3.53-3.49 and 3.87-3.80 km/s in A of A1 and A3, and D of A1, A2 and A3, respectively, were due to dissolved gases. Therefore, as water gradually replaces hydrocarbon in the reservoirs, the shearing ability of the rock decreases. The UCS increases exponentially with S_w except in reservoirs with dissolved gasses. The increase in UCS in most of the reservoirs imply an increase in mechanical and well-bored stability, while decrease in UCS and E in A and D of A1 and A3, may cause well-bore collapse. These models provide means to address production challenges arising from increasing water saturation, and could be used for reservoir monitoring and field development during oil and gas production.

Keywords: Rock-physics, Bulk modulus, Young modulus, Shear modulus, Unconfined compressive strength

Hydrocarbon Generation Potentials and Petrophysical Analysis of the Cretaceous Source and Reservoir Rocks Within the Salamat Basin, Central African Republic (CAR)

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Abstract

Since the independence of the Central African Republic, no viable or commercial quantities of oil and gas have been discovered in any of its sedimentary basins despite the presence of geological structures that could trap the hydrocarbon. Also, the Salamat basin has witnessed less exploration and published reports are limited. It is therefore imperative to understand the hydrocarbon prospectivity of the Salamat Basin using available subsurface data. This study focused on the determination of the maturity, timing, and distribution of hydrocarbon generation of the Cretaceous source rocks and the intrinsic petrophysical attributes of reservoirs in Aoukalé 1 well within the Salamat Basin. The available subsurface data namely: suites of well logs of Aoukale 1 well and 2-D seismic lines were digitized and analyzed using appropriate software. Check-shot, geochemical and biostratigraphic data of the Aoukale 1 well was also provided to evaluate the hydrocarbon generation potentials of the Cretaceous source rocks. 2D basin modeling was then carried out. The lithologic units are mainly shale and sandstone. Nine (9) reservoir intervals identified on log data show high resistivity indicative of hydrocarbon-bearing zones. All the reservoir sands have good porosities ranging from 15% to 25% and moderate to good permeability values ranging from 15 to 49 mD essential for hydrocarbon production. The water saturation values of RES-I and RES-VII are 29% and 28% respectively, which indicate high hydrocarbon saturation. The mapped source rocks started hydrocarbon generation during the Barremian and entered the main oil generation during the Aptian. Simulated model results revealed that sufficient generation for expulsion has occurred in the area of deepest burial.

The development of simulated models has provided clearer information on the Cretaceous rocks of the Salamat Basin which is valuable in future exploration targets. The presence of heavy oil in the basin may be due to trap and seal integrity.

Keywords: Hydrocarbon, Barremian, Aptian, Burial, Salamat Basin, Central African Republic

The Hydrocarbon Potential of the Northern Lüderitz Basin, Offshore Namibia

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Abstract

Along the Namibian margin, four main depocentres are recognized from north to south: Namibe, Walvis, Lüderitz and Orange basins. Although all of them are equally prospective only the Orange Basin has received major attention due to four recent light oil discoveries made by Total and Shell as operators, in addition to the Kudu Gas field discovered 1974. The aim of this study is to evaluate the hydrocarbon potential of the northern Lüderitz basin, with focus on Blocks 2412B and 2413B, covering an extension of 11,000km². More than 6,000km of 2D reflection seismic data has been acquired over the area of interest of which 4,485km were used by the authors, including two different vintages 2013 and 2019. The line spacing is 2-5km on average, providing a very good data grid. Twenty-six seismic horizons were interpreted featuring regional stratigraphic elements and specific exploration targets. Data from the well 2513/8-1, drilled in 1995 in the continental shelf was also available. A major submarine canyon which developed during Albian to Palaeogene times was identified and mapped across the area, showing a complex architecture with channel systems being developed initially in the south and migrating north as they get younger in the stratigraphy. The first channels (Albian) were deposited right on top of the Aptian Kudu shale (source rock) and represent the main target for exploration, displaying excellent amplitude anomalies distribution and some four-way closures in detached sections along the system. Secondary targets have been mapped within the Cenomanian and Santonian-Campanian channels. The Kudu Shale is expected to be mature providing access to charge to several identified leads. Multiple Direct Hydrocarbon Indicators (DHIs) such as shallow gas, gas chimneys have been mapped. A total of 16 leads are included in the inventory with initial volumes estimated over the four billion barrels of oil in place according to the best-case scenario. The work carried out allowed the identification of high priority areas where 3D seismic data will be acquired, bringing the project to a new level with the de-risking and ranking of the main leads and the selection of drillable prospects. The Northern Lüderitz Basin has all the necessary ingredients for a successful discovery, all petroleum system elements and processes has been identified and studied obtaining a very high confidence over the Cretaceous turbidites.

Keywords: Lüderitz Basin, Hydrocarbon potential, Canyon, Albian channels, Kudu shale, DHIs

The Petroleum Systems and Play Concepts of the Owambo Formation Within the Owambo Basin

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Abstract

Owambo Basin is a classical foreland basin in the northern part of Namibia developed through a strenuous history of rifting and compressional events since the Neoproterozoic. It is bordered by Namibia in the south, Angola in the north and possibly extends into southwestern Zambia. The extensional styles in the basin are the structural forms that indicate the beginning of the rifting of Rodinia continent which led to the deposition of the Nosib Group. The arch that bounds the basin resulted from the D₁ deformation episode characterized by E – W transpressive stress of the Kaoko and the N-S collisional stress grain of the Damara Belt. The subsequent D₂ deformation event at around 600 Ma folded the Mulden and underlying Otavi rocks to generate the dominant current structural manifestation of the basin. The final grain ensemble doubly plunging F₂ anticlines and synclines with an east-west polarity along the southern margin and N-S along the western margin. Karoo-related wrench deformation formed due to strike-slip deformation and folded the younger Karoo and Kalahari sediments. The evolution of the basin through geological time favoured the conditions for essential elements and processes of the petroleum system to be formed. This includes the source and reservoir rocks, seals, traps formation and generation-migration-accumulation of hydrocarbons. It appears that an active hydrocarbon system is present in the basin. The Owambo Basin is relatively underexplored with very few well data to constrain the geology. Exploration in the basin dates back to the 1950s. Although it has been over 60 years since exploration commenced in the basin, there is however no commercial discovery of hydrocarbon to-date. The exploration activities happened over short periods of time followed by long periods of inactivity. To date, few exploration wells have been drilled so far and few aeromagnetic, gravity and 2D seismic surveys have been completed. The existing seismic data does not properly elucidate the structural styles, direct hydrocarbon indications and migration. The lack of well and seismic data within the basin has resulted in poor understanding of the variable components of the petroleum systems and how they communicate. This project aims to provide understanding of the communication between the petroleum systems and their corresponding plays by using petroleum system investigations, to understand the structural regimes and migration conduits using seismic and to map out potential exploration area using a variety of software. By getting a better understanding of the structural regimes and the migration conduits feeding potential traps, we will be able to map out potential exploration targets. This will strengthen our knowledge of the Owambo Basin and move us closer to exposing its untapped potential.

Keywords: Foreland basin, Anticlines, Essential elements, Petroleum systems, Play

Hydrocarbon potential in Africa

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Abstract

With Total Energy's 2022 Venus-1 discovery and Shell's Graff-1 discovery the Orange Basin offshore Namibia has become the probably most sought-after petroleum province. These two discoveries halted the perception that oil companies rather divest across Africa, especially in frontier exploration. It is true, that Africa's share of global oil output has declined from 12.3% in 2010 to only 8.1% in 2021. The discoveries offshore Namibia came at the right time, as oil prices passed their last low in 2020 and do now constantly exceed 50US\$/barrel. As Shell made their third discovery with the Jonker-1x well, Chevron and Woodside Energy bought stakes in neighboring blocks, indicating the revived interest in frontier exploration. Namibia is not the only new E&P hotspot: The Baleine field, Côte d'Ivoire's largest discovery of 2021, is under development already. Other African projects, such as the pipeline from Kabaale in Uganda to Tanga Port in Tanzania is getting closer to its realization, and investments following the more recent discoveries in West Africa are likely; e.g., Senegal's 20tcf Yakaar-Teranga natural gas discovery could go into production next year. Herewith Africa's E&P landscape will no longer be dominated by the established producers such as Angola and Nigeria. Frontier exploration has proven to be successful, and with further discoveries Africa could be soon seen as an oil producing continent, in which several countries could enter a phase of unprecedented economic growth. Despite these opportunities, the pressure on Africa's oil and gas sector is growing. Global policies towards decarbonization challenges funding of oil and gas projects. In addition, reliance on oil and gas revenues could become riskier to oil producing countries. On the other side, Africa's energy demand could be 30% higher in 2040 than today, while global energy demand is predicted to increase by 10%. Therefore, the demand in fossil energy fuels will likely stay high for the next few decades during the ongoing energy transition. Natural gas, having a relatively low carbon footprint, will likely grow in demand as a transitional energy source.

Keywords: Africa, Frontier exploration, Orange Basin, Energy outlook

ST11: INVESTMENT IN THE MINERAL INDUSTRY: POLICY ISSUES, LEGISLATIONS, CHALLENGES, GOVERNANCE, AND BEST PRACTICES

ST11_S01: Implementation of a continental system for management of Africa's mineral and energy resources: the African Mineral and Energy Resources Classification and Management System (AMREC) and Pan-African Resource Reporting Code (PARC) (Special Session)

Africa Mineral and Energy Resources Classification and Management System (AMREC) and Pan-African Resource Reporting Code (PARC) Fundamentals for Sustainable Development of Africa's Minerals: Current State of Continental Implementation

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Abstract

AMREC and PARC are two critical tools for the realization of Africa Mining Vision (AMV). AMV, adopted by Heads of States in Africa in 2009, is a blueprint for resolving the stark paradox that Africa's vast mineral wealth exists side by side with pervasive poverty. One of the key objectives of the AMV is to achieve a step-change in the contribution of the minerals sector to sustainable development in the Africa region. A priority is to address a historical deficiency in its capacity to manage and optimize value from its abundant mineral and energy resources. Africa's abundance of mineral and petroleum resources has failed to deliver socio-economic benefits to its people. "Resource curse" is the sentiment often associated with Africa's mineral and oil wealth. Africa loses over USD 80 billion through Illicit Financial Flows (IFF) and Base Erosion and Profit Shifting (BEPS) mainly through the malpractices of multinational corporations. AMREC is a system tailored specifically to address Africa's challenges and therefore an essential tool to implement AMV and realize its grand objectives. AMREC will ensure proper resource estimation and classification are harmonized across Africa. PARC is a module within AMREC, which will facilitate transparent financial reporting of mineral projects. PARC will be used continent-wide for the industrial financial reporting of the total resource base of Africa to facilitate access to finance and attract the required capital investments. PARC also addresses the procedures and implementation strategy for recognizing Competent Persons. Competent Persons certified under PARC will sign off the public reports made available for all potential investors in Africa, whether domestic or foreign. It will provide a game-changing unified stock exchange and financial reporting code to attract responsible investment nationally, regionally and along global value chains. AMREC follows the entire resource lifecycle coherently and consistently, facilitating seamless management from in-ground resource exploration and classification to mining/recovery of resources, processing or value-addition, to trade and use, including re-use and recycling of tailings, residues and wastes. It will help effective capital allocation and build resilience in the continuously threatened industry by market volatilities. AMREC will also support capacity building to create an efficient and internationally recognized African professional workforce. AMREC is designed and developed by African experts for the peculiar needs of Africa as set out in the AMV. It is aligned both with the Africa Vision 2063 and the United Nations Sustainable Development Goals (SDGs). AMREC implementation is hosted by the Africa Mineral Development Centre (AMDC), which has included AMREC as one of its strategic work streams. AMREC is aligned with the United Nations Framework Classification for Resources (UNFC).

Keywords: AMREC, Mineral and Energy resources, PARC, Africa Mining Vision

AMREC as a Tool for Project Tracking

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Abstract

Despite the extensive mineral exploration occurring on the African continent, many African nations still lack a comprehensive understanding of their mineral resources. This deficiency can be partly attributed to resource classification and knowledge systems that have primarily focused on meeting the short-term economic requirements of investment and financial stakeholders. The absence of long-term mineral inventories has created challenges in revenue management, policy development, and strategic planning for numerous states. Therefore, it is imperative for African nations to embark on a systematic classification of their resources, enabling them to effectively plan and manage their role in the green energy transition. The United Nations Framework Classification-based African Mineral and Energy Resources Classification and Management System (AMREC) presents an opportunity for African governments, mineral project owners, funders, civil societies, and the general public to monitor the progress of mineral projects. AMREC, which incorporates both the social and environmental viability of mining projects, holds particular promise in consolidating Africa-wide data on mineral reserves and resources. This becomes especially pertinent in ongoing discussions regarding access to raw materials for the green transition and the development of regional value chains. AMREC equips stakeholders with the tools to address environmental impact and mitigation issues and can be integrated into various sustainability reporting frameworks. Furthermore, AMREC takes into account socio-economic factors such as gender equality, local employment, and social acceptance of mining operations. The Namibian case studies show how AMREC is an agile and dynamic tool that can be used as a central inventory repository with harmonized data across multiple projects. Consequently, AMREC is viewed as a potential solution for harmonizing resource management and promoting sustainable land use across Africa, with applicability at regional, national, and continental levels.

Keywords: AMREC, Mineral resource management, Mineral inventory, Namibia, Africa

AMREC and Financial Sustainability

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Abstract

The steady stream of international profit shifting in the African mining sector is driven by multinationals' aggressive tax planning, resulting in the erosion of the tax base and lower tax revenue. According to the IMF, tax evasion costs the African region between \$470 and \$730 million per year in lost corporate taxation revenue. Many African countries have tax legislation that is inadequately prepared to deal with fiscal loss as it evolves over time. Furthermore, the competition for resource investment is fueling tax competition, particularly in the form of corporate tax cuts, exemptions, and holidays. This results in project-by-project agreements based on financial terms. However, as a result, all African countries lose. To better address these concerns, African countries require the Africa Mineral and Energy Resources Classification and Management System (AMREC), which allows for effective standards and coordinated efforts to prevent illicit financial flows, financial burdens, and tax competition, among other things.

Keywords: AMREC, Tax planning, Corporate tax, Tax competition



AMREC-PARC deployment in Africa – The Role of Higher Education Institutes

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Abstract

The African Mining Vision (AMV) is a comprehensive framework that aims to foster sustainable and inclusive development of Africa's mineral resources. To achieve this, it requires the optimal use and management of these resources, as well as a common and consistent system for estimating, classifying and reporting mineral resources across the continent. The African Minerals & Energy Resources Classification and Management System (AMREC) together with the Pan-African Reporting Code (PARC) code named AMREC-PARC system is a viable tool for putting the AMV in motion, as it is tailored specifically to the African context and aligned with the principles and goals of the AMV. It provides a harmonized approach for resource estimation and classification, as well as a basis for building a unified stock exchange and financial reporting code that can attract responsible investments and enhance the value of mineral resources in regional and global markets. The AMREC-PARC system is therefore an essential tool for implementing the AMV and realizing its grand objectives. However, the success of the deployment strategy depends on the buy-in of various stakeholders, especially the higher education institutes (HEIs) that can provide training and education on the AMREC-PARC system to different actors in the mineral sector. HEIs have the expertise, resources and facilities to provide high-quality training and education in this emerging field, as well as the infrastructure, equipment and networks to support the implementation and evaluation of the AMREC-PARC system. HEIs can also leverage their existing curricula, programmes and partnerships to integrate the AMREC-PARC system into their teaching and learning activities. This paper discusses the role of HEIs in deploying the AMREC-PARC system in Africa, highlighting the benefits, challenges and opportunities of this approach. Furthermore, it discusses how the AMREC-PARC system aligns with the Pan-African E-Network and the African Virtual and E-University, which provide participants with flexible and accessible learning opportunities. The paper concludes by highlighting the potential of HEIs to contribute to the achievement of the Sustainable Development Goals and the African Union Agenda 2063 through their involvement in AMREC-PARC.

Keywords: Higher education institutes, AMREC-PARC, AMV

Utilizing AMREC for Mineral and Anthropogenic Resource Management: Exploring Namibian Case Studies

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Abstract

African Mineral Resources and Renewable Energy Classification (AMREC) is a resource project-based and principle-based classification framework related to the United Nations Framework Classification for Resources (UNFC), also referred to as UNFC-AMREC. UNFC is a system for classifying, managing, and reporting mineral, petroleum, renewable energy and anthropogenic resources and injection projects, which assists Governments and industry stakeholders to document and report on economic and non-economic value of mineral and energy resources. AMREC is specifically designed to meet the African continent's mining vision (AMV), for transparent, equitable and optimal exploitation of mineral resources to underpin broad-based sustainable growth and socio-economic development. It is also utilized to stimulate the exploration of mineral resources, simplify licensing procedures, and classify the status and potential contingencies that restrict asset development at a project level. However, most African nations do not yet have a clear understanding of the true worth of their endowments in mineral resources. Hence, to ensure a uniform resource classification and management system across Africa, the development of UNFC-AMREC and the Pan-African Resource Reporting Code (PARC) aims to promote financial reporting transparency and a larger participation of African citizens in the mining sector. AMREC tool coupled with information obtained from published and unpublished reports from public and private domains, is applied on abandoned mines (Abenab Vanadium Project and Oamites Mines) case studies to assess the sustainability and environmental and social viability of the mineral resource management in Namibia. In conclusion, according to AMREC, Abenab Vanadium Project is not environmentally and socially viable since no comprehensive social-environmental impact assessment has been conducted yet; hence it is categorized as potentially viable project with pending development in class E2c, F2.1, G3. While Oamites mine is classed as E3.2, F4.1, G4.1, due to low level of geological confidence; representing an exploration project that is non-active at the date of evaluation. Observed limitations to the application of AMREC include data gaps and the lack of harmonization of datasets from different sources. Although, the use of AMREC can educate different stakeholders, and result in a method for managing and extracting minerals that is sustainable.

Keywords: African Mineral and Energy Resources Classification (AMREC); United Nations Framework Classification for Resources (UNFC); Abenab Vanadium Project; Oamites Mine; African Mining Vision, Mineral resources

A Simplified Approach to Application of the African Minerals and Energy Resources Classification and Management System (AMREC) to Mineral and Energy Projects

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Abstract

In 2009, the African Heads of States adopted the Africa Mining Vision (AMV) as a blueprint for resolving the paradox of Africa's vast minerals wealth existing side by side with poverty. The key objective of the AMV is to achieve a step change in the contribution of the minerals sector to sustainable development on the continent. AMREC therefore is one of the tools that has been developed for the realisation and implementation of the AMV. Developed as a comprehensive system to classify and manage minerals and energy resources, AMREC is applicable to all projects including solid minerals and all forms of energy sources like petroleum and renewable energy. The classification system of AMREC is the internationally recognized United Nations Framework Classification for Resources (UNFC). UNFC is based on a three-dimensional consideration of projects on a three-axis framework i.e., Environmental-Socio-Economic Viability (E-axis), Technical Feasibility (F-axis) and Degree of Confidence (G-axis). This framework ensures that projects are not only classified based on their ability to be technically and economically viable but also based on their social and environmental considerations. The simplified application of AMREC therefore, involves a four-stage approach. Stage one involves resource estimation where industry standard techniques for estimation of resources are applied depending on the resource type being evaluated. Stage two involves resource classification and here the framework used is the UNFC. Stage three involves sustainability testing of the project for its conformity to the critical controlling factors for resource progression to a higher maturity class and alignment to the AMV, Africa Agenda 2063 and the global Sustainable Development Goals (SDGs). Stage four is what is called re-evaluation stage in which a decision to develop or not to develop a project has to be made depending on whether it has passed the sustainability test or not. This paper will therefore illustrate this simplified approach to application of AMREC using a Ugandan case study involving both mineral and energy projects. In this case study four mineral projects in Gold, Tin, and Salt together with the Malingo oil project were assessed based on the AMREC principles. The approach put emphasis on the sustainability testing which has elements of objectivity and the results showed that whereas a project can easily pass the estimation stage and even qualify for a higher maturity class, the result of the sustainability test can lead to a reclassification downwards based on the critical controlling factors on resource progression. In conclusion, therefore, the result shows that it is not enough to rely only on presence and classification of resources but also on how the resource projects conform to the critical factors that govern sustainable resource management.

Keywords: Sustainability, Classification, Resource Management

The Pan-African Resource Reporting Code (PARC) and Capacity Development

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Abstract

There are many mineral management systems and reporting codes globally that are responsible for standardizing and streamlining /evaluating exploration and mineral management system reports. These reporting codes emanate from Canada, Australia, USA and Europe mainly. Only South Africa (SAMREC) out of all the African countries has a code. The lack of reporting of code bodies and subsequent obvious disadvantage this poses for the continent and the individual African nations has prompted the African Union Commission through the African Minerals Development Centre as part of the implementation of the AMV to develop the AMREC/PARC code. Individual African Nations developing their codes will erode investors' confidence and hamper funding for mining and development budgets. Stock exchanges will be wary of such codes as most African nations do not have a juristic and legal regulatory body for their mining industry. The fundamental purpose of PARC is to support stockholder as well as stakeholder confidence and ensure that in alignment to the Africa Mining Vision and Agenda 2063, good social, environmental, and economic benefits are assured for Africa. The relevant constituency that PARC addresses include investors (stockholders) and stakeholders such as communities, governments, operators, professional bodies etc. PARC is applicable to Minerals, Petroleum, Renewable energy and Anthropogenic resources. Resource reporting under PARC is based on the available internal AMREC inventory. Only the AMREC code-classes and sub-classes, with their numerical codes as mentioned. The main principles governing the operation and application of PARC are good social, environmental, and economic benefits as called for in the African Mining Vision including transparency, materiality, and competence. Competency requires that the Public Report be based on work that is the responsibility of suitably qualified and experienced persons who are subject to an enforceable professional code of ethics and rules of conduct and are classified into Core Value, generic and specific functional competencies. There are capacity development challenges as there is inadequate post qualification professional training modules and experience in project management to bring exploration projects to definitive feasibility (DFS) stage coupled with poor understanding of the Stock Market leading to low experience and accessibility to appropriate technology. Under PARC, Continuous Professional Development CPD focused on managed process of specialized knowledge needed to meet resource management functions will be mandatory. It includes point based system, Leadership academy, valuation workshop. Delivery will be both physical and web based, with guidance notes and papers, it will involve collaboration with training centres in Africa. Apart from the core technical courses, it will also involve trainings on legal framework for exploration and mining projects, understanding contractual agreements and contract negotiations, environmental laws and compliance, basic courses in report writing for the PARC code, mining finance, corporate stocks exchange and the mining industry, artisanal mining frame works and mining governance landscape in African mining jurisdictions amongst others.

Keywords: PARC, Code, Professional, Capacity, Regulatory

ST11_S02: Mining taxation, fiscal policies, and fiscal instruments**Transfer Mis-Pricing: Sectoral challenges for mining tax administration, reviews and recommendations****Lovisa Amukwa-Kanyemba***Women in Mining Association of Namibia**msamukwa@icloud.com***Abstract**

The majority of world class mineral resource projects are spearheaded by multinational corporations. The complexity of mineral supply chains and its capital-intensive nature often places a burden of tax design to developing host countries. This introduces another challenge, “transfer pricing”, whose potential impact is often not adequately appreciated. The concept of transfer pricing is broad, and its definitions varied. This presentation reviews sector specific transfer (mis)-pricing, how multi-national corporations exploit legislation loopholes for tax base erosion and profit shifting. Governments can address transfer mispricing is by passing laws and regulations that request companies to apply the “arm’s-length” principle where related-party transactions are treated as if they were transactions on an open market. However, capacity for tax administrations to implement tax avoidance rules to deal with transfer mispricing is critical. The presentation further reviews global regulatory enforcements that aim to curtail transfer pricing abuses. It concludes by summing up all the dimensions of the topic.

Keywords: Mispricing, Mining tax, Mineral resource, Laws and regulations



De-bunking resource nationalism: perspectives from fiscal policy and revenue sharing modalities

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Abstract

In Sub-Saharan Africa, many developing countries are dependent on their mineral wealth for their economies to thrive. However, it has been noted by institutions such as the World Bank and the OECD that this dependency creates implications for fiscal policy design, in terms of micro- and macroeconomic management. A number of these implications are enlightened by Broadway and Keen (2010). This presentation looks at fiscal policy design to generate much needed sustainable revenue for the host countries. Much research for fiscal sustainability in the resource sector has commended economic diversification to create economic linkages between mining and other sectors. This presentation does not discontent with these recommendations, but it aims to approach the issue from a different macro-economic stabilisation perspective, and adds on the existing knowledge on how to achieve fiscal sustainability for resource dependent developing countries. A case study on Namibia's resource revenues, relative to mid-term fiscal framework will be briefly discussed to shed more light on the matter.

Keywords: Resource revenue, Fiscal framework, Fiscal sustainability, Developing countries

Reference: Broadway, R. and Keen, M. 2010. Rent taxes and royalties in designing fiscal regimes for nonrenewable resources. In: *Handbook on the Economics of Natural Resources*, 97-139. [https://doi:10.4337/9780857937568.00011](https://doi.org/10.4337/9780857937568.00011)

Financial valuation of green field and early-stage exploration projects - challenges and opportunities

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Abstract

The valuation of mineral projects is a complex process influenced by multiple factors, including project characteristics, developmental stage, and chosen valuation methodology. Mineral projects are typically evaluated based on their technical or market value. Technical value relates to the projected net economic benefits of a project, while market value considers the monetary exchange that would occur between willing buyers and sellers in an arm's length transaction. Three primary valuation approaches are employed: the Income approach, Market approach, and Cost approach. Early-stage and greenfield exploration projects, lacking demonstrated economic viability, possess limited technical value. Nevertheless, they carry intrinsic value due to their potential for discovering mineral deposits. In such cases, the Market and Cost Methods are often employed to determine project value. In Namibia, many active exclusive prospecting licenses are held by previously disadvantaged Namibians (PDN) who face challenges in securing financial resources. Consequently, these properties remain underdeveloped in terms of geological knowledge and mineral potential assessment. PDNs frequently seek foreign partners or buyers for license development. However, Namibia lacks a centralized and publicly accessible repository for documenting these transactions, resulting in a scarcity of data required for applying the Market approach. Additionally, license owners may not have invested significantly in exploration, limiting their ability to employ the Cost Method. Through an analysis of numerous market transactions in the past four years, Odikwa Geoservices observed a wide range of exploration license prices in Namibia, spanning from NAD 10,000 to several million. This study sheds light on the challenges faced by Namibian license holders and buyers in determining the value of early-stage/green-field mineral exploration properties and the evolving landscape of mineral project valuation in Namibia.

Keywords: Financial valuation, Mineral exploration project, Green-field, Namibia

Tackling Illicit Financial Flows for Sustainable Development

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Abstract

Illicit financial flows (IFFs) are a development challenge facing Africa. IFFs deprive countries of the required financial resources to finance sustainable and inclusive development. In addition to the financial implications, IFFs are detrimental to good governance, institutional effectiveness, and the rule of law. The situation is particularly precarious in the extractive industry compromising developmental opportunities of commodity-dependent Africa. Africa is believed to have lost substantial resources through illicit financial outflows, mainly through trade mis-invoicing as well as by other illegal activities. These outflows are of serious concern, given inadequate growth, high levels of poverty, resource needs, and the changing global landscape of official development assistance. The exact level and scale of IFFs are difficult to ascertain owing to the absence of clear data and given that these flows are largely hidden. The ability to identify and monitor IFFs remains a critical gap for countries in Africa, which hinders required efforts to stop these outflows. This calls on countries to generate their nationally owned estimations/ statistics on the extent of these flows to inform the right policy interventions. The importance of measuring and quantifying the total value of IFFs has gained international attention resulting in a priority area for achieving the 2030 Agenda for Sustainable Development, as reflected in target 16.4: *“By 2030, significantly reduce illicit financial and arms flows, strengthen the recovery and return of stolen assets and combat all forms of organized crime”*. To measure progress towards achieving this target, Indicator 16.4.1: *“Total value of inward and outward illicit financial flows (in current United States dollars)”* was adopted. The Report of the High-Level Panel (HLP) on IFFs from Africa, chaired by former President Thabo Mbeki, and endorsed by the African Union Commission (AUC) in 2015, contained 21 recommendations that African Countries need to address. This session aims to raise awareness of the phenomenon of IFFs, highlight the progress that Namibia achieved, and call for more hands to join the Global Call to Action to stop the bleeding from Africa.

Keywords: Illicit financial flows, Sustainable development, Commodity

Investment in the mineral industry: greenfield exploration and extractive industry- pitfalls and opportunities

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Abstract

Traditionally and specifically in Namibia, greenfield exploration business models were mostly where you have junior miners raising money on stock exchanges in the UK, Canada or Australia. Private Equity firms from the very said jurisdictions also played a vital role. These juniors would then develop these to a stage where majors (such as at the time Rio Tinto, Teck, BHP, Falconbridge and Anglo) would take over these assets. A few things have changed since then. The majors barely have a footprint in Namibia and those present do not have major explorations teams. The absence of the majors means investments largely happen in the form of raising capital in foreign jurisdictions. Over the past few years the GRN rightly has made it possible for the general public to acquire EPLs a lot easier. But not all Namibian are able to raise funds externally. This presentation looks what the current situation in Namibia is - specifically with a view at highlighting why it is difficult to receive funding from local financial institutions. Alternative capital market structures which might assist with raising funds are also addressed.

Keywords: Mining industry, Green field exploration, Pitfalls, Opportunities, Extractive



ST12: GEOSCIENCE EDUCATION FOR SUSTAINABLE DEVELOPMENT**ST12_S01: Geoscience and public awareness****The Role of Geosciences in Achieving Africa's Development Goals****Paschal Ogechukwu Amaechi*, Mimonitu Opuwari***University of the Western Cape, Bellville, South Africa***Corresponding author: pamaechi26@gmail.com***Abstract**

Geosciences play a crucial role in addressing Africa's challenges and achieving its development goals. This paper explores the potential of earth sciences to contribute to Africa's development by addressing key issues such as natural resource management, climate change adaptation, and disaster risk reduction. Africa is rich in diverse natural resources, including minerals, oil, gas, and water. Earth sciences provide the necessary tools and knowledge to effectively manage and sustainably exploit these resources. Through geophysical exploration, remote sensing, and geological mapping, earth scientists can identify and assess mineral deposits, oil and gas reserves, and groundwater sources. This information is essential for informed decision-making and responsible resource extraction, ensuring equitable economic development and minimizing environmental degradation. Furthermore, Africa is highly vulnerable to the impacts of climate change, including droughts, floods, and desertification. Earth scientists contribute to climate change adaptation efforts by studying past climate patterns, predicting future climate scenarios, and developing mitigation strategies. By analyzing geological data, earth scientists can identify regions prone to specific climate hazards and recommend appropriate measures to build resilience and reduce vulnerability. Additionally, earth sciences play a vital role in disaster risk reduction. Through geological hazard assessment, seismic monitoring, and early warning systems, earth scientists can help mitigate the impacts of earthquakes, volcanic eruptions, landslides, and tsunamis. This knowledge is crucial for urban planning, infrastructure development, and emergency preparedness, ultimately saving lives and minimizing economic losses. In conclusion, earth sciences offer valuable insights and tools to address Africa's challenges and achieve its development goals. By effectively managing natural resources, adapting to climate change and reducing disaster risks, Africa can harness the potential of earth sciences to foster sustainable development, economic growth, and the well-being of its people.

Keywords: Geosciences, Africa, Development goals, Natural resources, Climate change

Enterprise Risk Management Implementation and the Operational Performance of Wholesale Businesses in Southwest Nigeria

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Abstract

The study examined enterprise risk management implementation and the operational performance of wholesale businesses in Southwest, Nigeria. Examined the major indicating factors for the implementation of enterprise risk management by the wholesales businesses in Southwest, Nigeria; Investigated the factors that influence enterprise risk management implementation by the wholesales businesses in Southwest, Nigeria; Investigated the functions of enterprise risk management by the wholesales businesses in Southwest, Nigeria; Examined the relationship between enterprise risk management implementation and competitiveness of wholesales businesses in Southwest, Nigeria; Investigated the relationship between enterprise risk management implementation and achievement of objectives by the wholesales businesses in Southwest, Nigeria; Examined the relationship between enterprise risk management implementation and customers' satisfaction of wholesales businesses in southwest, Nigeria. The study adopted the descriptive research design of the survey type. Sample size for this study consisted of one thousand two hundred (1 200) respondents which was selected using multistage sampling techniques. Structured questionnaire was used to collect the data. Data collected were analyzed using descriptive statistics such as simple percentage inferential statistics while ANOVA was used to test the hypotheses. Findings of the study revealed that, there is a significant relationship between enterprise risk management implementation and customers' satisfaction of wholesales businesses in southwest, Nigeria. This study therefore concluded that, enterprise risk management implementation improves operational performance of wholesale businesses in Southwest, Nigeria. Based on the findings of this study, the following recommendations were made; Business managers are encouraged to be proactive in the adopting strategic risk management, safety measures should but into consideration when engaging in any risk management.

Keywords: Enterprise, Risk Management, Wholesale Businesses, Operational Performance.

Exploring Science Diplomacy in the Digital Age: Opportunities and Challenges - A Case Study of Namibia (Poster)

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Abstract

The advent of the digital era has revolutionized communication and information exchange, offering new avenues for scientific collaboration and international cooperation. The digital age has created unprecedented opportunities for global scientific collaboration. Digital platforms provide efficient means for scientists to connect, communicate, and collaborate across borders, facilitating the exchange of knowledge, data and expertise. Real-time collaboration through virtual meetings, webinars and online conferences has become crucial for international scientific dialogue, transcending geographical barriers and fostering participation from diverse stakeholders. This investigation explores the role of science diplomacy in the digital age, with a focus on the opportunities and challenges it presents, using the Geological Survey of Namibia as a case study. It highlights the impact of the digital era on scientific collaboration and international cooperation, as well as examines the benefits of digital platforms, social media and online collaboration tools, with regard to global scientific collaboration, rapid dissemination of scientific information, and increased accessibility to scientific knowledge. However, challenges such as information overload, misinformation, the digital divide, concerns about data security and intellectual property rights need to be addressed. By effectively utilizing the opportunities and mitigating the challenges, international scientific cooperation and diplomacy can be advanced in the digital age.

Keywords: Digital era, Science diplomacy, Digital platforms, Global scientific collaboration, Challenges in the digital age

The Earth Sciences and Challenges that Africa is Facing

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Abstract

A prosperous Africa can only be achieved if Pan-Africanism prevails. An integrated African continent can be attained if all the African nations unite for a common goal. Earth sciences play a vital role in transforming Africa from evils of poverty, unemployment, underdevelopment, climate change, and build inclusive economic growth and attain sustainable development goals. The African continent hosts some of the world's richest mineral resources, for instance diamonds, critical minerals, gold, copper, zinc, uranium, REEs, PGEs, chromium, nickel, and significant oil reserves. With such resources at hand, African countries through research and development should be contributing significantly to the development of the continent. The increasing demand in natural resources, driven by the continual rise in the world population growth, needs to be addressed continually. While Africa is blessed with diverse and abundant natural resources, the continent still faces economic challenges. Therefore, there is a need to explore how the African people can benefit from their mineral resources. The main beneficiaries of the resources from Africa are the developed world, mainly because there is not much value addition on the continent. Earth Scientists need to join the debate on value addition and ensure sound policies that galvanize governments to pursue this route vigorously. Good examples of countries that went this route are India, Brazil, Chile, Malaysia and recently China, to the extent that a dedicated University of Geosciences was established in Beijing. The earth sciences are the cornerstone in addressing the African challenges and remedy the imbalance in development by contributing to Africa's sustainable development through the discovery of new mineral resources, beneficiation, manufacturing of goods, information sharing and knowledge-based exchange, connecting young minds to science and engineering. Earth scientists need to dedicate time to public engagement on the value of scientific research and education, providing appropriate science news to pupils and the community, fostering geoscience careers and training, and by producing well educated, equipped and professionally recognized geoscientists and engineers. Adverse impact of climate change such as severe weather events lead to economic inequalities, poor access to energy and water scarcity, and Africa is not well prepared to cope with these events. Africa must cultivate a culture of producing earth science knowledge to harness the exploitation of the continent's mineral wealth. If Africa's development challenges are not solved, the continent's future will always be uncertain. African people, as examples elsewhere show, can rise above these problems that plague the continent. Political will, hard work and good work ethics are a prerequisite to excellence.

Keywords: Earth science, Challenges, Africa, Economic growth, Sustainable development

Analysis of digital information literacy (DIL) skills of geoscientists at the Geological Survey of Namibia: A holistic view

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Abstract

Digital information literacy of professionals plays a critical role in transforming navigation of and interaction with the ever-changing and evolving digital environment. Digital information literacy allows individuals to participate in the economy and the digital society effectively. With the digital transformation that the world is experiencing, it is critical that geoscientists, as well as members of other professions, are continuously keeping up-to-date with the necessary skills to effectively function in their respective spheres. To explore digital information literacy skills this study used the Association for College and Research Libraries (ACRL) Framework of Information Literacy for Higher Education (2016) as a theoretical background. The framework allows to envision information literacy as an extending arc of learning throughout users' professional careers and as converging with other academic and social learning goals. Methodologically the study collected quantitative data via online questionnaires with 32 (60%) geoscientists of the Geological Survey of Namibia (GSN) at various levels. Qualitative data were collected through semi-structured interviews from purposively sampled managers (7) and librarians (3); auto-ethnography was used as a secondary qualitative data collection method. To get a holistic view of the geoscientists' digital information literacy skills, the study asked two critical questions: a) what digital information literacy skills do geoscientists possess and b) what challenges are they facing?

The study found that generally geoscientists have basic information processing skills, but limited skills to appropriately use and interact with digital technology tools. Efficient access and use of information in different digital formats as required of the modern geoscientist was found to be another challenge. Moreover, the lack of digital information training opportunities and collaborative spaces was found to hamper the acquisition and enhancement of digital information literacy skills of GSN geoscientists. The study also found that there is a need to prioritize digital information literacy training, collaborative spaces, professional support, funding and continuous training in the use new technologies to upgrade the geoscientists' digital information literacy. Similarly, key role players like GSN managers, librarians and geoscientists themselves, need to work together in order to develop programmes to improve the digital information literacy skills of geoscientists enabling them to navigate this digital era and perform in roles which are becoming continuously more digital as a result of technological development.

Keywords: Digital literacy, Digital skills, Geoscientists, Geological Survey of Namibia

Reference:

Association of College and Research Libraries. (2016). *Framework for information literacy for higher education*. Available: www.ala.org/acrl/standards/ilframework [2021, June 15].

Public acceptability of the mineral extraction industry in Mozambique: A critical perspective

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Abstract

The mineral extraction industry involves any operation that extracts raw materials from the Earth, including metals, minerals and oil, to provide goods and services to society. The mineral extraction industry in Mozambique is highly growing. This exponential growth is accompanied by several challenges, including rising concerns about the industry's impact on people's lives. Among the key challenges faced by the mineral extraction industry is public acceptability. In Mozambique, several social problems sparking from mineral extraction are constantly reported. Most of these problems lead to interruption of mining activities (the case of Vale Moatize, 2018), destruction and vandalization of mining company's properties (the case of Tantalum mine in Gilé, 2015), and uprising against the stakeholders. It is thus unprecedentedly important to evaluate the level of public acceptance of mineral extraction in Mozambique, and the main factors that control it. This talk, considered as preliminary to a more detail follow up discussion explores the current trend of public acceptability of mineral extraction in Mozambique, and evaluates the possible factors that affect it. Among the key factors highlighted that may influence public acceptability of the mineral extraction industry in Mozambique are: (1) the level of trust in the stakeholders, (2) the educational background, (3) the local cultural/personal value system, and (4) the level of understanding of the importance of mineral resources. Educational background can be improved by introducing the cost/benefit concepts of mineral extraction in compulsory educational curriculum. However, does better information about the importance of the mining industry for societal development help to build trust between the stakeholders and improve the acceptability in Mozambique? To which extent do the people's cultural and personal values affect the acceptability of mineral extraction in Mozambique? The talk will tackle these and other questions, which are crucial for sustainable mining in Mozambique. Enhancing the quality of the narrative, considering the differences in educational background, and ensuring public engagement with the sector, e. g., providing job opportunities, can improve the level of trust and positively influence the public acceptability of the extraction industry in Mozambique.

Keywords: Public acceptability, Extraction industry, Local community, Mozambique

Equipping science teachers with multimodal literacy skills to improve science education in classrooms: A case study of a Geoscience Teachers' Workshop

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Abstract

Science teachers play a key role in developing future leaders in science and technology by fueling the curiosity of students and encouraging further exploration into topics such as environmental protection, climate change, natural resource management, etc. Thus, it is important that teachers are equipped and supported by theoretically well-founded strategies to develop and enhance their teaching methods in science education. Multimodal literacies encompass a range of communication modes, including visual, auditory and tactile elements that allow for multiple forms of presentation and communication. They employ media such as videos, other visuals, arts, spoken and written words as means for information transfer and instruction. Equipping science teachers with the know-how of effectively incorporating multimodal literacies in their classrooms will greatly enhance the quality of earth science education.

This study aims to explore the utilization of multimodal literacies in earth science education and its impact on teaching practices for science teachers. By equipping science teachers with the knowledge and skills of introducing multimodal literacies to their teaching schedules, it seeks to shed more light on the Geoinformation Division's efforts with respect to science teacher training and on the potential of multimodal literacies to enhance earth science education in the classroom. Additionally, the study examines the challenges that science teachers may encounter in implementing multimodal literacies and explores strategies for overcoming these obstacles.

Keywords: Science teachers, Multimodal literacies, Geoscience education

Using the Media to Raise Awareness on the Importance of Geoscience in Namibia (Poster)

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Abstract

The Ministry of Mines and Energy was established (per Article 100 of the Namibian Constitution) to take custody of the country's geological, mineral and energy resources, and to ensure that these resources contribute to Namibia's socio-economic development. The Department of the Geological Survey is responsible for collection, collation and dissemination of geological data and to provide basic geological information through outreach programmes. These outreach programmes are conducted to increase public awareness on the vital role geosciences play in society. The outreach programmes bring awareness to the public on the use of natural resources, their interaction with the environment and contribution to socio-economic development. In addition, the programmes provide an opportunity to expose the Namibian youth to geoscience career opportunities and positively influence an uptake of geoscience as a potential field of study. They are collaborative efforts between the Geological Survey of Namibia (GSN) and other organisations such as Young Earth Scientist (YES) Namibian Chapter, Geological Council of Namibia, Goethe Institute, various operating mines and tertiary education institutions. Through the participation in the International Geoscience Programme's (IGCP) project 685, the Geological Survey of Namibia, with volunteers from the Young Earth Scientist Namibian Chapter (YES) Network developed a three-minute, motion graphic outreach video focusing on geoscience and sustainable development as a creative way to engage young people/students, educators and the community at large on the importance of geoscience, and awaken children's interest in geosciences, and science in general; it is used for outreach programmes in schools (high school and primary) and communities. In addition, in 2022 GSN and the Geoscience Council of Namibia embarked on an initiative to engage Namibians via the national radio platform through airing a series of geoscience talk shows in nine languages. The main objective of this project was to communicate different aspects of geoscience and their application to socio-economic development to the various communities and population groups throughout the country. Please follow the link below to view the outreach video: <https://www.youtube.com/watch?v=D-I7nnSiFIg&t=70s>

Keywords: Ministry of Mines and Energy, Geoscience, Outreach

“Be an Energy Geoscientist – make a difference!”**Bernie Vining***bavining@btinternet.com***Abstract**

“Be an Energy Geoscientist – make a difference!” Why is this an important message? How do we inspire, recruit and retain the next generation of geoscientists for Africa? These questions are critical in the context of the current crisis in geoscience, climate change and energy demand of the future.

Why is energy geoscience important? The journey, from the Industrial Revolution, to the advent of the petroleum era, to the energy transition of today, illustrates the important role geoscience, and its associated breakthrough technologies, have played in everyday life. The global population exceeded 8 billion people in November 2022 and will reach 11 billion by the end of the Century. The consequent impact upon the Earth's systems and the increasing demand for energy worldwide is an immense global challenge. Climate change is undoubtedly the major challenge for the world and energy geoscientists are key enablers to sustain and improve the quality of life globally. The world is moving towards a climate-neutral (net zero) energy system that needs to be secure, reliable, sustainable, and affordable. As the energy transition gathers pace, the demand for carbon neutral hydrocarbons, particularly gas, will continue to play an integral role in the changing energy supply mix. In parallel, the proportion of renewable low carbon energy sources, as a percentage of the total, will expand. Education, training and development of skilled geoscientists in Africa, supported by UNESCO IGCP, is able to effectively and efficiently undertake integrated subsurface analysis of geological systems. These are essential across the spectrum of energy-related activities from sustainable oil and gas production, subsurface energy storage, the placement of wind turbines to geothermal energy sources. Whilst quality geoscience underpins most of the energy solutions for today and tomorrow, there is a crisis in geoscience. In recent years there has been a persistent decline in the number of students enrolling in university geoscience undergraduate and postgraduate taught courses. The root causes of this decline will be examined. How did we get here? Is the limited public, school, and media recognition of the importance of geoscience in everyday life around the world playing a significant role? A hindcast perspective is presented to better understand the current situation. How do we make change happen? What does success look like? Two case studies will be presented of programmes, with global outreach, and designed to inspire and attract students to geoscience in their journey through school, university, into employment and their subsequent career development. The activities of the Energy Transition Centre for Masters' Training (CMT), an affiliated UNESCO International Geoscience Programme and the GeoNetZero Centre for Doct Training (CDT) provide a model for the way in which academia, industry and government can collaborate effectively to address these challenges in geoscience through various initiatives including a Geoscience Ambassador Programme; Industry Placements; and bespoke MSc and PhD research and training. Collaboration, instilling new ways of working, being flexible, adaptable, and agile are essential. The key message is “Be an Energy Geoscientist – make a difference!”

Keywords: Energy scientist, Geoscience, UNESCO

Geosciences in Africa: an editorial project based on the members of the PanAfGeo Project network

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Abstract

The PanAfGeo project (Pan-African Support to Geological Sciences and Technology Africa – EU Partnership) was implemented in 2016 and promotes governance and capacity building in African geological surveys through collaboration with European geological surveys. The main activity is to provide technical training for professionals from African geological surveys. As a result of the project, close contacts are being established between African geoscientists working in government departments and universities. During the first phase of the project (2016-2019), 1068 geologists from 49 African countries participated in the training. During the second phase currently underway (2021-2024), several hundred African geologists have already taken part, and this number continues to grow as more training sessions are organised almost every month. In the project concept, African geoscientists are not only trainees, but also act as lecturers in these sessions. The mutual relationships established between African and European geologists, and above all between African geologists, has generated an excellent opportunity to compile the knowledge and advances accumulated about geosciences in Africa, and to prepare a monograph of Pan-African relevance, the working title of which is "Geology of Africa". The various chapters of the monograph will be prepared by teams of authors from different African countries, compiled according to the following standardised scheme: (1) introduction (including geographical location, basic information about each country, state of geological knowledge), (2) outline of the geological framework (structural geology, tectonics, stratigraphy, etc.), (3) mineral resource potential (metals, energy resources - including geothermal energy, industrial rocks and minerals, etc.), (4) geohazards (natural and human induced), (5) geological heritage, (6) summary, including challenges and problems to be solved, and (7) references. Each chapter will include specific graphic data, especially maps, while the monograph will conclude with several chapters summarizing the different thematic areas on a continental scale. The size of each chapter will be around 10 to 15 text pages. Chapters will be prepared and submitted in the working language of the authors (English, French or Portuguese), with the final book being published in all three languages. The entire monograph preparation process will be overseen by a board of editors, composed of prominent African and European geoscientists. All articles will follow the classic procedure that accompanies the publication of peer-review scientific articles in international journals. The monograph is aimed at universities, geological surveys, institutions working on the protection of the environment and particularly with the preservation of both geological and mining heritage, as well as entrepreneurs wishing to invest in the African mining sector. The initiative also provides an opportunity for continent-wide cooperation between experienced African researchers and young geologists, who should gain professional experience alongside their peers. An important guiding concept of the monograph is to describe the geology of Africa by African experts.

Keywords: PanAfGeo Project, Geoscience in Africa, PanAfGeo publication "Geology of Africa"

ST13: THE FOURTH INDUSTRIAL REVOLUTION, ARTIFICIAL INTELLIGENCE, AND INFORMATION MANAGEMENT**ST13_S01: The fourth Industrial revolution and its impact on mineral resource countries**

Dealing with unpredictability is a significant challenge in all aspects of life, work, and particularly in the mining sector: Can machine learning assist in managing unpredictability and more informed decision-making throughout the mining process?

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Abstract

The mining industry is facing increasing challenges due to unpredictability. This is due to a variety of factors, including the complexity of mining operations, the variability of ore bodies, and the changing global economic landscape. Machine learning can be used to help manage unpredictability in mining. Neural network modelling is a type of machine learning that can be used to analyze large amounts of data and identify patterns. This can help to uncover trends and make more informed decisions about mining operations. Micromine has developed neural network modelling technology that can be used to help manage unpredictability in mining. This technology can be used to emulate the work of thousands of experienced geologists at the click of a button. This can help to improve decision-making and reduce risk in mining operations. This paper will discuss how neural network modelling can be used to manage unpredictability in mining. It will also discuss how this technology can be used to revolutionize the mining industry.

Keywords: Neural network Modelling, Machine learning, Unpredictability, Mining, Decision-making



The Fourth Industrial Revolution and Its Impact on Mineral Resource Countries

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Abstract

The Fourth Industrial Revolution (4IR) has ushered in a transformative era of technological advancements, characterized by the fusion of digital, physical and biological systems. This revolution is reshaping economies, industries and societies around the world, with profound implications for countries rich in mineral resources. 4IR has the potential to revolutionize the mining sector, leading to substantial changes in operations, economic structures and sustainable resource management practices. This study examines the impact of the 4IR on mineral resource countries, focusing on the three key dimensions, technological disruptions, economic restructuring and diversification opportunities, and sustainable resource management. A comprehensive review of relevant literature and identification of key areas of impact was followed by a mixed-methods approach, combining quantitative analysis of economic data and case studies from selected mineral resource countries. The research methodology involved collecting and analysing data from diverse sources, including industry reports and academic studies. Under the header of technological disruptions, the findings highlight major impacts through the introduction of automation, robotics and artificial intelligence, which will improve efficiency, safety and productivity in mining operations. 4IR also presents opportunities for economic restructuring and diversification, enabling mineral resource countries to move beyond resource extraction, and to promote long-term economic growth and resilience, while fostering innovation in high-tech industries. Lastly, sustainable resource management has become a crucial aspect, with the need to adopt cleaner technologies offered by 4IR, implementing responsible mining practices, and addressing environmental concerns. Facing the challenges associated with sustainable resource management is vital to ensure the responsible extraction and utilization of mineral resources.

Our findings show that the Fourth Industrial Revolution will have a significant impact on mineral resource countries, with both opportunities and challenges. Understanding and harnessing these impacts will be essential for mineral resource countries to maximize the benefits and negotiate the challenges of 4IR.

Keywords: Fourth Industrial Revolution, Mineral resource countries, Technological disruptions, Economic restructuring, Mining sector

Data Analytics, Machine Learning, and Big Data Analytics: The Future of Mineral Exploration and Development

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Abstract

The Fourth Industrial Revolution (4IR) or Industry 4.0 is the next phase in the digitization of the manufacturing sector, driven by disruptive technologies such as connectivity, data and computational power; analytics and intelligence; human-machine interaction as well as advanced engineering. This revolution is driven by, among others, cloud technology, Machine Learning (ML) and Artificial Intelligence (AI), Big Data Analytics (BDA) complemented with block chain technology, the Internet of Things (IoT) and 5G technology. Africa is a major producer of many essential mineral commodities, with considerable resources and reserves of metals and minerals such as gold, diamond, cobalt, bauxite, iron ore, coal, and copper across the continent. Most African countries are therefore highly dependent on mineral exports, making-up a significant proportion of the African Gross Domestic product (GDP). This industry is an important source of export earnings for many African countries and as such is critical to economic growth in Africa. The technological drivers of the 4th Industrial Revolution are blending the physical, digital, and biological worlds in virtually all economies and industries. These technologies are therefore transforming and disrupting almost every business sector, of which the entire mining value chain within the mining sector and most importantly its underlying mineral resource in Africa is not an exception.

Keywords: Machine learning, Bi data analytics, Data analytics, Fourth Industrial Revolution



ST13_S02: Information management systems and value-added products**Exploring Management Practices of Tailings and Their Impact on Downstream Economies and the Environment: Insights from Uis, Namibia (Poster)****Hilya Amukwa^{a*}, Absai Vatuva^b**^a*International University of Management, Windhoek, Namibia*^b*University of Namibia-Southern Campus, Keetmanshoop, Namibia***Corresponding author: hamukwa@gmail.com***Abstract**

The mining industry plays a substantial role in improving the quality of life by creating jobs, skills and knowledge, contributing to the Gross Domestic Products and Foreign Direct Investment, improving infrastructures, public health services, education and government revenues. However, there are volumes of studies on negative socio-economic (e. g. ghost towns) and environmental consequences of mining, which are mostly considered as base in determining the level of sustainability of mining activities. Thus, the information at hand is biased and often misleads the regulators and public at large. The thriving settlement of Uis serves as a case study for economic activities related to the Mine Closure Framework of the Chamber of Mines and Ministry of Mines and Energy. The Uis settlement was established in 1958 as workers' settlement to exploit the tin deposits in the area. This study is based on a detailed review of available literature and field observations. In addition, a qualitative approach was adopted that included interviewing key stakeholders regarding the extent of their awareness on tailings management/mine closure framework and plans for contribution to the economic growth of the settlement. Positive impacts resulting from sustainable tailings management practices on downstream economies as observed in Uis include the brick production industry, which uses unique processes to extract clay from old mine slime dams to produce high strength quality bricks under environmentally friendly conditions. The tailings ensure a stable supply of raw materials for brick production, which at the same time contributes to rehabilitating the mine. Water-filled old pits in Uis serve as tourist attraction and fish farms for local communities. Furthermore, other old tailings can be exploited for critical metals such as lithium that were previously not considered. While the activities in the Uis settlement may be coincidental to the Mine Closure Framework, such downstream economic diversification may be exemplary to establishing smart and thriving mining towns elsewhere.

Keywords: Tailings, Sustainable environmental management, Uis Tin Mine, Downstream economies, Responsible mining

Cloud solutions to streamline the ‘Drill hole to Decision’ workflow

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Abstract

Today’s geoscientists have access to more data than ever before. Accuracy and confidence in this data is as important as ever and the ability to filter through libraries of datasets and find the current versions can be the key in timely decision making. This is a challenge in exploration or production drilling with the data often being collected offline or in remote locations. ‘Seequent, the Bentley subsurface company,’ sits at the centre of the web of these collisions, converting complexity to clarity. As the workforce has de-centralised with the ability of remote working, the risk of data silos has increased within a project team and solutions need to be found to rebuild the ‘Connected Project Environment.’ Geoscientists working in isolation do not have the opportunity to understand the whole environment of the project, nor make informed decisions from collaborative workflows. The following presentation sets out a methodology which better enables collaboration and communication across a diverse team of geoscientists within a regional or global geography. Integration of these teams’ resources is achieved via integrated cloud-based solutions that tackles this challenge. It includes powerful visualisation and collaboration while providing the “one version of the truth”. Case studies from Free gold Ventures Ltd and Gran Columbia Gold highlight the challenges that were raised and how they were overcome.

Keywords: Cloud solutions, Datasets, Drilling, Workflow, Challenges

The New Mineral Management System in Mozambique: New Technologies for Better Data Handling

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Abstract

Over the last decades, document management has been accompanied by the fast evolution and introduction of new technologies. Considering the strong need of making geological and economic data available to the mineral industry, the entire economy, the society and science, the DNGM (National Directorate of Geology and Mining) designed the project of implementing a new flexible mineral management system (MIS). The MIS was financed by World Bank and aims at the development of an easy to use and complete geological database and effective public relations. The new MIS was implemented between 2017 and 2022 based on an MS SQL server database engine and ESRI technologies (backend). The frontend was implemented using ESRI technologies as well. Today, the MIS contains 2015 geoscientific maps, 2900 unpublished reports, 13 geophysical datasets, 13 geochemical datasets, and almost 1000 mineral occurrences. We will present the structure and functionalities of the system and discuss the new opportunities of distributing data for mineral sector development, national planning, science and education.

Keywords: Data management, Mineral information system

Advancing Geological Data Dissemination: A Web Cartographic Support System for the Geological Survey of Namibia (Poster)

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Abstract

This project focuses on the creation of a web-based cartographic support system aimed at enhancing the accessibility and distribution of geological data at the Geological Survey of Namibia. The Cartography Subdivision's primary objective is to visualize spatial information within the organization. This encompasses a wide array of cartographic tasks, including producing, reviewing, and updating national geological cartographic data, which span various forms of publications from large-scale and small-scale geological to topographic and thematic maps. The development of this web-based cartographic support system represents a substantial leap forward in geological data dissemination. The seamless and reliable online platform facilitates remote access to geological maps, fosters geotourism by highlighting geological landmarks, and streamlines access to valuable information for the mineral exploration sector (e. g. drill hole locations). The primary goal is to construct a cartographic web application that equips users with a robust suite of tools to reference pertinent geological features. The intention is to transition from traditional walk-in data access to a digital realm, thus empowering remote users to conveniently obtain geological information. Notably, users are able to visualize Namibia's geology at 250 k scale and gauge the availability of maps at other scales, allowing them to make informed decisions about scale and pricing options. The forthcoming webmap application, developed by the Cartography Subdivision of the Namibian Geological Survey, encompasses three distinct sub-modules. 1) An interactive interface, granting access to basic geological maps of the country, showing major stratigraphic units and lithologies. 2) A geotouristic map showing locations and photographs of geological sites of interest with touristic value, some of which have earned the designation of National Monuments. Explanations of each site's geological significance aim to enhance visitor engagement, disseminate information, and evoke appreciation for Namibia's geological wonders. 3) A drillhole webmap giving online access to drill hole information and the availability of drill core for the mineral exploration sector. These data are derived from open file exploration reports submitted by companies engaged in mining and mineral exploration activities in Namibia. Given the constant influx of fresh information, regular updates are essential to maintain accuracy and relevance. Anticipated to be finalized by the end of this year, the development of these webmaps promises to provide an efficient tool for disseminating and accessing geological data to a diverse range of users.

Keywords: Web cartography, Geological maps and information, Geotourism

Machine Learning Seismic Imaging and Interpretation

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Abstract

Machine learning (ML), explainable interpretable machine learning XML in seismic interpretation uses computer algorithms for understanding the relationships between large amounts of complex, interrelated subsurface geological data. Artificial intelligence is an adaptive, cognitive science with applications for geosciences subsurface imaging and interpretation. Artificial Neural Network RNN-time series data, ANN-CNN Convolutional Neural Network, Deep Neural Network (DNN), ResNet Residual Neural Network, unsupervised and supervised machine learning, deep learning, reinforcement learning for seismic imaging and inversion, seismic attributes, seismic interpretation, reservoir characterization, geosciences data analytics, big data analytics, data assimilation modelling and simulation can all be done by ML. Physics Informed Neural Network PINN, greybox model [whitebox-physics, blackbox-data, black+white=grey], Graph Neural Network GNN machine learning for subsurface imaging and interpretation can all be handled by ML Dictionary learning is a branch of signal processing and machine learning that aims at finding a frame (called dictionary) in which some training data admits a sparse representation. Machine learning is useful in seismic interpretation because it solves two significant problems that seismic interpreters face: interpreting large volumes of data and understanding the relationship of various types of data at once. ML is a technique that allows intelligent computing systems to learn instructions to solve complex problems and provide precise results. Seismic attributes are any measurable property of seismic data and are produced to help enhance or quantify features of interpretation interest. Machine learning application for deepwater hydrocarbon exploration seismic geomorphology, seismic facies, seismic stratigraphy seismic attributes, seismic imaging and interpretation channel detection seismic data spectral decomposition by wavelet transform for thalweg sinuous channel detection, ChannelSeg3D deep learning for channel interpretation in 3D seismic image, CNN seismic channel interpretation involves detection channel structures which often appears as meandering shapes in 3D seismic images. SpiNet seismic pattern interpretation network, SegNet image segmentation network, seismic reflection termination seismic facies analysis FaciesNet are employed for seismic interpretation. Seismic data spectral decomposition by wavelet transform for channel detection, wavelet transform for machine learning WCNN training CNN with wavelet transform for image classification and geological subsurface feature extractions of deepwater hydrocarbon exploration (carbonate reservoir). Meta seismic attributes for seismic imaging and interpretation for deepwater hydrocarbon exploration. Multi-component seismic data 4C/2D, 4C/3D, seismic imaging and interpretation is done by using machine learning.

Keywords: Seismic imaging, Machine learning, Wavelet transform, Channel detection

ST13_S03: Artificial intelligence, big data, and mineral system approach in mineral predictive mapping: Background and applications**The Role of Artificial Intelligence in Cartography (Poster)****Anna Ambata***Geological Survey of Namibia*anna.ambata@mme.gov.na**Abstract**

Artificial intelligence (AI) is the field of technology designed to “think” independently. One area where artificial intelligence has shown promise is cartography. Various case studies have been used to understand the implementation and benefits of artificial intelligence specifically in geological cartography. Results showed that the integration of artificial intelligence has in fact numerous benefits, which include reduced time frames in processing new digital geological data, elimination of “human” errors, and less time needed in map editing. Artificial intelligence, particularly machine learning models, have been successfully applied to automate and improve cartographic processes in achieving the above ends. While the benefits of AI in cartography are evident, challenges such as data storage and lack of skill to interpret AI-driven results have still to be overcome.

Keywords: Artificial intelligence, Cartography, Machine learning



Copper / Cobalt, Tin and Gold prospectivity mapping in the Katanga and Equateur regions of the Democratic Republic of Congo based on self-learning algorithms and field verification

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Abstract

The executed study of test zones for of prospectivity analysis using geological, geochemical, and geophysical GIS data and logical decision rules for selected sites in DR Congo was part of the Mining Sector Governance Project (PROMINES), which was implemented in 2015-2018 by the government in collaboration with geoscientific, environmental, and social consultants. Aerial geomagnetics and spectrometry, lithological and structural mapping, and stream sediment geochemistry datasets were provided by project partners and supplemented by own field observations in the area of Kolwezi. ANN-based algorithms trained with observed mineral occurrences and minerogenetic models were used to map the prospectivity of Au, Sn, and Cu/Co. The main types of Cu/Co mineralization are: 1.) Ecailles (layered blocks) of the Roan Group, 2.) Mineralization associated with thrusts, 3.) Concealed layered Kamoia-Kakula type deposits. Separate models were created for Sn, and for Kibaran and pre-Kibaran Au mineralization in Katanga and separately in the Equateur region. The results lead to identification of new targets for the investigated commodities. They were prioritized, and selection criteria and follow-up exploration measures were recommended. Since the finalization of PROMINES, recent developments in demand have given new importance mainly to battery metals such as lithium, which is bound to pegmatites such as those at Manono, and to cobalt as it occurs in the entire Copper Belt. Hidden stratabound deposits of the Kamoia-Kakula type are now among the world's largest copper/cobalt reserves.

Keywords: Prospectivity mapping, Self-learning algorithms, DRC, PROMINES

The digitisation of exploration targeting: from intuition to quantitative hybrid modelling – background and examples from the African continent

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Abstract

Based on centuries of collective experience, in 1556, in the famous mining town of Freiberg in Germany, Georgius Agricola started to fix mineral exploration and mining knowledge on paper. This was a starting point of many developments to deeper understand the position of a mineral occurrence in its geological environment, and consequently of developing methods for knowledge-based exploration targeting. Principles of the genesis of mineral occurrences (metallogeny) were deduced. On the other hand, over the centuries a giant amount of geoscientific data was accumulated and recently made available in national and international databases. Today the amount of data increases faster than ever before. At the same time the demand for storage and analysis of large data sets increases significantly. The public availability of geodata is becoming a key factor for developing national economies as well as international relationships. With this regard, the creation of national datasets (geology, minerals, geophysics, geochemistry) is of exceptional importance for attraction of investment. Value-added products such as precise mineral and metallogenic maps, mineral predictive maps, and mineral development plans complete the investment attraction documents and are important means for improved national development planning as well. They help to plan infrastructure and to protect still undiscovered resources against blocking by man-made constructions. In the presentation, we discuss the development of national geo-scientific databases, provide an overview of the history and actual status of mineral predictive mapping and show examples of beautiful and informative value-added products.

Keywords: Mineral exploration, Mineral occurrence, Value-added products, Metallogeny

Artificial neural network (ANN) based Au exploration targeting in a brownfield area near Dunkwa, Ghana

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Abstract

The Dunkwa brownfield area is located in the famous Ashanti Greenstone Belt, which hosts several large, well-known gold deposits such as Prestea, Obuasi and Edikan, as well as countless placer mines that are mainly exploited by artisanal and small-scale mining (ASM) operations. About 35% of Ghana's annual gold production of 142 tonnes (2019, Ghana Chamber of Mines) is extracted by ASM operations. As such, they contribute significantly to Ghana's national income generated by mining and are an important factor in poverty reduction and national development. Due to declining production figures, depleted resources and enormous ASM-related environmental damage, the Ghanaian government has initiated the search for new Au targets suitable for exploitation by ASM operations. The exploration targeting method applied combines the knowledge-based exploration model approach with the data-driven ANN technology for target identification. Existing airborne geophysical datasets in combination with mineral occurrence mapping and a river sediment and shallow borehole survey were used as the data basis. As a result of the survey, several targets for ASM gold mining in hard rock were identified, ranked and recommended for further activities. The methodology and results presented here are intended to serve as a case study and guide for other similar activities throughout the country and abroad. The methodology developed is very cost effective and can be implemented quickly.

Keywords: Artificial neural network, Gold exploration, Ghana

Mineral predictive mapping with Artificial Neural Networks (ANNs) of gold, base metals, and nickel occurrences in Burkina Faso

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Abstract

Burkina Faso, with its rich geology composed of Birimian greenstone belts and alternating crystalline basement of the West African Craton, aims at diversifying its mineral production mainly focused on gold. The Government, via the Ministry of Energy, Mines and Quarries, has commissioned the development of a new Mineral Plan of the country through the Bureau of Mines and Geology (BUMIGEB). This new Mineral Plan, realized by Beak Consultants GmbH in cooperation with BUMIGEB, integrates a national inventory of mineral resources, mineral prediction maps for Au, Ni, Mn, Sulphides (Cu, Zn, Pb, Sb), Fe-Ti-V, and bauxite, a target-generation and evaluation for additional strategic minerals such as uranium, lithium and sulfides. Mineral predictive models were generated using the metallogenic knowledge and available data on the geological, geochemical and geophysical context. They integrate data based on the latest ANN (Artificial Neural Networks) technologies available within the advangeo® Prediction software developed by Beak Consultants. The developed models provide a brand-new comprehensive prospecting tool. Promotion charts were established to attract investment specifically for gold, base metals (Zn, Pb, Cu, Sb), Fe-Ti-V, U, Li and Ni. Finally, a detailed programme of exploration activities as well as a communication plan were proposed to support the mineral industry of the country for the next ten years ahead.

Keywords: Machine Learning, Artificial Neural Networks, Minerals, Mining exploration, Metals

Exploration Information System – linking of mineral systems and mineral prospectivity mapping

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Abstract

The "Exploration Information System" (EIS) project, funded by the European Union (EU) Horizon Europe research and innovation funding programme, aims to discover new sources of critical primary raw materials within the EU by combining mineral systems modelling and mineral prospectivity analysis methods. As exploration data continues to emerge, the need for efficient data analysis becomes crucial, considering the high cost of data acquisition. Efficient analysis of expensive exploration data has become crucial, and recent advancements in artificial intelligence and machine learning algorithms within geographic information system (GIS) platforms have enabled the integration of geological knowledge and exploration data into complex mathematical models for predicting the existence of new mineral occurrences. The EIS project promotes a hybrid approach that utilizes mineral systems modelling as the foundation for mineral prospectivity modelling. A crucial component of the EIS is a library of geological fingerprints representing diverse types of mineral systems. These fingerprints are used to identify the most relevant mappable geoscientific features essential for successful prospectivity analysis. The project focuses on three mineral systems as case studies: cobalt minerals in volcanogenic massive sulfide (VMS) systems, lithium-tin-tantalum-tungsten minerals in granite/pegmatite-related systems, and rare earths-cobalt minerals in iron oxide copper-gold (IOCG) systems. Selected mineral deposits within the partner countries of the EU serve as study or test sites, and reference sites in South Africa and Brazil, specifically the Li-bearing pegmatite in the Orange River Pegmatite Belt and the Carajás IOCG province, provide additional insights. This project aims to enhance access to critical raw materials in Europe by providing new information on critical mineral systems and efficient data analysis tools, ultimately expanding knowledge of existing deposits within Europe. The development of new digital exploration tools will accelerate the discovery of mineral deposits (such as Li, W, Ta, Co, and REE) within the EU. An ideal exploration information system comprises components for different stages of mineral prospectivity analysis. The presentation will showcase the newly developed EIS Toolkit, which includes also not only preprocessing tools and validation tools, but also new data analysis methods by incorporating artificial intelligence, machine learning, deep learning. In addition, in the talk, it will be highlighted how geo-models and mineral systems modelling is being integrated into mineral prospectivity mapping. Upon completion, the EIS will consist of a collection of software tools for semi-automated exploration targeting. These components will be built as modules within an open-source community-based platform, encouraging contributions from developers worldwide, beyond the project consortium, to foster product development and maintenance.

Keywords: Mineral systems modelling, Mineral prospectivity mapping, GIS

Modelling of Prospectivity for Copper–Gold Deposits in the Brazilian Mineral Province of Carajás using Support Vector Machine: A Case Study to Address Imbalanced Training Samples

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Abstract

Machine learning has become an engaging tool in several geoscience fields, particularly in mineral exploration in which it is applied for mineral prospectivity modeling. Algorithms of machine learning are devised with assumption of reasonably balanced quantity of training samples for accurate approximation of limits between classes (e.g., in mineral prospectivity modeling: known prospective and non-prospective sites). In reality, however, known prospective sites are significantly fewer than non-prospective sites. The use of imbalanced data renders proper training of a machine learning algorithm difficult because the learning is biased toward the majority class (i. e. the non-prospective sites for mineral prospectivity modeling). In this presentation, we treat the setback of training samples consisting of unequal numbers of known prospective and non-prospective sites via SMOTE (Synthetic Minority Over-sampling Technique) in modeling of prospectivity for deposits of copper–gold in the Brazilian mineral province of Carajás using support vector machine. The initial training samples for the minority class (i. e. known prospective sites) was adjusted by oversampling the known prospective sites by means of SMOTE and by randomly undersampling the majority class (i. e. non-prospective sites) at various ratios, thereby creating 400 sets of training sites with ratios of prospective to non-prospective sites varying between 600:30 and 30:600. Every set of adjusted prospective and adjusted non-prospective sites was used to train a support vector machine to create a copper–gold prospectivity. Success-rate curve and F1 score were used to assess the performance of the support vector machine models of prospectivity for copper–gold deposits created using individual sets of training sites with different ratios of prospective-to-non-prospective sites. The outcomes disclosed that SMOTE amplified considerably the performance of support vector machine modeling of prospectivity for copper–gold deposits in the study area. The chief variations in the performances of the created support vector machine models of prospectivity for copper–gold deposits elucidate the susceptibility of mineral prospectivity modeling to the quantity and spatial distribution of training samples for prospective and non-prospective sites. The greatest performances of support vector machine modeling of prospectivity for copper–gold deposits in the study area using SMOTE were attained with training samples consisting the same numbers of prospective and non-prospective sites. The finest support vector machine model of prospectivity for copper–gold deposits in the study area was obtained when the original training samples were adjusted at 600:600 ratio of prospective to non-prospective sites. This model had 100% correct classification of the training prospective sites and nearly 80% correct classification of the testing prospective sites, and it delineated prospective zones that cover just 7% of the study area.

Keywords: Mineral prospectivity modelling, Carajás mineral province, Imbalanced training samples, SMOTE, Support vector machine

GOLDEN Artificial Intelligence (AI) - Artificial intelligence platform for mineral exploration, mining operation monitoring, and support of site closure/post closure

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Abstract

In the scope of the GoldenEye project, OPT/NET delivered the next generation of AI exploitation system: a hybrid platform which combines the processing & automation capabilities of AI with the natural problem-solving abilities of humans. We have developed dedicated applications with our novel approach based on the Artificial Intelligence Knowledge Packs (AI KPs), integrated in GOLDENAI Engine, to rapidly interpret the geographical patterns and environmental impacts caused by the mining activity. The main goal of the GOLDENAI Engine is the ingestion of different data sources into a data cube representation for a given area of interest (AOI). The platform consists of two main components: the back-end (mentioned as 'OCLI' hereafter) and the front-end (mentioned as 'GOLDENAI GUI' hereafter). OCLI processes the AI knowledge packs (AIKPs) and handles the data mining process through pipelines. This involves automated modules for data acquisition, data preprocessing, image processing (e.g., denoising, edge detection, etc.), and AI processing. In particular, for a given area of interest (AOI), it first collects the related satellite data products (from the DIAS services, Euro Data Cube (EDC), EOS or Supplier's API), and prepares analysis ready data (ARD) by performing data cleaning, transformation and filtering. GOLDENAI GUI acts as a general repository of data in Cloud Optimized GeoTIFF (COG) format and can be used as a 2D and 3D visualization platform by the public, mine site owners and stakeholders with different authentication and authorization access levels. It's powered by OGC web services and deliver EO, Drone (UAV) Sensing and Proximal Sensing data which can be interactively explored. Several Knowledge Packages (KPs) related to the technological solutions of the GoldenEye project can be found in the GEO Knowledge Hub (GKH). In this paper, the KP related to the GOLDENAI platform will be presented, including the description of the integrated AIKPs, such as:

- AI KP for mineral mapping - Band-ratios based on WorldView-3
- AI KP for mineral mapping - SPCA based on WorldView-3
- AI KP for UML clustering based on Copernicus Satellite imagery (Sentinel-1 SLC)

Keywords: GOLDEN-AI platform, AI KP, EOD, ARD, Mineral exploration

GoldenEye: Earth observation, drone and proximal data integration in 2D and 3D using machine learning for cost-efficient exploration targeting – Case study about stratiform tin mineralization in Bockau, Erzgebirge/ Germany

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Abstract

The “GoldenEye” project has implemented a unique combination of remote sensing and positioning technologies, exploiting Earth observation and Earth GNSS data, together with data fusion and processing powered by data analytics and machine-learning algorithms. The “GoldenAI” platform allows satellites, drones and in-situ sensors to collect high-resolution data, which can be processed and converted into actionable intelligence for safety, environmental monitoring and overall productivity, allowing more efficient exploration, extraction and closure. These tools have been demonstrated in 5 field trials sites in Germany, Bulgaria, Romania, Kosovo and Finland. The German field trial site “Bockau” is located in the Erzgebirge, which is a Variscan orogenic belt located at the northern margin of the Bohemian Massif, bordering Germany and the Czech Republic. The Erzgebirge mining district has been mined for 800 years and is most famous for its mineralization of Sn, W, U, Ag and Li. In the western part of the Erzgebirge, the Bockau deposit is located. There, potentially economic ore bodies in a type of stratiform tin mineralization have been discovered. The mineralization consists of disseminated and often fine-grained cassiterite in phyllites and quartzite schists. The presented use case in Bockau focuses on the exploration of these potentially economic ore bodies, which have so far received little study. Firstly, a smaller area in the Bockau deposit area was covered by drone-base electro-magnetic (EM) survey to identify structures in the underground. In addition, a drone-based LiDAR survey was conducted to map mine workings and tectonic structures that can be identified on the surface through elevation mapping. For proximal (spectral) field measurement, a new active hyperspectral sensor (AHS) and a new portable RAMAN device were used at hand specimen, surface outcrop walls and old underground mine workings. Finally, machine learning was applied using Artificial Neural Networks (ANN) for mineral prospectivity mapping in 2D and 3D using advangeo[®] Prediction software. The final results of the data fusion improved ore body mapping in 3D showing structures and ore bodies in the underground on a local scale, as well as increased the potential on discovery of new mineral deposits on a regional scale. The paper has been compiled in the frame of “Earth observation and Earth GNSS data acquisition and processing platform for safe, sustainable and cost-efficient mining operations (GoldenEye)” project.

Keywords: GoldenEye, Drone, 2D data interpretation, 3D data interpretation

2D Mineral Predictive Mapping Applied to the Medellín Region, Colombia

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Abstract

Cascades of information are inflowing to databases piling up on already existing data, which poses an enormous challenge to human brains to compile, mine and interpret. Geodatabases, filled with geospatial and geoscientific data, are one such example where new measuring techniques and sensors gather tons of new entries, for instance, aerial and satellite measuring techniques. Nonetheless, the combination of machine learning (ML) algorithms and GIS based approaches has allowed the development of new methods in mineral exploration. One such case is that of the integration of artificial intelligence modelling and mineral predictive mapping as a tool to support mineral deposit exploration and targeting. In this study, feed-forward back-propagating artificial neural networks (ANN), under a hybrid approach, were implemented in conjunction with the mineral systems method in order to identify the most favourable areas for selected mineral deposit types (porphyry, orogenic, epithermal and intrusion-related-Au deposits) at a regional scale. In consequence, similar process-like occurrences were grouped. This process was based on the workflow under the name knowledge discovery in databases (KDD), as defined by Fayyad *et al.* (1996), and the mineral systems approach of McCuaig *et al.* (2010). This work is a novel application of this methodology in Colombia for a region of approximately 21.867 km² and aims to improve the knowledge of mineral deposits from the data in the hands of the Servicio Geológico Colombiano (SGC). Base data used comprised of magnetic, radiometric and geologic information, from which several rasters were extracted which describe the characteristics of the deposits. All information was then normalized using a linear scaling method. The general selected ANN attributes were a sigmoid activation function, a balancing ratio of 50% and a slope-dependent mean square error (MSE) algorithm for the weight adjustment. For the results, the best performance was obtained for an ANN with a single hidden layer and for maximum number of iterations between 250 and 500. Further iterations proved to overfit the training data, whereas the usage of a second hidden layer did not give any acceptable outcomes. The overall performance and verification of the models was carried out through the examination of receiver operator (ROC) and mean square error (MSE) curves, with values over 0.9 and below 0.02 respectively. Validation of the same models was carried out using different ANN configurations as well as with the available geochemical data. Obtained models show a good visual fit to the training data and even properly identified wrongly labelled deposits. Target areas of interest were selected for future exploration campaigns in order to identify the respective mineralization indicators. This project highlights the potential of predictive mapping as a tool for the assessment of favourable areas for potential investing of mining companies in Colombia.

Keywords: Mineral predictive mapping, Machine learning

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The Nigerian Mineral Resources Decision Support System (NMRDSS): A milestone in mining sector related data management and analysis

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Abstract

In an era of digital transformation and digital technologies, information must be readily available for decision-making challenges. Decision support systems have emerged as invaluable tools offering organizations the means to navigate countless entries, optimize choices, and achieve results based on data. In Nigeria a Mining Support System has been implemented to allow knowledge-supported mining sector investment decisions, through accessibility to the essential geological information required. The architecture is based on two main components, a back end that controls the data entry and data processing, and a front end that displays the data allowing analysis and decision making. The system has been built on state-of-the-art technology linking relational geo-databases to ArcGIS leveraging on data distribution and Windows security. The results of this implementation delivered the first constituent (back end) where information is divided into relevant modules, for instance mineral occurrences and spatial data, and allows all entries to be visualized in a GIS environment and to be filtered; the compilation of the information is successful by joining content and context data. The second component (front end) not only displays relevant information that allows external users to visualize in a transparent way the availability of data in areas of interest, but also uses geoprocessing tools for identifying mineral occurrences that follow certain criteria (e. g. 5 km distance from main roads). The link between the organization and external stakeholders was optimized and the flow of information goes in straighter paths. Additionally, the Ministry can now store data centrally enacting better standard operating procedures (SOPs) for data handling and data security. Furthermore, data back-up now forms an integral part of their procedures preventing loss of data originally acquired for large sums of money. In conclusion, the Nigerian Geological Survey (NGSA) now has a fully functional, robust and intuitive system that manages data, allowing both easy post-processing of data and the sharing of information with the relevant parties (e. g. investors). This paves the way for value-added products, such as mineral prediction and metallogenic maps.

Keywords: Value-added products, Mining information system, Decision-making

Appendix

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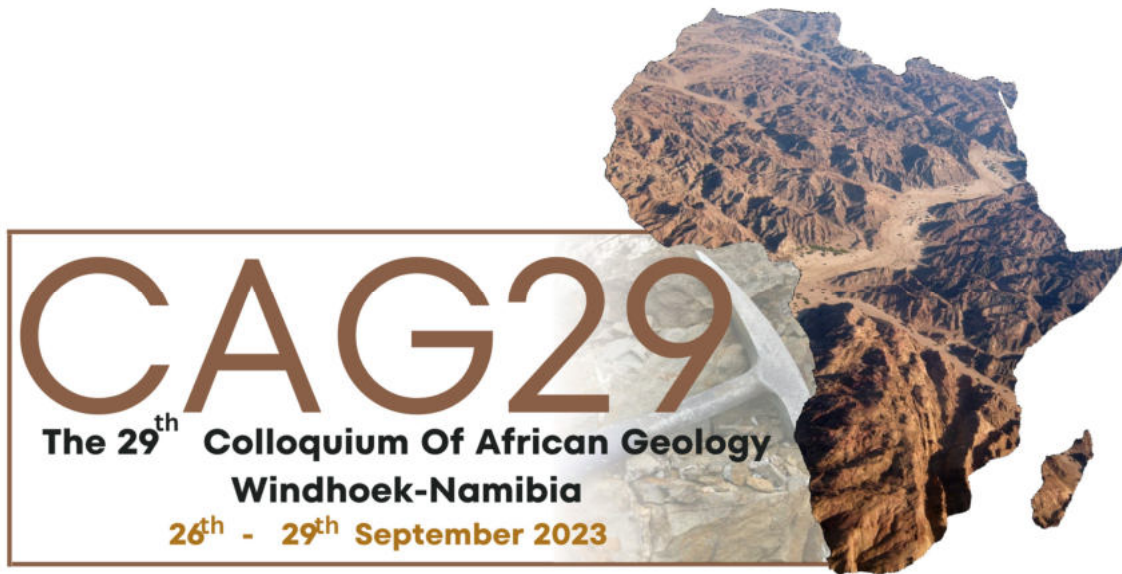
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The prominent & remarkable circular Richat structure 'Eyes of Africa' feature (diameter of almost 50 kilometres) in the Sahara Desert of Mauritania.