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GEOLOGY AND PALAEOBIOLOGY OF THE NORTHERN SPERRGEBIET, NAMIBIA

by

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Geology and Palaeobiology of the Northern Sperrgebiet : general conclusions and summary

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Cainozoic strata of the Northern Sperrgebiet comprise a wide range of deposits that accumulated by a variety of processes in diverse geomorphological settings including littoral marine zones, endorheic basins, shallow valleys, dolines, kamenitzas, volcanic craters and even on positive relief features. Fluids that eroded, transported and deposited sediments include water and wind, in a palaeoclimate that changed from humid subtropical to semi-arid and arid temperate with the passage of time. Diagenetic processes varied with time, being dominated in the Palaeogene by silicification, and during the Neogene by calcification. All this geological activity was played out against a background of changing sea levels and volcanic activity, a result of which is the juxtaposition of marine, terrestrial and volcanic deposits, sometimes in the same depression. The resulting stratigraphic succession is, as a consequence, highly varied with rapid lateral and vertical changes in lithology, small sediment bodies often being separated from other deposits, all of which makes correlation of strata difficult.

Palaeontology has played an important role in determining the relative positions of strata, and in some cases the biochronological ages of deposits, and have, as a result helped to sort out the stratigraphic sequence and the timing of events in the region. Such information is of importance to those interested in the origin and history of the diamond placer deposits of the Sperrgebiet. There remain, however, several uncertainties which require further attention. Fossils have also thrown a great deal of light on the palaeoenvironmental conditions that existed in the region since the Cretaceous.

Introduction

The Cainozoic deposits of the Northern Sperrgebiet came to world notice when diamonds were discovered near Lüderitz in 1908. Fossils were soon found by prospectors and miners and the first formal palaeontological articles were published soon after (Böhm and Weissermel, 1913). In the early 1920s (Stromer, 1922, 1923, 1926; Wenz, 1926) there was a flurry of palaeontological activity, partly fuelled by the desire to determine the sequence and timing of geological events and palaeoenvironmental conditions in the region so that the genesis of diamond placers could be better understood. There is still a certain degree of uncertainty about the ages of some of the strata in the area which the members of the Namibia Palaeontology Expedition have tried to resolve. This monograph represents the fruits of this effort carried out for one or two months of field work each year since 1993.

Because of diamond security and environmental impact concerns, access to the Sperrgebiet has been tightly controlled, yet the NPE was given relatively free access to certain areas including the classic fossil mammal localities worked by W. Beetz and others in the 1920's. In 2008, access to previously unstudied carbonate bodies was arranged, as a result of which four new fossil sites were discovered which will throw a great deal of light on the Cainozoic geology and palaeontology of the Sperrgebiet. A preliminary geological report of these carbonates is included in this monograph, but the fossils will take time to extract from their matrix and to study. All that can be said at the moment is that the deposits contain plant remains (sedges, algae, reeds), abundant freshwater gastropods (two varieties of *Lymnaea*, *Hydrobia* or *Tomichia*, a large planorbid), terrestrial snails (*Succinea*, *Dorcasia*, *Trigonephrus*, *Xeroceratus* and cfr *Gastrocopta*) pipid and ranoid frogs, a fish, crocodiles and mammals (carnivorans, rodents, small primate, an arsinoithere, two or three size groups of Hyracoidea). Preliminary identifications of the rodents and arsinoithere indicate a Lutetian age, close to 47 Ma.

The Sperrgebiet fluvio-paludal localities are richly fossiliferous, and each field season new taxa have been collected, an interesting point, because some palaeontologists consider it a waste of time to return to fossil sites more than four or five times due to the law of diminishing returns. In 2006 the first crocodile was recovered from the Northern Sperrgebiet. In 2007 the NPE found the first Tubulidentate fossil in the area, in 2007 the first *Afrohyrax* specimen was found (Fig. 1) and in 2008 the first varanid fossil.

As a result, over the years, the faunal list for the Sperrgebiet sites has grown enormously, and will continue to be augmented in the future (Tables 1 and 2). Prior to the NPE, only 25 Neogene animal taxa were described from the region, but the figure now stands at 93.

A second reason for continuing to prospect for fossils in the Sperrgebiet is that many of the taxa found there are represented by fragmentary remains, and each visit provides an opportunity to recover more complete fossils (Fig. 2). For example, until 2006 the only anthracothere fossils known from the region comprised a fragmentary tooth, a wind abraded talus and a vertebra. In 2006, a sand dune which had covered a large part of the Grillental 6 locality shifted more than a hundred metres northwards, leaving a clean swept surface of sediments

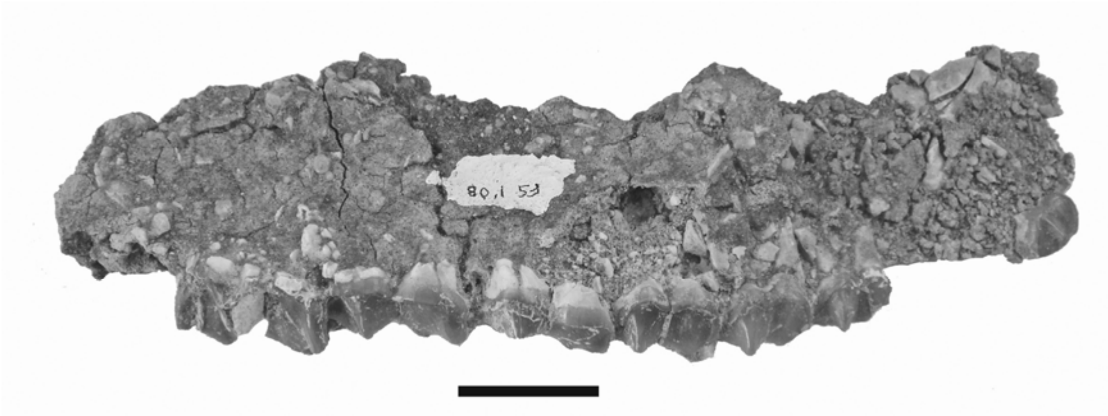

Figure 1. FS 1'08, *Afrohyrax namibensis* right maxilla containing C1/-M3, buccal view, from Fiskus, Northern Sperrgebiet, Namibia. The measurement C1/-M3/ in this specimen is 152 mm, which compares with two specimens of *Afrohyrax championi* from Kenya which measure 104.4 mm (for M 21294, 350'50) and 107.4 (for M 21295, 91'50) (scale bar : 20 mm).

Table 1. Supra-generic representation of fossils at the four main Early Miocene fluvio-paludal localities in the Northern Sperrgebiet, Namibia (the sites included are Elisabethfeld, Grillental, Fiskus and Langental).

Group	Pre-1980	2007
Insecta	0	1
Mollusca	4	6
Amphibia	1	4
Squamates	0	9
Chelonians	1	3
Crocodilia	0	1
Aves	0	10
Macroscelidea	2	5
Insectivora	0	5
Lagomorpha	1	1
Rodentia	8	15
Creodonta	1	6
Fissipeda	0	6
Proboscidea	0	2
Hyracoidea	1	2
Tubulidentata	0	1
Rhinocerotidae	1	3
Anthracotheriidae	0	2
Suidae	1	1
Sanitheriidae	1	1
Tragulidae	1	3
Pecora	2	5
TOTAL	**25**	**93**

behind it, exposing a partial skull and skeleton of *Brachyodus aequatorialis*.

A second example concerns the large hyracoid *Afrohyrax namibensis*, hitherto known only from its holotype from Grillental 6. In 2008, the NPE found a second specimen at Fiskus, which has a more complete tooth row (Fig. 1).

The converse happens as well, with dunes advancing over exposed deposits to hide them for several years. Grillental Carrière provides a fine example with a huge dune advancing on it from the south. From 2003 to 2005 the deposits were well exposed in the downwind lee of the dune and the NPE found many hundreds of fossils. By 2008 the deposits were completely buried under this huge dune, and it will take several years for it to advance far enough (about 700 metres) to re-expose the deposits on its trailing side.

Aeolian movement of sand in the Sperrgebiet happens at several scales and in several directions. In the Langental, for example, the predominant southerly wind regime results in the build-up of sand shadows in the lee of plants and trommel screen heaps left over from German mining activities. This sand cover hides fossils, but a good blow from a north wind or an east wind can remove enough of this sand to expose fossils that were previously invisible. Even in 2008, an extended period of north wind exposed fossils in areas that have been extensively prospected for 15 years. For this reason, it will continue to be worth while prospecting areas that have been thoroughly examined previously.

Summary of the Cainozoic stratigraphy of the Northern Sperrgebiet west of the Chameis-Rotkop road

The Cainozoic rocks of the Northern Sperrgebiet result from a wide variety of geological processes that were active in a near coastal, sub-humid and later

Table 2. Faunal lists : Taxonomic representation at the four main Early Miocene fluvio-paludal fossiliferous localities of the Northern Sperrgebiet (EF – Elisabethfeld, GT –Grillental, FS – Fiskus, LT – Langental) (+ recorded pre-1980, x present, - no record, # termite hives, * eggshells).

Taxon	Pre-1980	EF	GT	FS	LT
Namajenga mwichwa Pickford, 2008	-	-	#	#	-
Lymnaea aff. *natalensis* Krauss, 1848	+	-	X	-	X
Lymnaea aff. *truncatula* (Müller, 1774)	+	-	-	-	X
Bulinus Müller, 1781	-	-	-	-	X
Urocyclidae indet.	-	-	X	-	-
Trigonephrus Pilsbry, 1905	+	X	X	-	-
Dorcasia Gray, 1838	+	X	X	-	-
'Xenopus' stromeri Ahl, 1926	+	-	X	-	X
? Pipinae indet.	-	X	-	-	-
Ranoid indet. A	-	-	X	-	-
Ranoid indet. B	-	-	X	-	-
Varanidae indet.	-	-	X	-	-
Geckonidae indet.	-	X	-	-	-
Amphisbaenia Gray, 1844	-	-	X	-	-
Lacertilian indet.	-	X	X	-	X
Scolecophidea indet.	-	-	X	-	-
? *Python* sp. A	-	-	X	-	-
? *Python* sp. B	-	-	-	-	X
Natricinae indet.	-	-	X	-	-
Viperidae indet.	-	X	-	-	-
Pelomedusa senutpickfordina de Broin, 2008	-	-	-	-	X
Namibchersus namaquensis (Stromer, 1926)	+	X	X	X	X
aff. *Mesochersus* Lapparent de Broin, 2003	-	-	-	-	X
Crocodylu-s cf *gariepensis* Pickford, 2003	-	-	X	-	-
Struthio coppensi Mourer-Chauviré, Senut, Pickford and Mein, 1996	-	X*	*	*	*
cf *Oligocorax littoralis* (Milne-Edwards, 1871)	-	X	-	-	-
Accipitridae indet.	-	X	X	-	X
Charadriform indet.	-	X	-	-	-
Megapaloelodus A.H. Miller, 1944	-	-	X	-	-
Mionetta Livezey and Martin, 1988	-	-	X	-	X
Anserinae indet.	-	-	X	X	X
Phasianidae indet.	-	-	X	-	-
? *Palaeortyx* Milne-Edwards, 1869	-	X	-	-	-
Coliidae indet.	-	-	X	-	-
Myohyrax oswaldi Andrews, 1914	+	X	X	X	X
Myohyrax pickfordi Senut, 2008	-	-	-	-	X
Protypotheroides beetzi Stromer, 1929	+	X	X	X	X
Brachyrhynchocyon jacobi Senut, 2008	-	X	-	-	-
Hypsorhynchocyon burrelli Senut, 2008	-	-	X	-	X
Gymnurechinus leakeyi Butler, 1956	-	-	X	-	X
Amphechinus rusingensis Butler, 1956	-	-	-	-	X
Protenrec butleri Mein and Pickford, 2003	-	X	X	-	X
Prochrysochloris cf *miocenicus* Butler and Hopwood, 1957	-	X	-	-	X
? *Erythrozootes* Butler and Hopwood, 1957	-	-	-	-	X
Austrolagomys inexpectatus Stromer, 1924	+	X	X	-	X
Vulcanisciurus africanus Lavocat, 1973	-	X	X	-	X
Protarsomys macinnesi Lavocat, 1973	-	X	X	-	X
Parapedetes namaquensis Stromer, 1926	+	X	-	-	-
Megapedetes cf *gariepensis* Mein and Senut, 2003	-	-	-	-	X
Propedetes efeldensis Mein and Pickford, 2008	-	X	-	-	X
Diamantomys luederitzi Stromer, 1922	+	X	X	-	X

Table 2. (Continued)

Taxon	Pre-1980	EF	GT	FS	LT
Pomonomys dubius Stromer, 1922	+	-	X	-	X
Phiomyoides humilis Stromer, 1926	+	X	X	-	X
Apodecter stromeri Hopwood, 1929	+	X	X	-	X
Neosciuromys africanus Stromer, 1922	+	X	X	X	X
Neosciuromys fractus (Hopwood, 1929)	+	X	X	-	X
Bathyergoides neotertiarius Stromer, 1923	+	X	X	X	X
Efeldomys loliae Mein and Pickford, 2008	-	X	-	-	X
Geofossor moralesi Mein and Pickford, 2008	-	X	X	-	X
Microfossor biradiculatus Mein and Pickford, 2008	-	X	-	-	-
Metapterodon kaiseri Stromer, 1924	+	X	-	-	-
Metapterodon stromeri Morales, Pickford and Soria, 1998	-	-	-	-	X
Hyainailouros Biedermann, 1863 or *Megistotherium* Savage, 1973	-	X	X	X	-
Isohyaenodon Savage, 1965	-	X	-	-	-
Teratodontidae Savage, 1965	-	-	-	-	X
Namasector soriae Morales, Pickford and Salesa, 2008	-	X	-	-	-
Ysengrinia Ginsburg, 1965	-	X	X	X	X
Leptoplesictis senutae Morales, Pickford and Salesa, 2008	-	-	X	X	-
Leptoplesictis namibiensis Morales, Pickford and Salesa, 2008	-	-	-	-	X
Viverridae indet. I	-	X	-	-	-
Viverridae indet. II	-	X	-	-	-
Afrosmilus africanus (Andrews, 1914)	-	X	X	X	X
Eozygodon morotoensis (Pickford and Tassy, 1980)	-	X	-	-	-
Gomphotheriidae indet.	-	X	-	-	-
Afrohyrax namibensis Pickford, 2008	-	-	X	X	-
Prohyrax tertiarius Stromer, 1923	+	X	X	-	X
Orycteropus africanus (MacInnes, 1956) or *O. chemeldoi* Pickford, 1975	-	-	X	-	-
Brachypotherium heinzelini Hooijer, 1963	+	-	-	cf	X
Chilotheridium pattersoni Hooijer, 1971	-	-	X	-	-
Aceratherium acutirostratum (Deraniyagala, 1951)	-	-	-	X	-
Brachyodus depereti Fourtau, 1918	-	-	X	-	X
Brachyodus aequatorialis MacInnes, 1951	-	-	X	-	-
Nguruwe namibensis (Pickford, 1986)	+	X	X	X	X
Diamantohyus africanus Stromer, 1922	+	X	X	X	X
Dorcatherium cf *moruorotensis* Pickford, 2002	-	-	X	-	-
Dorcatherium songhorensis Whitworth, 1958	+	-	-	-	X
Dorcatherium cf *parvum* Whitworth, 1958	-	-	-	-	X
Propalaeoryx africanus (Whitworth, 1958)	+	X	-	-	-
Propalaeoryx stromeri Morales, Soria and Pickford, 2008	-	-	X	X	X
Sperrgebietomeryx wardi Morales, Soria and Pickford, 1999	-	X	-	-	-
Namibiomeryx senuti Morales, Soria and Pickford, 1995	-	X	-	-	-
Namibiomeryx spaggiarii Morales, Soria and Pickford, 2008	-	-	cf	cf	X

arid to semi-arid environment (Beetz, 1926), with much re-working of clastic material from older to younger strata. Furthermore, there has been a variety of diagenetic processes active, leading to silicification, calcification and gypsification of pre-existing rocks, and a variety of weathering processes was active (ferruginisation, salt weathering, wind abrasion, etc.). There was a great deal of volcanic activity, manifested mainly as intrusions of various sorts (dykes, domes) but also as sub-aerial facies (welded tuffs, lava flows).

In the Sperrgebiet, there are today several major belts where certain geological processes are concentrated (Beetz, 1926; Corbett, 1989; Miller, 2008). The same kind of zonation may have existed in the past. There are the coastal belt with beaches and other littoral deposits, a near coast wind deflation belt, dune corridors, yardang fields, and in the interior a more vegetated belt with widespread sand sheets obscuring much of the underlying rock succession. These belts tend to be oriented northwest-southeast (Beetz, 1926; Corbett, 1989).

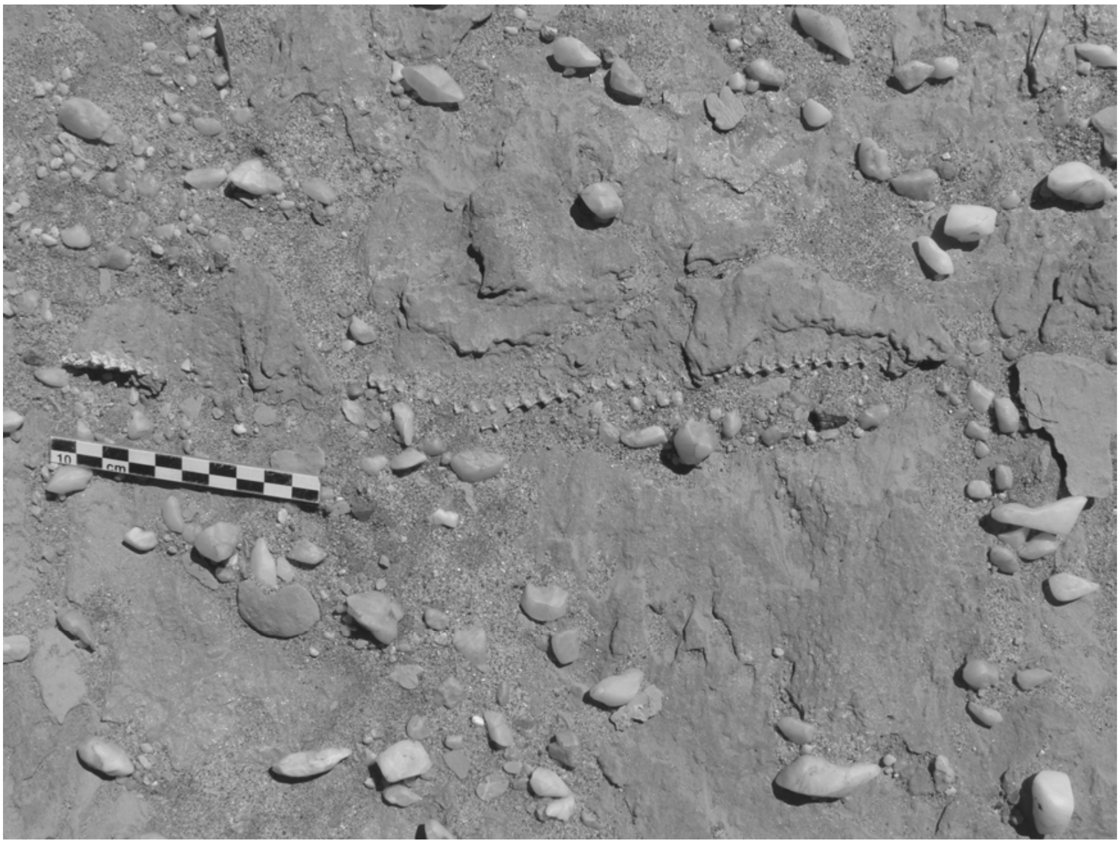

Figure 2. EF 30'07, articulated snake skeleton from Elisabethfeld, Northern Sperrgebiet, Namibia.

In brief, the Cainozoic clastic sediments exposed in the Sperrgebiet can be conveniently organised into four main depositional categories; A) doline and kamenitza deposits of small areal extent, dominated by sandy marl and well bedded carbonates, B) shallow water marine deposits, C) coarsening upwards fluvio-paludal deposits, with pedogenic overprinting in cases, maturing to calcrete and calc-crust sheets in instances. The latter deposits form extensive hamadas over much of the Sperrgebiet. The fourth category D) comprises aeolian deposits. In addition to these four widespread sediment types, there are minor facies such as scree deposits which can be economically important, but which are generally non-fossiliferous. This section of the paper will focus on the dolines, kamenitzas and fluvio-paludal deposits.

In broad terms, category A) was active during the Palaeogene, B) was active during the Eocene and Plio-Pleistocene, category C) was dominant from Early Miocene until Plio-Pleistocene times, and category D) has been active since the onset of the Middle Miocene with an early episode during the Palaeogene.

Diagenetic processes in the Sperrgebiet changed through time. The Palaeogene was dominated by silicification and some dolomitisation of limestones, the base of the Neogene was dominated by pedogenic calcrete genesis, but by the late Miocene it was dominated by non-pedogenic calc-crust genesis (the Namib Calc-crust). The Plio-Pleistocene experienced salt and gypsum deposition, as well as some calc-sinter formation.

Some silicification may well have been related to hydrothermal activity, but some appears to have been synsedimentary, accumulating in near-surface carbonates precipitating in dolines and kamenitzas. The Namib "Calcrete" of Van Greunen (undated) is non-pedogenic, and caps a vast area of the Namib, having formed at various altitudes and even on quite steep slopes. It is likely that this "calcrete" is genetically related to the occurrence of frequent coastal fogs in the region, which brought inland the essential humidity required for the dissolution of calcite followed by its precipitation, leading to the development of this widespread duricrust which formed on all rock types. Apart from salt pans which result mainly from evaporation of sea water in back beach lagoons, saline and gypsum deposits of the Sperrgebiet result from the inland drift of sea spray or aerosols containing minute amounts of H_2S and NaCl which builds up over the millenia to add salt to existing deposits and under favourable circumstances results in the formation in gypcretes or deposits of fibrous gypsum in marls.

The Sperrgebiet kamenitzas and dolines and their infillings

Kaiser (1926) mapped several sediment filled

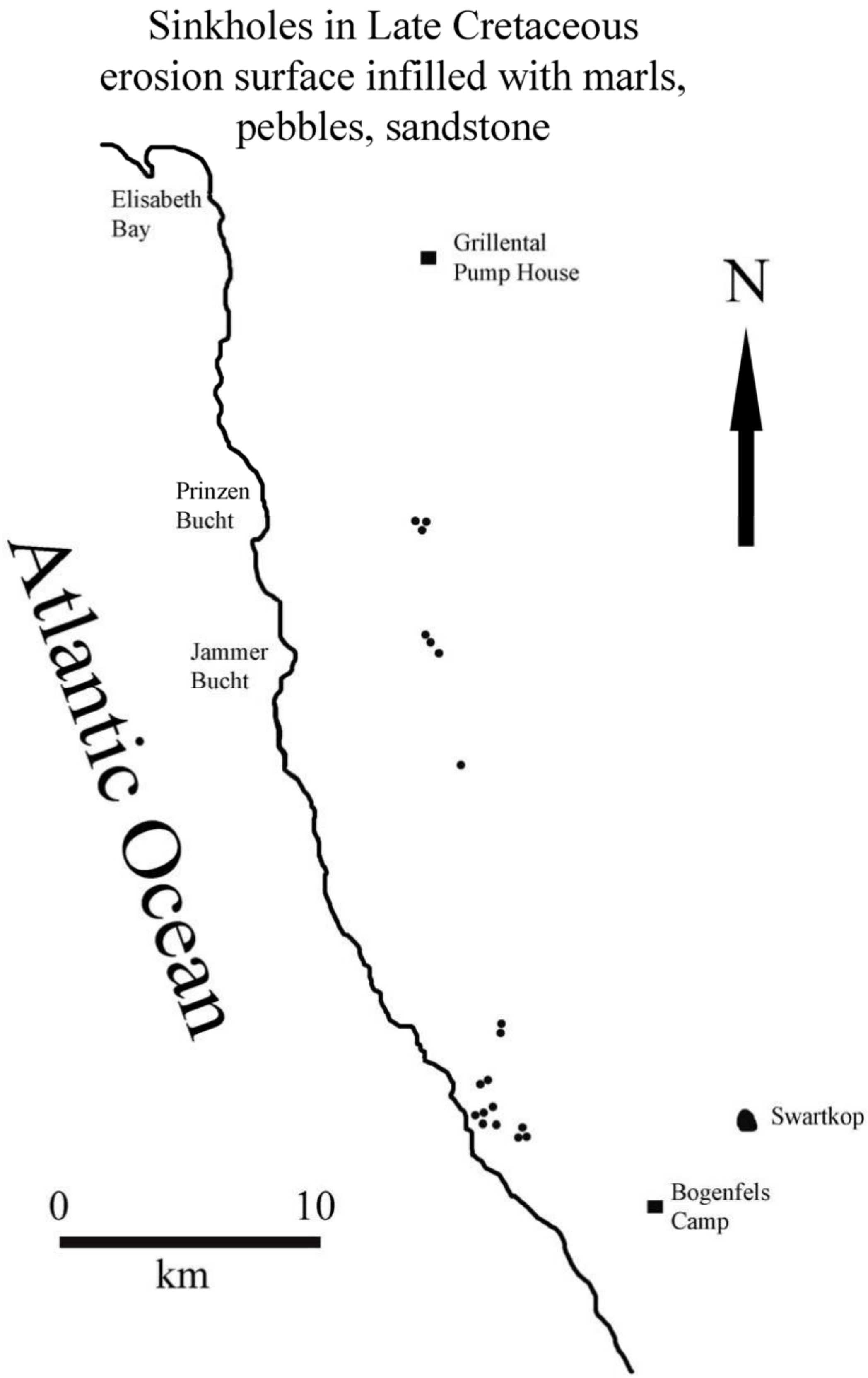

Figure 3. Dolines in the Northern Sperrgebiet mapped by Kaiser (1926) and Van Greunen (undated).

depressions in the dolomitic basement of the Northern Sperrgebiet (Fig. 3). He reported that these were dolines infilled with sandy marls and locally derived clasts of country rock. These dolines are generally less than 200 metres in diameter. Because they are unfossiliferous, and are isolated from other Cainozoic rocks, the age of these doline infills has remained uncertain. The only exception containing fossils known to Kaiser was Chalcedon Tafelberg, which has a chalcedonic limestone cap overlying sandy marl, which was estimated by him to be Cretaceous age, but which was redated to the Miocene after a volcanic dyke cutting the underlying marls was dated to ca 15 Ma (Stocken, 1978). It is now considered to be Palaeogene, more precisely Lutetian in age.

Other authors (Liddle, 1971; Kalbskopf, 1977) have tended to interpret these roughly circular depressions as volcanic craters, but the only one associated with primary volcanic rocks is Chalcedon Tafelberg which has a dyke-like body intruding the sandy marl infilling the doline. It is perhaps more likely to represent a doline than a volcanic crater.

The NPE mapped four additional depressions capped by bedded carbonates, all of which are highly fossiliferous, and once the palaeontology has been attended to it should be possible to determine the precise age of the infillings. Preliminary assessment of the mammals indicates a Lutetian age (ca 47 Ma). The four examples found by the NPE appear to be shallow, flat bottomed depressions in bedrock dolomite, and would thus be kamenitzas rather than dolines (Fig. 4, 5). Black Crow, Steffenkop, Silica North (Fig. 6) and Silica South, in contrast to Chalcedon Tafelberg (Fig. 7), do not appear to have marly infillings beneath the bedded limestones, although drilling has not been undertaken to prove this; natural outcrops do not reveal what lies buried beneath the limestone caps. Examination of satellite imagery reveals that large kamenitzas (up to 200-300 metres diameter) are a common feature of the exposed dolomite outcrops of the Sperrgebiet (Fig. 5). Kamenitza is a Slavic word for a shallow, flat bottomed, roughly circular depression that develops in exposed carbonate country rock. Kamenitzas are generally small (20-100 cm) (Fig. 4) but they can get extremely large (up to several hundred metres diameter under favourable circumstances). Most of the Sperrgebiet examples have a shallow infilling of granules (possibly blown into them since they formed), but almost no previous examinations of these occurrences have been undertaken, and the literature is silent on their existence.

The Sperrgebiet Hamadas

Hundreds of square kms of the surface of the Sperrgebiet consist of hamadas. Hamada is an Arabic word for an arid, rock strewn plain, often with a scarp-like margin (Fig. 8). They form in arid areas

Figure 4. Small kamenitza in dolomite near Grillental, Northern Sperrgebiet, Namibia which has been sand blasted since its formation and is now the receptacle for a large clast and its sand shadow. The example is about 50 cm in diameter.

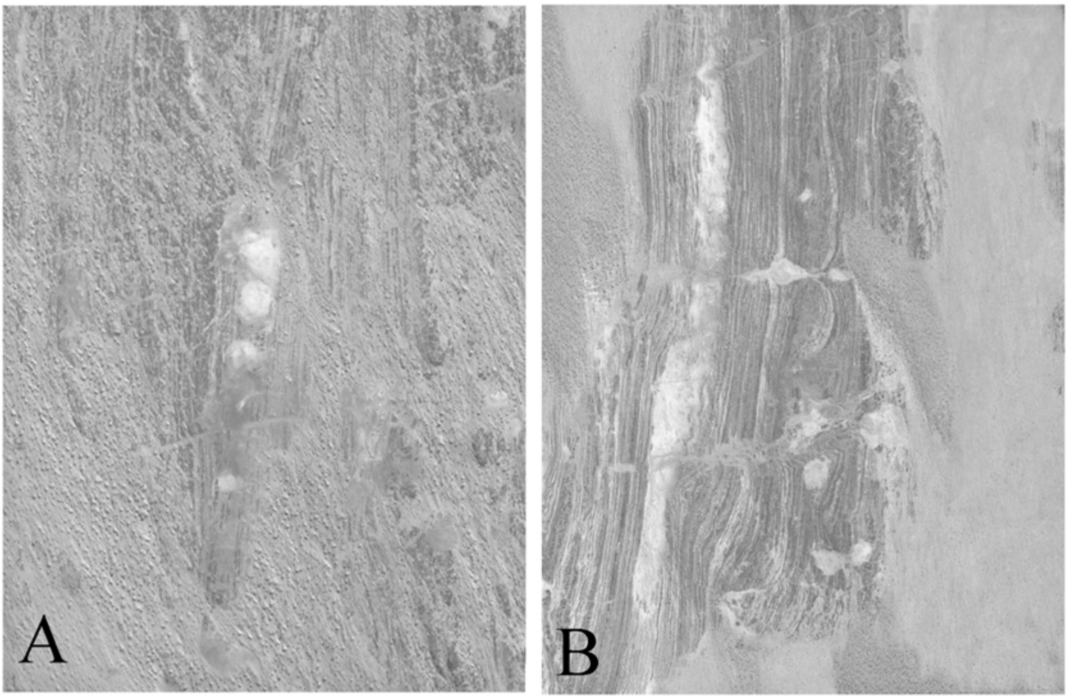

Figure 5. Vertical view of large kamenitzas in steeply dipping, well bedded Gariep Dolomite north of Bogenfels Camp, Northern Sperrgebiet, Namibia. The roughly circular white patches are large kamenitzas up to 200 metres in diameter, now infilled with a lag of quartz granules blown into them by the south winds. In (A) three large and two smaller kamenitzas form a linear series aligned north – south. In (B) 8 or more kamenitzas are visible, and in addition there is a shallow, elongated, north-south oriented valley likewise with an infilling of granules. The carbonates at Black Crow, Silica North and Silica South, explored by the NPE in 2008, probably represent similar depressions which filled with bedded carbonates during the Lutetian, rather than filling with granules.

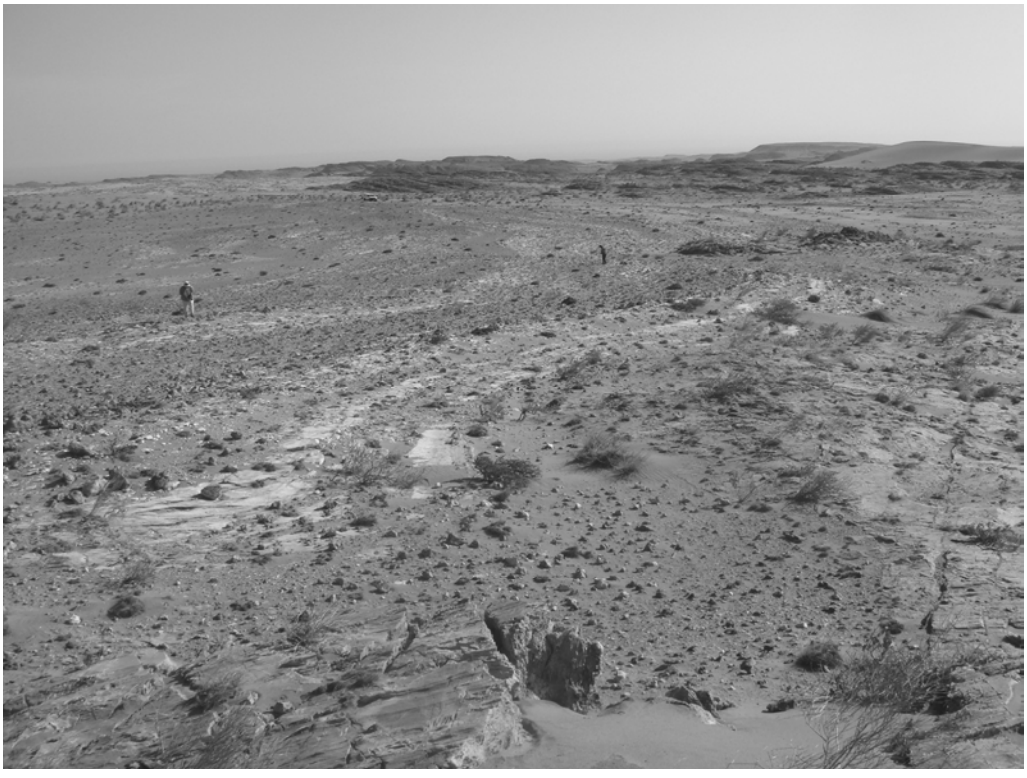

Figure 6. Silica North, bedded carbonate infilling a kamenitza dissolved into Gariep Dolomite (people and vehicle in distance for scale). The white bedded carbonates are exceptionally richly fossiliferous. Dark rocks to the right (north) and in the distance are Gariep Dolomite.

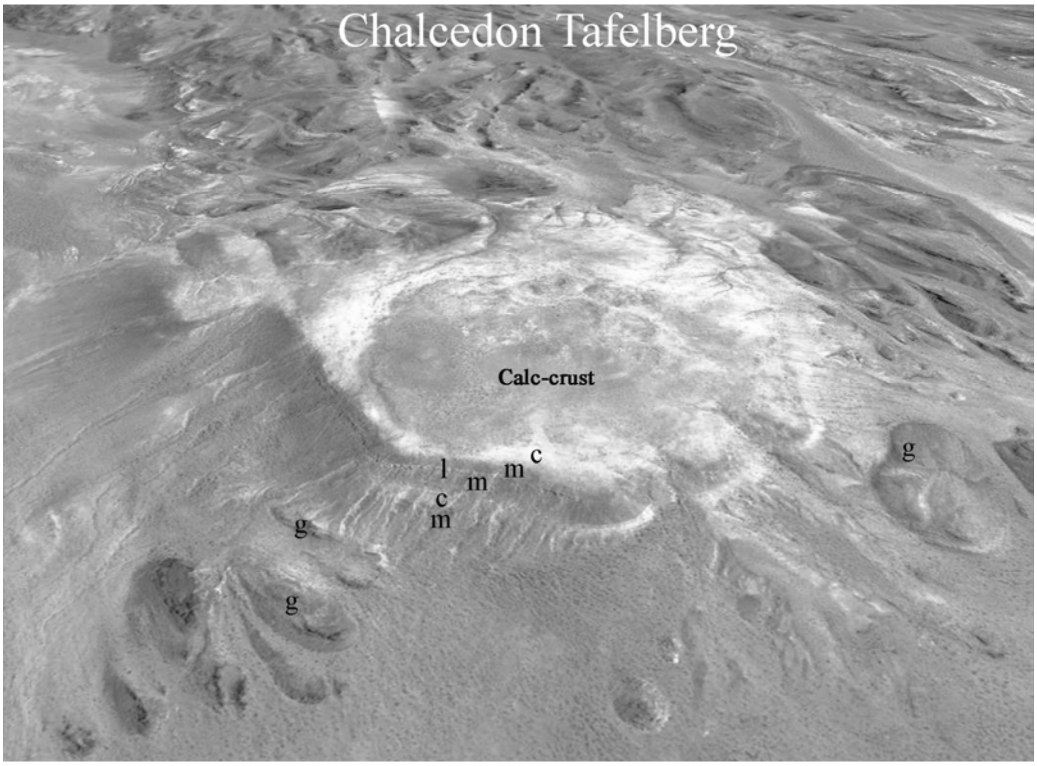

Figure 7. An oblique view of Chalcedon Tafelberg from the south, modified from Google Earth. Chalcedon Tafelberg owes it origin to sedimentation within an ancient doline eroded into Gariep Dolomite (g), infilled by marl (m), limestone (l) and chalcedonic limestone (c). The top of the hill and its northern slopes are covered in Namib calc-crust (grey tones at top of hill) attributed by previous authors to the Namib Calcrete.

Figure 8. Small plateau north of Bogenfels Camp comprised of a cap of Blaubock Conglomerate cemented by Namib calc-crust (= Namib Calcrete of previous authors), overlying marls (steep slopes) and dolomite bedrock. The upper surface of the plateau is a classic hamada, viewed from the summit of a neighbouring dune.

where infrequent but often violent rainstorms in neighbouring hills and mountains flush enormous quantities of sediment from high ground, dumping it in neighbouring low-lying country. The water is often so charged with sediment that it forms a sludge that can carry large boulders along with it. This sludge then spreads out laterally as soon as the power of the flow diminishes. Further downstream finer sediments are deposited, which tend to fill valleys, thereby smoothing out the topography, and allowing subsequent flash floods and sheet wash to travel further downstream than prior ones. In the Sperrgebiet the resulting deposit is a coarsening upwards sequence of silts, sands, marls and conglomerate. Once a flash flood has ended, there is often a short period of slacker water flow which can rework fines in the deposits, resulting in the accumulation of lenses of sandstone and silt, but these tend to be much more restricted in area than the sheet wash deposits and they are relatively thin. Repetition of the sheet wash process leads to the formation of incredibly widespread sheets of conglomerate, as separate flood episodes tend to be directed laterally or extend further distally than previous ones, and they can even rework pre-existing loosely consolidated deposits. In the Sperrgebiet, despite the vast areas covered by hamadas, there are only three main conglomerate horizons, the lowest called the Blaubock Conglomerate, the upper two attributed to the Gemsboktal Conglomerate. Aeolian deflation then occurs which removes clay, silt and sand from the surface exposures of the deposit, a process which results in the development of a lag of boulders which armours the surface. In the Sperrgebiet, exposed boulders are frequently facetted by wind-driven sand, forming classic dreikanters and polykanters. In addition, over much of the area, the surface is exposed to duricrust genesis which cements the conglomerate into a resistant mass. Erosion of the lime cemented hamada plain by rain water and wind removes the soft marly deposits underlying the lime cemented hamada surface, undercutting it to form low scarps.

Northwest of Strauchpfütz, the lower Gemsboktal Conglomerate contains huge blocks of Strauchpfütz calcrete (Fig. 9, 10). The upper Gemsboktal Conglomerate does not contain such rocks because by the time it accumulated the carbonate layers had been completely buried, not only by the lower conglomerate, but also by the Kalkrücken aeolianite (Fig. 11).

It has been reported that the Sperrgebiet Blaubock and Gemsboktal Conglomerates are up to 10 metres thick (Stocken, 1978; Miller, 2008), but this is erroneous, the thickest conglomerates that we have

Figure 9. Very coarse Gemsboktal Conglomerate 1 km northwest of Strauchpfütz, comprising large boulders of Early Miocene Strauchpfütz Calcrete and smaller boulders and cobbles typical of the Gemsboktal Conglomerate, including phonolite blocks. The deposit is underlain by marls with calcareous nodules.

Figure 10. Same locality as figure 9, showing the hamada surface of the Lower Gemsboktal Conglomerate stretching away westwards until it reaches outcrops of Late Miocene Kalkrücken aeolianites and overlying fluviatile grits, which are in turn capped by the Upper Gemsboktal Conglomerate forming the skyline. Two factors render the hamadas resistant to erosion ; the boulders strewing the surface form a lag deposit resistant to wind erosion, and cementing by the Namib calc-crust consolidates the surface further. The white boulders in the image are reworked clasts of Strauchpfütz Calcrete and some of the black cobbles are phonolite from the Klinghardt volcanic field.

observed being about 1 metre, even in rather narrow valleys. In widespread hamadas, the boulder layer is thin, usually less than 0.5 metres. The scarp edges of hamadas are generally covered in a scree of reworked boulders, which armours the slopes beneath the scarp which can be up to 10 metres tall, thereby giving the impression of a great thickness of conglomerate, but excavations in several places along these slopes reveal that they are fine grained, marly to sandy, often with calcareouos nodules.

The Sperrgebiet Aeolianites

In the area between Chameis and Rotkop and west of the road, there are relatively small occurrences of aeolianite, unlike the zone further inland where extensive aeolianite outcrops occur at Rooilepel, Karingarab, Obib and other places. The main areas with such deposits west of the road are at Kalkrücken near Glastal, north of Idatal and in the Grillental-Fiskus zone.

The aeolianite deposit at Kalkrücken is sandwiched between two successions of coarsening upwards fluvial rocks comprising the Gemsboktal Conglomerate (Fig. 11). It is locally widespread, but outcrops are generally small because the upper Gemsboktal Conglomerate obscures it over a wide area. Small outliers of this aeolianite occur plastered to the surface of the Strauchpfütz calcretes. An eggshell of *Diamantornis laini* collected in this aeolianite dates it to the Late Miocene, ca 8-6 Ma.

Coarse aeolianite deposits north of Idatal and in the Fiskus area have yielded eggshells of *Struthio daberasensis*, indicating a Plio-Pleistocene age, ca 4-2 Ma.

The Sperrgebiet Calc-sinters

Scattered outcrops of calc-sinter occur in various places in the Sperrgebiet. The most extensive deposits occur in the west end of Grillental, at Gamachab and at Buntfeldschuh. An important occurrence is at Kaukausib Fontein, where a large calc-sinter dome built up several metres above the surrounding countryside. All these calc-sinter deposits incorporate aeolian sand in them, and in cases have cross cutting relationships with layers of aeolianite, indicating that the lime was brought into the deposits by underground seepage rather than by surface processes. The only fossils found in Sperrgebiet calc-sinter occur at Kaukausib Fontein where a late Pliocene suid, a pedetid and bovids have been found. The geomor-

Figure 11. Upper Gemsboktal Conglomerate overlying Kalkrücken aeolianite in the Kalkrücken Valley. The conglomerate flanking both sides of the aeolianite, forms classic hamada surfaces.

phological relationships of the calc-sinter deposits and the fossils indicate that all of them are post-Miocene, and most are Pleistocene.

Sperrgebiet Diagenesis

The importance of diagenetic effects in the Sperrgebiet has been appreciated since the earliest days of diamond prospecting in the region. The co-occurrence between diamonds and agates, chalcedonies, and banded ironstone clasts was noted early, and geologists and prospectors alike studied any occurrences of micro-crystalline silica in the hope of throwing light on genesis of diamond placers (Beetz, 1926). Chalcedon Tafelberg was described in detail, as were silicified weathering products of basement rocks, silcretes and silicified fluvial sands. Less attention was paid to calcretes, even though it was known that some lime cemented gravels contained diamonds. Calc-sinters were noted and described but did not evoke a great deal of interest.

Silicification

A wide range of silicified rocks occurs in the Sperrgebiet. The oldest appear to be dark brown ferruginous crusts resulting from weathering of basement rocks which have been silicified to produce dark brown, shiny, irregularly shaped clasts.

Quartzites in the Sperrgebiet, generally known as the Pomona Quartzites, have been pervasively silicified. Fluvial deposits beneath the Swartkop Phonolite have also been silicified to produce quartzite.

Younger than the previous categories is a series of chalcedonic deposits, usually affecting well bedded, post-Cretaceous limestone bodies. Closely spatially associated with this type of chalcedony is a suite of silicified dolomite comprising either shiny, cream coloured or pale olive green rocks These rock types are quite distinctive and, as derived blocks, occur widely in the Neogene strata of the region.

These rock types are overlain by sedimentary chalcedony, indicating that silica-rich fluids circulated preferentially at the basement-sediment interface, and affected both the underlying dolomites and the overlying bedded carbonates. In some areas such as Black Crow, Silica North, and Silica South, silicification has proceeded to such an extent that huge masses of chalcedony have been formed. Close examination of these occurrences reveal that there are various sub-categories of chalcedony. Thin layers of limestone may be completely silicified, producing plates of chalcedony. Nodules of limestone can be silicified to produce irregular, potato-like masses of chalcedony, and veins of pure chalcedony can occur cross-cutting limestone beds and even extending a short way into the underlying marls. Fossil gastropods in these deposits are also often silicified.

At Black Crow, narrow tubes in the upper carbonates are lined with druzes of small euhedral crystals of quartz. These appear to be the youngest manifestations of silica deposition from fluids in the Cainozoic deposits of the Sperrgebiet.

Carbonate diagenesis

Carbonates are represented in the Sperrgebiet by vast masses of Proterozoic dolomites of the Gariep Group, and there are also veins and dykes of carbonatite in the region. Weathering, dissolution and erosion of the dolomites release huge volumes of carbonate into the environment, so it is not surprising to find varied manifestations of carbonate deposition in the Cainozoic strata of the region. These include the richly fossiliferous bedded limestones that accumulated in dolines and kamenitzas eroded into dolomites, pedogenic calcrete, calcareous duricrust and calc-sinter. In addition, many of the aeolianites in the Sperrgebiet are lightly to heavily cemented by calcite, as are trough cross-bedded grits in Grillental, Glastal and elsewhere. The most widespread Cainozoic carbonate in the Sperrgebiet is undoubtedly the Namib "Calcrete", which is a surface deposit but not of pedogenic origin. It is therefore not strictly speaking a calcrete, but a calc-crust, which developed on a huge variety of surfaces, including sloping ground where pedogenic calcretes would not normally develop.

While developing, the Namib calc-crust incorporated other rock types into it, including aeolian sand and in certain places vast numbers of *Trigonephrus* shells (Fig. 12) and occasional ostrich egg shell fragments. The land snail *Trigonephrus* burrows into loose surface deposits to escape diurnal predators and the dessication associated with the Namib Desert. They burrow as deep as possible, often coming up against a hard clast or layer which stops them. Here some of them die, so that over the years some rich accumulations of shells can accumulate, the fossil assemblage being an attritional one. The Namib calc-crust is often overlain by loose sand with a plant cover that is ideal for *Trigonephrus*. The upper surface of the calc-crust can contain vast concentrations of shells, some of which may become incorporated into the crust.

The Namib calc-crust is often nodular, quite thin in places, but up to a metre thick in favourable zones. It is pink to purple and brown in colour, indicating deposition in an oxidising environment. Occasionally there are green patches of calc-crust. Unlike pedogenic calcretes, the Namib calc-crust is not underlain by the lower soil horizons that typify true pedogenic calcretes. Neither is the Namib calc-crust a groundwater calcrete of the type that occurs widely in the fringe of the Otavi Mountains in Northern Namibia. Instead, it is possible that the formation of the Namib calc-crust is due to the frequent fogs that characterise the Namib Desert. The fog precipitates onto surface features throughout the desert, dampening loose deposits to a depth of a few cm. This moisture dissolves calcite dust in the superficial layers of the

Figure 12. Kalkrücken aeolianite indurated by a cement of Namib calc-crust incorporating abundant shells of the land snail *Trigonephrus*. This snail lives almost exclusively in winter rainfall zones or in the zone that experiences both winter and summer rainfall, but in the latter case the individuals tend to be small.

desert, and then precipitates it again as the layers dry out. Repeated many times the calc-crust eventually becomes thicker, harder and denser over time. Because fog precipitation occurs on all exposed surfaces, the Namib calc-crust forms on many surfaces, including quite steeply sloping ground. This is another feature which differentiates the calc-crust from pedogenic calcretes, which form in geomorphologically stable flat-lying ground, and not on unstable sloping ground.

Calc-sinter, in contrast, results from the deposition of calcite brought in by underground water which resurges at the surface as lime-charged springs, cementing rock surfaces and clasts in the vicinity and producing onyx-like deposits.

Palaeoenvironment and palaeoecology of the Northern Sperrgebiet

On the basis of 25 taxa (Table 1), Stromer (1926) considered that the Early Miocene vertebrates from the Sperrgebiet indicated the former presence of a steppe in the region. The sample at his disposal was dominated by hypsodont forms such as lagomorphs, rodents with high crowned cheek teeth and macroscelidids (which he thought were hypsodont hyracoids), but there were brachyodont ruminants and bunodont suids as well.

The more comprehensive samples now available reveal a greater representation of browsers in the Sperrgebiet fauna, tilting the balance towards a more closed type of palaeoenvironment with substantial stands of trees. Among the browsers are proboscideans, rhinocerotids, a large and a small hyracoid, and possibly some ruminants although the latter were probably already engaged in grazing behaviour (Table 3). The abundance of hives of the harvester termite, *Hodotermes*, in the Grillental deposits indicates the presence of grass, and a summer rainfall regime in which mean annual rainfall would have been between 200 and 750 mm. The palaeosol at Langental and the pedogenic calcretes at Strauchpfütz accord with this view, the closest match being with soil profiles close to Outjo and Grootfontein in northern Namibia.

By the late Miocene, however, the climate in the Northern Sperrgebiet had changed to a winter rainfall regime and had become more arid and more windy, as shown by the presence of aeolianite horizons and the abundance of *Trigonephrus*. This was the period during which the Gemsboktal Hamadas were formed indicating the occurrence of infrequent but violent rain storms similar to those that still occur today in the zone between summer and winter rainfall zones. The Namib calc-crust, which started accumulating during this period, suggests the occurrence of fogs which drifted far inland from the coast, frequently dampening the superficial layers of the Namib and promoting their cementation by dissolution and precipitation of ambient calcium carbonate. This process is still active in the Namib.

Closer to the coast, sea spray and aerosols derived from the sea, drift inland and precipitate as weakly saline solutions containing tiny amounts of hydrogen sulphide. Repeated many times, this process results in the accumulation of salt in the superficial deposits of the Namib, forming the so-called Salt Namib. As a result the sediments at Elisabethfeld, Grillental and Langental are salty to the tongue. The hydrogen sulphide reacts with calcium in the sediments which results in the formation of gysum. In the Sperrgebiet the gypsum thus formed is generally fibrous and often occurs as a thin, discontinuous layer in the soft superficial horizons of weathered sediment.

The Palaeogene faunas of Namibia

During the 2008 field season of the Namibia Palaeontology Expedition, four richly fossiliferous continental Palaeogene localities were discovered. Mapping and collecting at these localities leads us to reconsider the age of two previously known localities at Chalcedon Tafelberg and Gamachab.

Chalcedon Tafelberg was mapped as a Palaeogene deposit by Beetz (1926) but it was shifted to the Middle Miocene by Liddle (1971) and Stocken (1978) as a result of a radio-isotopic age determination of ca 15 Ma on a monchiquite lava that underlies the chalcedonic limestones. This estimate has been widely accepted by subsequent workers. We replace the Chalcedon Tafelberg sequence back into the Palaeogene because it is evidently extremely similar to deposits at Silica, North, Silica South and Black Crow.

Gamachab is a large exposure of calc-sinter of Late Pleistocene age, but at its northeast corner, slightly detached from the main outcrop is a small occurrence of silicified limestone. This site yielded a specimen of *Dorcasia* (Wenz, 1926). Our examination of this outcrop indicates that it is similar in overall facies to Black Crow, and we conclude that it too is a Palaeogene locality.

Most of the chalcedonic limestones in the Sperrgebiet are rich in plant remains, including algae and horse-tails. They also contain abundant freshwater snails, terrestrial gastropods, and a variety of vertebrates (Table 4) described in a companion paper in this volume (Pickford *et al*., 2008).

Conclusions

The Early Miocene fluvio-paludal deposits of the Northern Sperrgebiet have now yielded a total of 93 species of invertebrates and vertebrates, up from 25 species in the 1920's. The older carbonate deposits that accumulated in depressions in Gariep Dolomite yielded the first vertebrate fossils in 2008, which are still being extracted from the limestone. The fauna from these layers comprises abundant gastropods

Table 3. Ecological implications of fauna from the Northern Sperrgebiet, Namibia.

Taxon	**Common name**	**Ecological implications**
Namajenga mwichwa Pickford, 2008	Harvester termite	Grass
Lymnaea aff. *natalensis* Krauss, 1848	Freshwater snail	Stagnant pools
Lymnaea aff. *truncatula* (Müller, 1774)	Freshwater snail	Stagnant pools
Bulinus Müller, 1781	Freshwater snail	Stagnant pools
Urocyclidae indet.	Land snail	Humid
Trigonephrus Pilsbry, 1905	Land snail	Winter rainfall
Dorcasia Gray, 1838	Land snail	Winter rainfall
'Xenopus' stromeri Ahl, 1926	Clawed toad	Fresh water
? Pipinae indet.	Clawed toad	Fresh water
Ranoid indet. A	Frog	Fresh water
Ranoid indet. B	Frog	Fresh water
Varanidae indet.	Monitor lizard	Widespread
Geckonidae indet.	Gecko	Widespread
Amphisbaenia Gray, 1844	Amphisbaenian	Burrower
Lacertilian indet.	Lizard	Widespread
Scolecophidea indet.	Snake	Burrower
? *Python* sp. A	Python	Widespread
? *Python* sp. B	Python	Widespread
Natricinae indet.	Night adder	Widespread
Viperidae indet.	Adder	Widespread
Pelomedusa senutpickfordina de Broin, 2008	Freshwater turtle	Fresh water
Namibchersus namaquensis (Stromer, 1926)	Tortoise	Widespread
aff. *Mesochersus* Lapparent de Broin, 2003	Tortoise	Widespread
Crocodylus cf *gariepensis* Pickford, 2003	Crocodile	Sub-tropical to tropical
Struthio coppensi Mourer-Chauviré, Senut, Pickford and Mein, 1996	Ostrich	Open country
cf *Oligocorax littoralis* (Milne-Edwards, 1871)	Cormorant	Water
Accipitridae indet.	Bird of prey	Widespread
Charadriform indet.	Plover	Water
Megapaloelodus A.H. Miller, 1944	Flamingo	Water
Mionetta Livezey and Martin, 1988	Duck	Water
Anserinae indet.	Duck	Water
Phasianidae indet.	Game bird	Widespread
? *Palaeortyx* Milne-Edwards, 1869	Game bird	Widespread
Coliidae indet.	Mouse bird	Sub-tropical to tropical
Myohyrax oswaldi Andrews, 1914	Macroscelidid	Grazer
Myohyrax pickfordi Senut, 2008	Macroscelidid	Grazer
Protypotheroides beetzi Stromer, 1929	Macroscelidid	Grazer
Brachyrhynchocyon jacobi Senut, 2008	Macroscelidid	Omnivore
Hypsorhynchocyon burrelli Senut, 2008	Macroscelidid	Incipiently hypsodont
Gymnurechinus leakeyi Butler, 1956	Hedgehog	Widespread
Amphechinus rusingensis Butler, 1956	Hedgehog	Widespread
Protenrec butleri Mein and Pickford, 2003	Tenrec	Forest
Prochrysochloris cf *miocenicus* Butler and Hopwood, 1957	Mole	Burrower
? *Erythrozootes* Butler and Hopwood, 1957	Mole	Burrower
Austrolagomys inexpectatus Stromer, 1924	Pika	Grazer
Vulcanisciurus africanus Lavocat, 1973	Squirrel	Widespread
Protarsomys macinnesi Lavocat, 1973	Small rodent	Granivore
Parapedetes namaquensis Stromer, 1926	Spring hare	Open country grazer
Megapedetes cf *gariepensis* Mein and Senut, 2003	Spring hare	Open country grazer
Propedetes efeldensis Mein and Pickford, 2008	Spring hare	Open country grazer
Diamantomys luederitzi Stromer, 1922	Medium rodent	Grazer
Pomonomys dubius Stromer, 1922	Medium rodent	Grazer
Phiomyoides humilis Stromer, 1926	Small rodent	Granivore
Apodecter stromeri Hopwood, 1929	Small rodent	Granivore
Neosciuromys africanus Stromer, 1922	Medium rodent	Grazer
Neosciuromys fractus (Hopwood, 1929)	Medium rodent	Grazer

Table 3. (Continued)

Taxon	Common name	Ecological implications
Bathyergoides neotertiarius Stromer, 1923	Medium rodent	Burrower
Efeldomys loliae Mein & Pickford, 2008	Small rodent	Burrower
Geofossor moralesi Mein & Pickford, 2008	Small rodent	Burrower
Microfossor biradiculatus Mein & Pickford, 2008	Tiny rodent	Burrower
Metapterodon kaiseri Stromer, 1924	Small creodont	Carnivore
Metapterodon stromeri Morales, Pickford & Soria, 1998	Small creodont	Carnivore
Hyainailouros Biedermann, 1863 or *Megistotherium* Savage, 1973	Huge creodont	Carnivore
Isohyaenodon Savage, 1965	Small creodont	Carnivore
Teratodontidae Savage, 1965	Small creodont	Carnivore
Namasector soriae Morales, Pickford & Salesa, 2008	Tiny creodont	Carnivore
Ysengrinia Ginsburg, 1965	Medium amphicyonid	Carnivore
Leptoplesictis senutae Morales, Pickford & Salesa, 2008	Mongoose	Carnivore
Leptoplesictis namibiensis Morales, Pickford & Salesa, 2008	Mongoose	Carnivore
Viverridae indet. I	Mongoose	Carnivore
Viverridae indet. II	Mongoose	Carnivore
Afrosmilus africanus (Andrews, 1914)	Felid	Carnivore
Eozygodon morotoensis (Pickford & Tassy, 1980)	Proboscidean	Folivore
Gomphotheriidae indet.	Proboscidean	Bunodont
Afrohyrax namibensis Pickford, 2008	Hyrax	Folivore
Prohyrax tertiarius Stromer, 1923	Hyrax	Folivore
Orycteropus africanus (MacInnes, 1956) or *O. chemeldoi* Pickford, 1975	Aardvark	Burrower/termitivore
Brachypotherium heinzelini Hooijer, 1963	Rhino	Hippo-like body plan
Chilotheridium pattersoni Hooijer, 1971	Rhino	Tender herb grazer
Aceratherium acutirostratum (Deraniyagala, 1951)	Rhino	Browser
Brachyodus depereti Fourtau, 1918	Anthracothere	Tender herb grazer
Brachyodus aequatorialis MacInnes, 1951	Anthracothere	Tender herb grazer
Nguruwe namibensis (Pickford, 1986)	Suid	Omnivore
Diamantohyus africanus Stromer, 1922	Sanithere	Omnivore
Dorcatherium cf *moruorotensis* Pickford, 2002	Tragulid	Omnivore/ruminant
Dorcatherium songhorensis Whitworth, 1958	Tragulid	Omnivore/ruminant
Dorcatherium cf *parvum* Whitworth, 1958	Tragulid	Omnivore/ruminant
Propalaeoryx africanus (Whitworth, 1958)	Pecoran	Tender herb grazer
Propalaeoryx stromeri Morales, Soria & Pickford, 2008	Pecoran	Tender herb grazer
Sperrgebietomeryx wardi Morales, Soria & Pickford, 1999	Bovoid	Tender herb grazer
Namibiomeryx senuti Morales, Soria & Pickford, 1995	Bovoid	Tender herb grazer
Namibiomeryx spaggiarii Morales, Soria & Pickford, 2008	Bovoid	Tender herb grazer

(4 or 5 freshwater species, 4 or 5 land snail taxa), fish, pipid and ranoid frogs, crocodiles, birds and five or more mammals. When these are studied, it should be possible to tie down the age of these deposits which have hitherto been correlated either to the Eocene or older on the basis of stratigraphy and clast assemblages or to the Middle Miocene on the basis of radio-isotopic dates. Preliminary age assessments on the basis of rodents, a hyracoid and an arsinoithere are that the deposits are Lutetian, ca 47 Ma.

The faunal remains from the Early Miocene deposits indicate that the Northern Sperrgebiet was probably clothed in wooded savannah at the time of deposition (Fig. 13). The region was likely part of the summer rainfall belt, but a winter rainfall zone was not far away. The region later became subjected to violent rain storms in an arid environment, at least during the Middle and Late Miocene, as shown by the extensive hamadas that blanket hundreds of square kms in the region (Fig. 13). By the Late Miocene the region was in a winter rainfall belt as revealed by the quantities of large *Trigonephrus* shells preserved in the Namib calc-crust, a deposit that indicates that by that time the region was subjected to frequent fogs. By the Late Miocene the Northern Sperrgebiet had become arid to hyperarid with deposition of aeolianite.

The Palaeogene deposits of the Northern Sperrgebiet have only recently been recognised and sampled. They have already yielded abundant floral remains, and a rich and diverse invertebrate and vertebrate fauna. Preliminary assessments of the age of the deposits on the basis of biochronology, using North African faunas as a yardstick, indicate that the

Table 4. Fauna from Palaeogene sites in the Sperrgebiet, Namibia, based on preliminary studies by Pickford *et al*., 2008, and Rage pers. comm.). (CT – Chalcedon Tafelberg, SN – Silica North, SS – Silica South, BC – Black Crow, SK – Steffenkop, GM – Gamachab)

Taxon	CT	SN	SS	BC	SK	GM	Ecological indications
Ostracoda	-	x	x	-	-	-	Freshwater
Tomichia sp.	x	x	x	x	x	-	Freshwater snail
Lymnaeidae	x	x	x	x	-	-	Freshwater snail
Planorbidae	-	-	x	-	-	-	Freshwater snail
Dorcasia sp.	-	x	x	x	-	x	Land snail, summer rainfall
Trigonephrus sp.	-	x	x	x	-	-	Land snail, winter rainfall
Xerocerastus sp.	-	x	-	-	-	-	Land snail, summer rainfall
Succinea sp.	-	x	x	-	-	-	Land snail (humid areas)
Pupillidae?	-	-	-	x	-	-	Land snail
Pisces	-	x	x	-	-	-	Fresh water fish
Amphibian (Pipidae)	-	x	-	-	-	-	Clawed toad, tropics to sub-tropics
Amphibian (Ranoidea)	-	x	x	-	-	-	Frog
Amphibian (Anuran indet.)	-	x	x	-	-	-	Frog
Squamate (lizard)	-	x	-	-	-	-	Lizard
Squamate (amphisbaenian)	-	x	-	-	-	-	Burrowing lizard
Squamate (snake)	-	x	-	-	-	-	Snake
Crocodilia	-	x	x	x	-	-	Crocodile, subtropics to tropics
Aves	-	-	x	-	-	-	Bird
Todralestidae (*Namalestes*)	-	-	-	x	-	-	Small carnivore
Erinaceidae	-	-	-	x	-	-	Insectivore (hedgehog)
Macroscelididae	-	x	-	-	-	-	Insectivore (elephant shrew)
Proviverrinae	-	-	-	x	-	-	Insectivore or tiny carnivore
Hyaenodontidae (*Pterodon*)	-	-	-	x	-	-	Medium-sized carnivore
Pholidota	-	-	-	x	-	-	Pangolin (prey - termites, ants)
Hyracoidea (*Namahyrax*)	-	x	x	x	-	-	Medium sized bunodont hyrax
Arsinoitheriidae (*Namatherium*)	-	-	-	x	-	-	Large lophodont mammal
Primates (*Namaia*)	-	x	-	x	-	-	Small bundont primate, arboreal
Zegdoumyidae (*Glibia*)	-	-	-	x	-	-	Bundont rodent, may be arboreal
Myophiomyidae (*Silicamys*)	-	x	-	-	-	-	Bunodont rodent, granivore
Phiomyidae (*Apodecter*)	-	x	-	-	-	-	Brachyodont rodent
Phiomyidae (*Protophiomys*)	-	x	x	-	-	-	Brachyodont rodent
Diamantomyidae (*Propomonomys*)	-	x	-	-	-	-	Hypsodont rodent
Bathyergidae (cf *Bathyergoides*)	-	x	-	-	-	-	Hypsodont, burrowing rodent

deposits are likely to be Early to Middle Eocene (broadly Lutetian, considerably earlier than the Rupelian deposits of the Fayum, Egypt) but because the dating of the North African faunas is still a matter of debate, and considering the vast distance between the Sperrgebiet and the Maghreb, the preliminary age determination of the Namibian sites may require tuning in the future as studies progress.

Despite the fact that the Sperrgebiet Palaeogene deposits are 7000 km south of their North African correlates, they share several mammal lineages with the septentrional faunas, suggesting the presence of relatively unhindered access between the latitudinal extremities of the continent at that time. Nevertheless, there are signs of endemism in the Sperrgebiet faunas, including the presence of three genera of land snails that are today confined to Southern Africa (*Dorcasia*, *Trigonephrus*, *Xerocerastus*) and early members of rodent (Bathyergidae) and macroscelidean lineages that occur abundantly in the Early Miocene deposits of the same region but which have not so far been reported from North Africa.

The presence of Primates, arsinoitheres, hyracoids and a diversity of rodents, carnivorans and insectivores in the Sperrgebiet Palaeogene deposits suggests that during the Lutetian the region enjoyed a tropical to sub-tropical climate with a fair amount of rainfall, but the occurrence of the land snail *Trigonephrus* indicates the possibility of a winter rainfall belt not far from the localities. A tropical to sub-tropical climate is supported by the presence of pipids at the sites (Rage pers. comm).

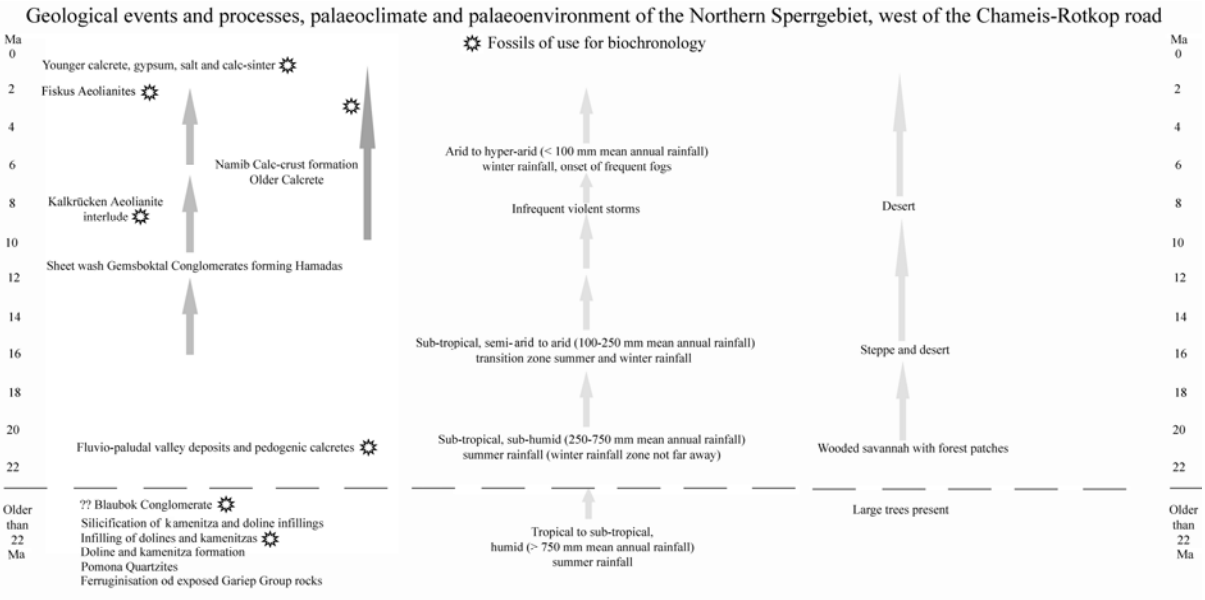

Figure 13. Summary of geological events and processes, palaeoclimate and palaeoenvironment in the Northern Sperrgebiet west of the Chameis-Rotkop road, Namibia. The timing of events is based largely on biochronology. Chronology of the period prior to 22 Ma will be clarified once the faunas from the kamenitza infillings have been studied.

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