

B. REPORTS ON UNIVERSITY RESEARCH PROJECTS

**A PRELIMINARY APPRAISAL OF THE TECTONIC AND
SEDIMENTOLOGICAL ENVIRONMENT OF THE SINCLAIR
SEQUENCE IN THE KLEIN AUB AREA**

by

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ABSTRACT

The Klein Aub area in SWA/Namibia exposes Late Proterozoic metasediments and metavolcanics of the Sinclair Sequence, which rest on a Lower to Middle Proterozoic basement. The basement is block faulted and, in the vicinity of Klein Aub, forms a major basement high which supplied sediment into a fault bounded basin. Major faults tapped felsic and minor mafic magma to produce the volcanics of the Nückopf Formation. Continued block faulting resulted in the development of narrow, deep graben sub-basins in which the sediments and volcanics of the Grauwater Formation were

deposited. Major basement uplift accompanied deposition of the Doornpoort Formation, a widespread unit of red-bed alluvial fan conglomerates grading basinwards into sheet flood, braided stream and aeolian sediments. Cessation of faulting was followed by the deposition of the Kagas Member of the Klein Aub Formation in a shallow lacustrine environment.

1. INTRODUCTION

The Klein Aub copper mine is situated about 70 km SW of Rehoboth (Fig. 1). A sequence of Late Precambrian rocks is exposed be-

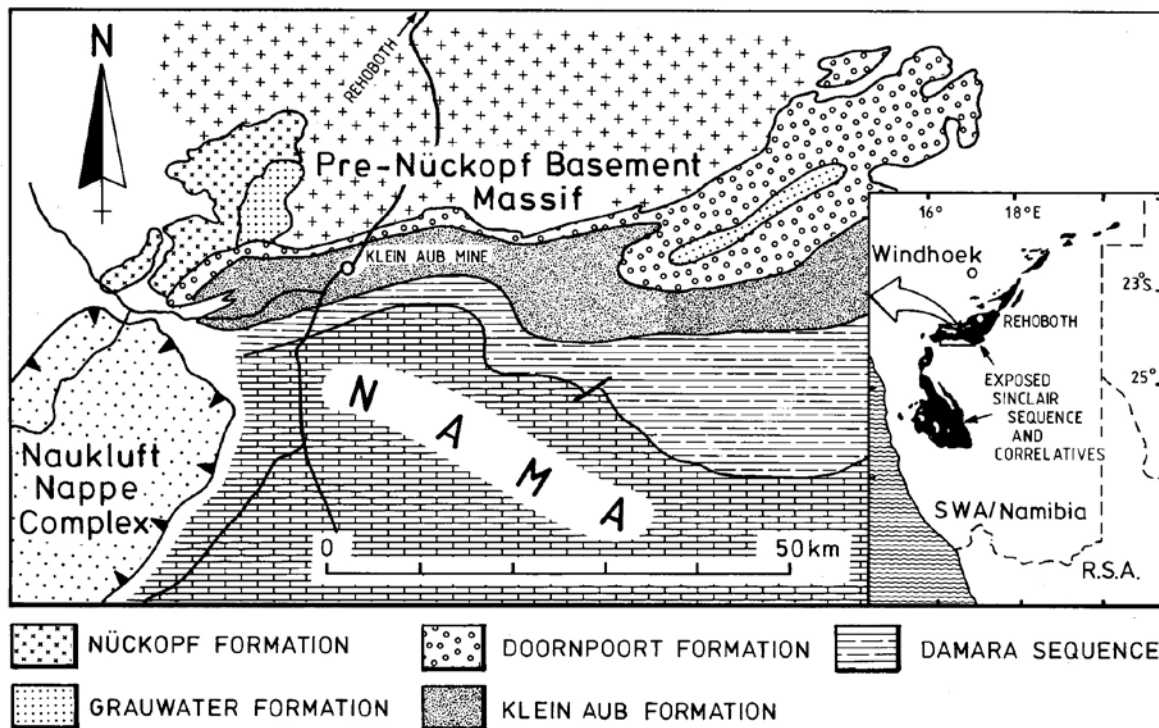


Fig. 1: Geological sketch map of the Klein Aub area and surroundings.

tween an older basement massif to the north and the younger cover of Nama sediments to the south. The western boundary of exposure is given by the younger Naukluft Nappe Complex and a number of basement faults. To the east the rocks are covered by Kalahari sand which has an increasing thickness towards Botswana (Fig. 1).

Initial mapping of the area was carried out by De Kock (1934) and later by Handley (1965). The Late Proterozoic rocks were mapped in detail and correlated with a similar sequence in the Dordabis and Witvlei areas by Schalk (1960, 1967, 1970, 1973). Ruxton (1981) described the sedimentology of the Doornpoort and Klein Aub Formations and presented a synsedimentary and early diagenetic model for the Klein Aub copper deposit. The geology is represented on the 1:100 000 scale geological map (Schalk, 1960, 1967, 1973) and on the Geological Map of South West Africa, scale 1:1 000 000, by the Geological Survey (1980). Ahrendt *et al.* (1978) investigated the degree of metamorphism and

made age determinations. Maiden *et al.* (1984) compared the Klein Aub deposit with other Proterozoic copper deposits in southern Africa and South Australia.

As part of a study on regional controls on the localisation of copper mineralisation, 22 detailed sections were measured across the Late Precambrian sequence over a strike length of some 70 km. These allow a detailed appraisal of basement/cover relationships and sedimentological features of the area.

2. GEOLOGICAL SETTING

The oldest rocks in the Klein Aub area are various mid-Proterozoic granites and several formations comprising metaquartzite, phyllite, conglomerate, amygdaloidal basic lava and some acid metavolcanics (Fig. 2). South of Rehoboth, the oldest granite, the Swartmodder Granite, has an isochron age of $1\ 668 \pm 26$ my (SACS, 1980). These mid-Proterozoic rocks form a basement to the units of interest to this study.

	Formation	Lithology	Maximum thickness (m)	Age (Ma)	
NAMA SEQUENCE GROUP	KUIBIS	Grey-black limestone with intercalated green shale	180-360		
		Basal sandstone and quartzite with thin conglomerate	0-100		
DAMARA SEQUENCE GROUP	BLAUBEKER	Conglomerate			
	KAMTSAS	Quartzite, conglomerate, arkose			
SINCLAIR SEQUENCE	KLEIN AUB	Dikdoorn ^x Member	Fine-grained purplish quartzite, rare gritty layers		3700
		Kagas ^x Member	Shale, shaly quartzite, calcareous shale, lenses of limestone		
		Eindpaal ^x Member	Conglomerate interfingering with quartzite		
		Leeuberg ^x Member	Reddish and brownish quartzite and basal conglomerate		
	DOORNPOORT	Red quartzite and minor red shale; amygdaloidal basic lavas, acid tuff and pyroclastics, coarse conglomerate in lower part of succession	>3500		1 132
	Gamsberg Granite Suite	Various granites, granophyre, aplitic granite, pegmatite			1010-1090
	GRAUWATER	Purplish-grey and brown quartzite, minor basic lava and rhyolitic tuff; locally coarse basal conglomerate	>2000		
NÜCKOPF	Mainly acid volcanic rocks (rhyolite, ignimbrite, tuff, pyroclastics, quartzfeldspar porphyry), subordinate basic lava and pyroclastics; quartzite and conglomerate	>2000	1080-1232		
	Pre-Nüeckopf basement	White and grey metaquartzite, phyllite, sericite, quartzite, conglomerate, basic lava, minor acid volcanic rocks; various granites	2000?	1668±26	

Fig. 2: Stratigraphy of the Klein Aub area (after SACS, 1980); x after Schalk (1970).

Unconformably overlying the above basement are rocks which are stratigraphically equivalent to the Sinclair Sequence of the Helmeringhausen area (SACS, 1980). The Nückopf Formation (Fig. 2), forming a mountainous region to the NW of Klein Aub (Fig. 1), consists mainly of acid volcanic rocks (rhyolite, ignimbrite, ashflow tuff, pyroclastics and quartz-feldspar porphyry) with subordinate basic lava and pyroclastics and minor quartzite and conglomerate (SACS, 1980). From radiometric age measurements of Nückopf lavas it appears that these were deposited between 1080 and 1232 my (Burger and Coertze, 1973, 1975, 1978; Burger and Walraven, 1978).

A succession of more than 2 000 m of purplish grey and brown quartzite, the Grauwater Formation, overlies the Nückopf Formation (Fig. 2). Additionally it includes basic lava and rhyolitic tuff. Locally a coarse basal conglomerate is developed. The Nückopf and Grauwater Formations have a limited distribution on the flanks of the pre-Nückopf basement high.

More or less simultaneous with the accumulation of the Nückopf Formation the Gamsberg Granite Suite was emplaced (Fig. 2). The youngest members of this suite even intruded the Grauwater Formation. The Gamsberg Granite Suite shows an assemblage of various granite, granophyre, aplitic granite and pegmatite, with a Rb-Sr age of $1\ 092 \pm 40$ m.y. (SACS, 1980). The Nückopf and Grauwater Formations are unconformably overlain by the Doornpoort Formation (SACS, 1980). This unit is composed of conglomerate, sandstone, minor red shale and basic volcanics (Fig. 2).

On top of this Formation the Klein Aub Formation is developed which Schalk (1970) divided into four units: the Leeuberg, Eindpaal, Kagas and Dikdoorn Members (Fig. 2). The Leeuberg, and Eindpaal Members consist of red conglomerate, sandstone and quartzite. The components of the Kagas Member are grey and greenish, fine-grained sandstone, shale, calcareous shale and subordinate limestone. The Dikdoorn Member comprises purplish quartzite with a few gritty layers.

Schalk (1970) separated these four units from the underlying Doornpoort Formation by an unconformity. Detailed mapping as part of the present study gave no indication of such an unconformity. We are therefore in agreement with Ruxton (1981) that there is a conformable sequence from the Doornpoort Formation up into the lower part of the Klein Aub Formation in the area of consideration. However, based on field observations, facies distribution and the different sedimentary environments a disconformity seems to separate the Kagas Member from underlying units (Fig. 3). In this we disagree with Ruxton (1981) who interpreted interfingering relationships between the Kagas and Eindpaal Members. We would therefore like to see a revision of the stratigraphy so that the Leeuberg and Eindpaal Members are incorporated into the Doornpoort Formation, while the Klein Aub Formation is restricted to the Kagas and Dikdoorn Members.

So far no age determinations for the Klein Aub Formation are available, but according to the SACS (1980) the deposition of both Doornpoort and Klein Aub Formation would have taken place between 1 000 and 900 my ago. These two formations form a belt that stretches E-W. The beds show usually a moderate to steep dip to the south. To the east of the Klein Aub mine they are slightly folded in a synform and antiform pair, the Rooidraai Syncline and the Witkop Anticline (Fig. 4), both plunging at a shallow angle in a south-westerly direction.

Metamorphism and deformation affected the sequence during Damaran time. Investigations on samples (drill core) from the Klein Aub Formation show that the temperature during metamorphism did not exceed 350°C (Ahrendt *et al.*, 1978). The rocks have undergone metamorphism of lower greenschist facies and show a slaty cleavage with a dip of some 70° to the NW. In some regions of the Klein Aub area the rocks contain a second cleavage. An age of 530 ± 10 my was determined for the peak of metamorphism and deformation (Ahrendt *et al.*, 1978).

Resting on the beds of the Klein Aub Formation are clastic sediments of the Kamtsas and Blaubeker Formations which represent the lowermost part of the Damara Sequence (Schalk, 1970) (Fig. 2).

To the south of Klein Aub, the Sinclair and Damara rocks are covered by the Kuibis Subgroup, the basal part of the Nama Group. A flat lying basal unit of quartzite is followed by grey to black limestone which forms a prominent ridge south of Klein Aub (Fig. 1).

3. BASIN DEVELOPMENT

Based on measured sections and additional interpretation from aerial photographs, the map of Fig. 3 shows the basement contact and the facies distribution around Klein Aub.

The northern margin-of the sedimentary basin of the Doornpoort and Klein Aub Formations had a WSW to ENE trend. Because of the present exposure of the beds only a limited impression can be gained of the basinal development perpendicular to the palaeobasin margin. The direction of the section presented in Fig. 4 is oblique to this margin. Unfortunately no information is available on the basement that underlies the Nama beds south of Klein Aub. The extensive block faulting and the bimodal character of the volcanism in this region indicate a terrain of early intracratonic rifting. Fig. 5 demonstrates in four sketches the tectonic, volcanic and sedimentological development of the basin from Nückopf to Klein Aub times.

3.1 Stage 1: Nückopf Formation

During stage 1, strong block faulting of the pre-Nückopf basement massif produced a major positive basement feature in the vicinity of Klein Aub. Pre-

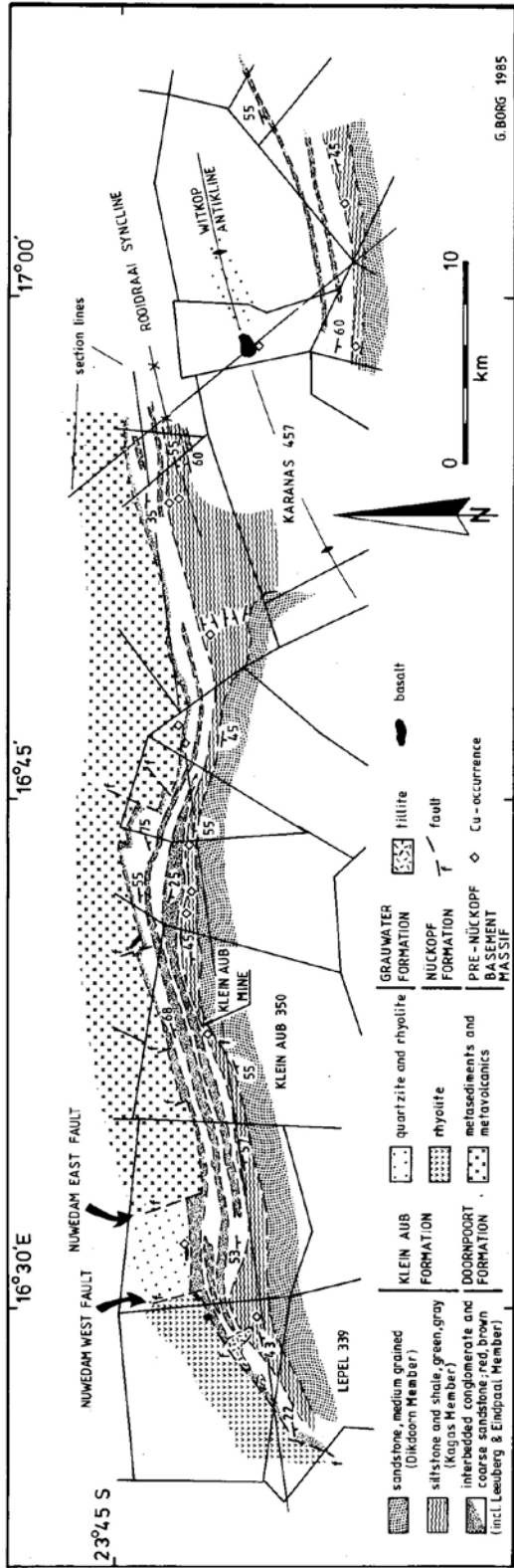


Fig. 3: Geological map, showing the facies distribution within the Klein Aub and Doornpoort Formations and the contact to the underlying units.

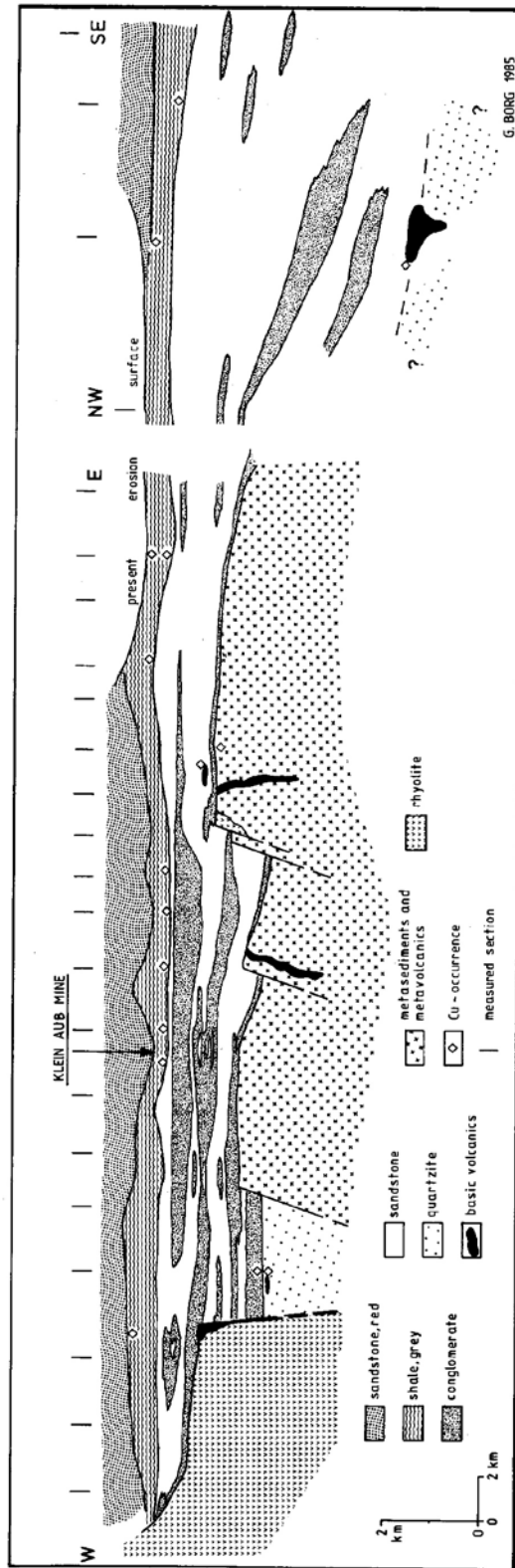


Fig. 4: Section (W-E), showing the vertical and lateral facies distribution, the basement contact and copper occurrences in the Klein Aub area.

liminary mapping indicates a throw of up to 2 000 m on the Nuwedam East fault which forms the western edge of the basement high. High level granitoids of the Gamsberg Suite invaded the pre-Nüekopf basement and rhyolite, ignimbrite and tuff of the Nüekopf Formation extruded and filled deep graben structures on the flanks of the basement high. Some faults tapped mantle magma sources to produce basic lavas interbedded with the acid volcanics. Minor quartzite and conglomerate are the result of erosion from the basement high.

3.2 Stage 2: Grauwater Formation

Strong block faulting and uplift of the pre-Nüekopf basement massif continued during this stage. In the vicinity of Klein Aub there was 2 000 m of movement on the Nuwedam West fault to produce a tectonic high of exposed Nüekopf Formation forming the western side of a deep, narrow graben. The Grauwater Formation, restricted to such graben sub-basins, derived its sediments partly by erosion from the pre-Nüekopf basement massif and partly by erosion from the newly uplifted Nüekopf Formation. Minor acid and basic volcanism accompanied deposition of coarse clastic sediment.

3.3 Stage 3: Doornpoort Formation (including Leeuberg and Eindpaal Members)

The Doornpoort Formation, with its large lateral extent of coarse clastic sediment, represents a stage of decreased block faulting but extensive uplift and erosion of basement and older Sinclair units. Conglomerate fans, originating from these uplifted rocks, interfinger with sandstone basinwards. The thick (3 599 m) sequence ultimately covered the pre-Nüekopf basement high. Continuing minor movement along the block faults is indicated by significant thickening and thinning of conglomerate members (Fig. 4). Minor basic volcanics extruded along faults during early Doornpoort time.

3.4 Stage 4: Klein Aub Formation (Kagas and Dikdoorn Members only)

There is no evidence for continuing block faulting activity during this stage; volcanic activity had also ceased. Fine- to medium-grained clastic sediments deposited in laterally extensive beds covered the older Sinclair rocks and the basement high.

4. SEDIMENTOLOGY AND DEPOSITIONAL ENVIRONMENT

Two major types of depositional environment can be distinguished within the Doornpoort and Klein Aub Formations. An alluvial fan sequence is followed unconformably by fine clastic sediments, deposited in a lacustrine environment. As discussed above the boundary between these two environmental types does not

coincide with the stratigraphic boundary between the Doornpoort and the Klein Aub Formations as mapped by Schalk (1970), but with the boundary between the Eindpaal and Kagas Members of the Klein Aub Formation. In the present study the Doornpoort Formation is described as one environmental unit with the Leeuberg and Eindpaal Members of the Klein Aub Formation. These three units of coarse-grained, red clastic sediments contrast with the fine- to medium-grained, dark coloured sediments of the overlying Kagas Member.

4.1 Doornpoort Formation (including Leeuberg and Eindpaal Members)

In general, the Doornpoort Formation represents a fining upward mega-sequence of red conglomerate, sandstone and minor siltstone. A great portion of this formation consists of brownish red conglomerate with clasts of granite and metamorphic and volcanic rocks from the uplifted underlying units. It is polymict, poorly sorted and in some units poorly rounded. It is generally clast supported, with an average pebble diameter between 10 and 15 cm; maximum diameters of single boulders can exceed 50 cm. It represents a facies of alluvial fans which extend south from the pre-Nüekopf

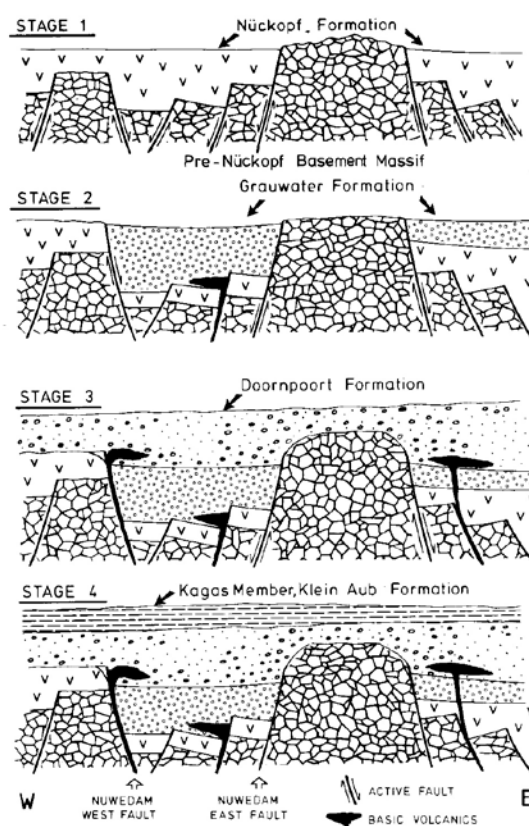


Fig. 5: The tectonic, volcanic and sedimentological development of the basin from Nüekopf to Klein Aub times.

basement high and to the east and west into deeper parts of the basin.

Surrounding and interfingering reddish to purple sandstones show a range of preserved sedimentary structures. Planar laminated grits and coarse- and fine-grained sandstones are common, representing sheet flood deposits which surround the alluvial fans. At the base of these beds flute marks are preserved. Temporary aqueous, oxidising conditions are testified by purple sandstone with oscillation ripples. Mud cracks occur in locally developed siltstone and red mudstone layers together with complex ripple systems, suggesting alternating periods of shallow agitated water followed by emergence. Aeolian sandstones, well sorted, forming more than 10 m wide tabular cross sets, occur as intercalations between the facies types mentioned above.

The range of sediment types is completed by the channel fills in braided streams with grain sizes from basal conglomerate to fine-grained sandstone at the top.

Ruxton interpreted the sediment types of the Doornpoort Formation, with the exception of a thin basal conglomerate, as derived from "lateral moving channels and bars" (Ruxton, 1981, p. 35). By contrast our data indicate a more complex depositional environment for the Doornpoort to Eindpaal time which can be summarised as follows: in a fault bounded, probably intracratonic basin, clastic sediments and subordinate basic volcanics were deposited. Alluvial fans, derived from faulted basin margin rocks, were surrounded by sheet flood deposits and braided stream sediments.

Temporary, shallow lakes formed between and in front of the fans. Constant wind in an arid or semi-arid climate created aeolian dunes. Fig. 7A is a composite of the sediments and structures, showing the palaeoenvironment.

Of particular importance is the relationship between sedimentation and continued basement uplift. The strong connection between block faulting, basin configuration, volcanism and sedimentary facies types can be seen at the boundary between the Grauwater and Doornpoort Formation as shown in Fig. 6.

The succession begins with the sedimentation of medium- to coarse-grained, purplish red sandstone deposited in a relatively quiet environment of braided streams (Fig. 6, phase 1).

- Block faulting affected the region causing uplift of the source area and the extrusion of basic volcanic rocks along extensional structures in various parts of the basin (Fig. 6, phase 2).
- While proximal alluvial fans formed in front of horst shoulders of the block faulted basement, sandstone deposition continued distant from the source area (Fig. 6, phase 3).
- In phase 4 the alluvial fans extended far enough into the basin to cover the braided stream and sheet flood deposits with conglomerate. These again were fining upward, representing the beginning of a new, similar cycle.

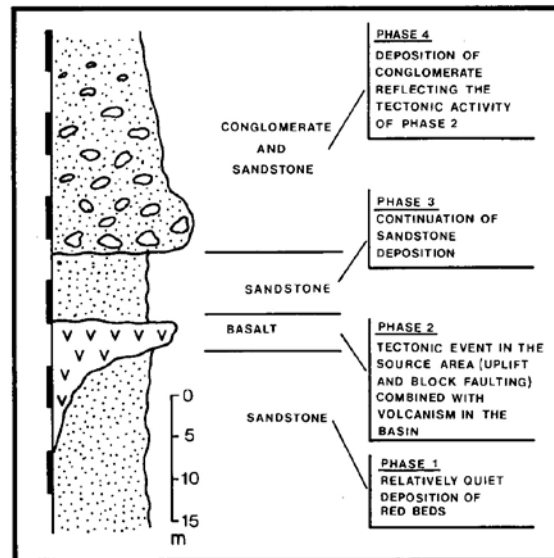


Fig. 6: Relationship between tecto-volcanogenic activity and lithostratigraphy.

Similar facies associations are found in great number in different parts of the world. One example, including alluvial fans, braided stream deposits and intercalated aeolian dunes, is described from the Upper Triassic/Lower Jurassic of Nova Scotia (Hubert and Mertz, 1984). Another example of a comparable environment is reported from the Upper Proterozoic Copper Harbour Conglomerate, Michigan, which underlies the famous copper deposits in the Nonesuch Shale at White Pine (Elmore, 1984).

4.2 The Kagas Member of the Klein Aub Formation

Three parameters characterise the change from the Doornpoort to the Klein Aub (Kagas Member) sediments: the difference in grain size, the change in colour of the rocks and the presence of carbonate. In contrast to the Doornpoort Formation (and the Leeuberg and Eindpaal Members) the Kagas Member is dark grey to greenish in colour, although recent weathering causes a brownish (oxidised) coating. The Kagas Member contains clastic metasediments with a grain size that ranges from mud to medium-grained sand and in addition contains finely laminated detrital limestone. Metamorphism is of low grade and deformation is generally not of sufficient intensity to obscure the great number of sedimentary structures.

Two main facies types can be recognised:

- a) cross-bedded sandstone-siltstone
- b) laminated siltstone-mudstone with minor limestone.

Cross-bedded, green to grey, fine-grained sandstone and siltstone are found in beds up to 70 cm thick. They show wave ripple cross lamination with irregular lower bounding surfaces, which is typical for either current or

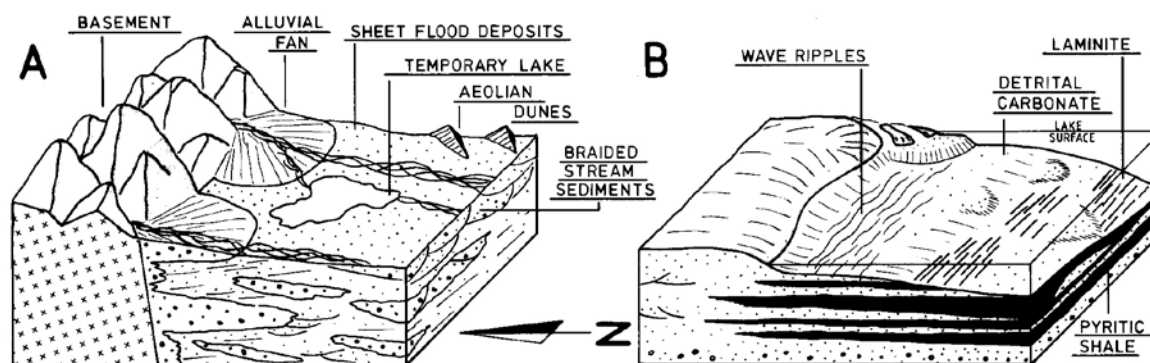


Fig. 7: Palaeoenvironmental models for the Doornpoort Formation (7A) and the Kagas Member of the Klein Aub Formation (7B).

wave processes in shallow water (Reading, 1979). Oscillation ripples occur throughout this facies type. The sandstone-siltstone facies interfingers with laminated rocks of interbedded siltstone and mudstone which are hosts to copper mineralisation at Klein Aub. Horizons can be traced over distances of several kilometres. Individual laminae vary from less than 1 mm to 5 mm in thickness and are not graded. A portion of the laminites consists of interbedded siltstone and detrital limestone (“calcsiltite”).

Syneresis cracks, showing indications of upward filling, are present in the laminite beds. They can originate from the dewatering of coarser layers following rapid sealing by mud. On the other hand, the building up of osmotic pressure, caused by a marked salinity increase of the water overlying the sediment, creates the same features (Reineck and Singh, 1980).

Pyrite is abundant in both the laminated siltstone-mudstone facies and in the cross-bedded sandstone-siltstone facies. It is found finely disseminated and as cubes with a size of up to 10 mm. Pressure shadows indicate a pre-deformation origin for the pyrite. It is inferred to be an early diagenetic feature, formed by shallow burial of sediment into an anaerobic environment.

The presence of wave ripple cross lamination and oscillation ripples in the sandstone-siltstone facies imply a near shore depositional environment, whereas a more distal, deeper environment for the laminite facies is indicated by increased sediment thickness and a decreased proportion of oscillation ripples.

The orientation of ripple marks and flute casts indicates that the sediments are derived from a source area to the north. Time equivalent facies types with a more proximal character, which might be expected closer to the source area, are not present, perhaps having been removed by erosion.

Although a shallow marine environment is not totally excluded by the sedimentary features observed, they are consistent with a lacustrine environment (Donovan, 1975; Reading, 1979). We therefore concur with Ruxton (1981) in proposing a shallow lacustrine deposition for

the Kagas Member. The proposed depositional model for the Kagas Member is shown in Fig. 7B.

4.3 Relationship between the Doornpoort and Kagas Facies

Whether the alluvial fan facies of the Doornpoort Formation develops into a lacustrine or playa/sabkha facies to the south, or whether it is followed by a repetition of the alluvial fans and another basement high is speculative. The same is valid for the northern facies successions of the Kagas Member, which are eroded. No interfingering of the alluvial fan sequence with the lacustrine facies can be observed. No indication is given that the lacustrine facies transgresses over the alluvial fans or is even derived from these as suggested by Ruxton (1981). Therefore the contact between the two facies associates can be regarded as transitional.

5. CONCLUSIONS

The Doornpoort and Klein Aub Formations are underlain by heavily block faulted basement and older cover rocks. These older cover rocks are preserved in down faulted blocks east and west of a major basement high which formed a horst block controlling the distribution of the Sinclair metavolcanics and metasediments.

The rocks of the Doornpoort Formation and the Leeu-berg and Eindpaal Members of the Klein Aub Formation were deposited in a fault bounded basin. They constitute a fining upward red-bed sequence of alluvial fan, sheet flood, braided stream and aeolian sediments which formed in an arid to semi-arid climate. The sediment was derived from uplifted basement and older Sinclair units to the north.

The sediments of the Kagas Member of the Klein Aub Formation are fine-grained sandstones which formed in a lacustrine basin that deepened to the S or SE. The sediments were deposited under reducing conditions or underwent a stage of anaerobic, early diagenesis. No facies transgression of the lacustrine facies over the al-

luvial fans can be observed. Whereas the influence of the block faulting of the basement on the Doornpoort beds was very strong it decreased during Klein Aub times.

6. ACKNOWLEDGEMENTS

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