

STRATIGRAPHY OF THE KLEIN AUB AREA

SEQUENCE	GROUP	FORMATION	LITHOLOGY	MAXIMUM THICKNESS (m)	AGE (Ma)	POSSIBLE CORRELATIVES (locality)
	Nama	Kutais	Grey-black limestone with intercalated green shale. Basal sandstone and quartzite with thin conglomerate.	180-150 0-100	510- 719 (1)	
		LIZDREKER	Conglomerate (tuffite)	300	850-	
DANABA	Beuab	KAMTAS	Quartzite, conglomerate and arkose.	6200?	750 (2)	Doruchau Fm. (Dordabla)
		KLEIN AUB	Dikdoorn Beds* Fine-grained purplish quartzite, rare gritty layers. Kapas Beds* Shale, shaly quartzite, calcareous shale, lenses of limestone.	1500 600		Ghanzi Fm. (Botswana)
		DOORPOORT	(Including the Eendberg and Eindpaal Beds* of the Klein Aub Formation of Schalk (1970)) Laminoid red conglomerate, red and brown quartzite, arkose and minor red shale. Locally tholeiitic basalt in lower part of sequence.			Eker'son Fm. (Mitsvlei) Auburn Fm. (Sindlari)
SINCLAIR		GRAUWATER	Rhyolitic tuff, purplish-grey and brown quartzite with conglomeratic lenses.	1000	990- 1069 (1)	
		BUCKOOP	Felsic lavas and pyroclastics (rhyolite, syenite, tuff, quartz porphyry, quartz-feldspar porphyry) with minor quartzite and conglomerate.	1500 2000		K'Gobe Porphyry (Botswana) Gortloogende Porphyry (E-hakibla)
			CAMBRIC GRANITE SUITE			
DEERBOTH			Various igneous and metamorphic complexes		>1668 (4)	

* proposed by Schalk (1970)

Table 1: Stratigraphy and brief lithological description of the formations in the Klein Aub area. After Schalk (1970) and SACS (1980). The division between the Doorpoort and Klein Aub Formations follows a revised stratigraphy, suggested by Ruxton (1981). Age data from (1) Ahrendt et al. (1978), (2) Hawkesworthy et al. (1981), (3) SACS (1980) and Maling and Reid (in press).

3.2 Stratigraphy and Radiometric Ages

The Kalahari Copperbelt consists of volcano-sedimentary units of the 1300 to 950 Ma old Sinclair Sequence, for which the type-locality is in the area of Sinclair Helmeringhausen (Fig 2.1; SACS, 1980). The stratigraphy in the different areas along the Kalahari Copperbelt can be broadly subdivided into three units.

Generally the sequences consist of a lower, felsic volcanic unit, a mafic volcanic and red bed unit and a marine, or locally lacustrine unit at the top. In order to define the local stratigraphies and formation names, each area is briefly described below.

The Klein Aub Area

The area contains a volcano-sedimentary succession with a total thickness of approximately 11 km. The four formations of the Sinclair Sequence which are distinguished in the Klein Aub area can be divided into three stages. The two lower units, the Nuckopf and Grauwater Formations represent an felsic volcanic stage (Fig 3.1, 3.2, Table 1). They are preserved in graben structures and consist of more than 4000 m of mainly rhyolitic felsic porphyries and felsic pyroclastics and minor coarse elastic sediments which become more common in the upper part of this unit, the Grauwater Formation.

The Doornpoort Formation unconformably overlies the Grauwater Formation and is made up of a sequence of a mafic volcanics and red beds (Fig 2.2, Table 1). However, the lower part of this formation contains intercalations of amygdaloidal basaltic lava up to several hundred metres thick.

The uppermost unit, the Klein Aub Formation, contains dark grey, pyritic, finely laminated sandstone and siltstone, quartzite, subordinate limestone and arkose. In this study the Leeuberg and Eindpaal Beds of Schaik (1970) are regarded as part of the Doornpoort Formation (Table 1, following a subdivision based on lithological similarities and facies interpretation, first proposed by Ruxton (1981).

The Klein Aub Formation is unconformably overlain by clastic sediments of the Kamtsas and Blaauw Formation that represent the basal part of the Late Proterozoic Damara Sequence (Table 1). These formations unconformably overlain by rocks of the Cambrian Nama Group (SACS, 1980; Table 1).

The Gamsberg Granite Suite, which locally intrudes both the Nuckopf and the Grauwater Formations, has been dated by various authors and a variety of ages have been published such as 1059 ± 30 Ma, 1069 ± 30 Ma, 1069 ± 70 Ma, 1110 ± 90 Ma (all U-Pb; Hugo and Schaik, 1974), 1078 ± 30 Ma (U-Pb; Burger and Coertze, 1973-74) and 1092 ± 40 Ma, 1079 Ma (Rb-Sr; Mallin and Reid, in press). Zircon from volcanics of the Grauwater Formation gave ages of 990 ± 300 Ma and 1069 ± 70 Ma (both U-Pb; Hugo and Schaik, 1974).

The Dordabis and Witvlei Areas

The correlatives of the Sinclair Sequence occur in narrow thrust slices and are exposed between Dordabis and Witvlei (Fig 2.1). The stratigraphic units of the Dordabis area (Fig 3.2, Table 1) comprise the Dordabis Formation, which is overlain by the Nuckopf and Doornpoort Formations (Williams-Jones, 1984). The formations consist of tholeiitic basalt, flow top breccias, interflow sediments, quartz-feldspar porphyry, conglomerate, quartzite and minor siltstone. In the Witvlei area the Nuckopf and the overlying Eskadron Formations (Schaik, 1970; Fey, 1976) contain red quartz-feldspar porphyry, basaltic lavas, conglomerate, arkose, quartzite and minor pyritic siltstone. Zircon from a rhyolitic porphyry from the Nuckopf Formation have been dated by Van Niekerk and Burger (1980c) yielding a U-Pb age of 1110 ± 40 Ma.

The Oorlogsende Area

Close to the SWA/Namibia - Botswana border, a thin tectonic sliver of Middle Proterozoic rocks is exposed, and contains the Oorlogsende Porphyry (Fig. 2.1). The rock types exposed include quartz porphyry, rhyolitic, tuffaceous ignimbrite and flow banded rhyolite (Hegenberger and Burger, 1985). The same authors obtained a radiometric age of 1094 ± 19 Ma by dating zircons from the Oorlogsende Porphyry.

The Ghanzi and Lake N'Gami Areas

The correlatives of the Sinclair Sequence are only sporadically exposed in a 30 - 40 km wide belt in northwestern Botswana (Fig. 2.1) and are mostly covered by Holocene Kalahari sand and calcrete. Thomas (1973) distinguished two major stratigraphic units in the Lake N'Gami area, the Kgwebe and Ghanzi Formations (Fig. 2.2). The Kgwebe Formation consists of more than 3000 m of quartz-feldspar porphyry and rhyolite in the lower part and basalt towards the top of the unit, which is known as the Toteng Diabase. The Ghanzi Formation contains red conglomerate, grit and arkosic sandstone in the basal part of the unit (Fig. 2.2). These coarse clastic sediments are overlain by fine-grained dark grey, pyritic sandstone and siltstone, which grade into marl and limestone higher in the stratigraphic succession.

Rb-Sr data from the Kgwebe Porphyry gave ages of 906 ± 36 Ma (Harding and Snelling, 1972), 820 ± 20 Ma and 821 ± 43 Ma (Key and Rundle, 1981). Ages of 649 ± 18 Ma and 566 ± 25 Ma from the Toteng Diabase are interpreted as metamorphic ages (Key and Rundle, 1981).

The Shinamba Hills and Goha Hills Areas

The Shinamba and Goha Hills are situated in northern Botswana (Fig. 2.1) and geological information about the area is derived from scarce outcrops (core hole cores).

The oldest unit, the Kgwebe Formation, consists of rhyolitic lavas with lenses of silicified sandstone and siltstone. This is overlain by a thick clastic unit, containing basaltic conglomerate and sandstone in the basal part and limestone with minor intercalations of siltstone at the top, the Ghanzi Formation. A quartz porphyry from the Goha Hills yielded Rb-Sr ages of 968 ± 16 Ma and 981 ± 43 Ma (Key and Rundle, 1981).

3.3 Deformation and Metamorphism

Several periods of tectonism affected the region, but the principal deformational and metamorphic event was the Damara Orogeny. The rocks have been faulted, folded and thrust to varying degrees, depending on their position within the Kalahari Copperbelt. At Klein Aub, deformation has developed both large open folds and a slaty cleavage, that dips steeply to the north. In the Dordabis and Witvlei area the remnants of the Kalahari Copperbelt are preserved as tectonic blocks or in open folds bounded by narrow thrust slices. In contrast to the Klein Aub area, this area underwent more intensive faulting and folding. This deformation produced northeast trending fold axes and a strong cleavage.

The Kalahari Copperbelt of the Ghanzi and Lake N'Gami areas forms a prominent northeast trending structural ridge, which was named the Ghanzi-Chobe Foldbelt by Meixner (1983). The southeastern flank of the ridge is steeply inclined and forms the basement of the Passarge Basin (Reeves, 1979; Meixner, 1983). Here the Damara Orogeny produced large open folds with fold axes trending northeast and a weak slaty cleavage. Major block faulting affected the sequence during Karoo times producing deep graben structures (Thomas, 1973). The areas of the Shinamba Hills have been deformed into open folds, truncated by later subvertical faults.

The various segments of the Kalahari Copperbelt underwent lower greenschist facies metamorphism but even delicate sedimentary structures are still preserved. Because of the low grade of metamorphism sedimentological terminology is directly applied. Muscovite from the Klein Aub area has been dated to determine the peak of metamorphism and deformation in this

region. The investigation gave an age of 520 ± 10 Ma, which is the main deformational event of the Damaran Orogeny and the temperature of this regional metamorphism was determined as below 350°C by illite crystallinity studies (Ahrendt et al., 1978).

4. VOLCANIC ROCKS OF THE SINCLAIR SEQUENCE

The lower part of the Sinclair Sequence contains an abundance of volcanic rocks of both felsic and mafic chemical composition. These volcanics occur either as several hundred to thousands of metres thick units at the base of the stratigraphic succession or as cyclic intercalations within the sequence.

4.1 Felsic Volcanic Rocks, Nückopf and Grauwater Formations

The Nückopf Formation rests unconformably on the older basement (Fig. 3.1 and Table 1) and consists of 2000 m of felsic volcanic rocks that are preserved only in graben structures.

These felsic volcanics include a variety of pyroclastic rocks (Plate 4.1) such as rhyolitic volcanic breccia, pyroclastic block tuff with angular ignimbrite clasts, tuffaceous ash flow deposits, flow banded quartz and quartz-feldspar porphyries, ignimbrite, and welded tuff. Conglomerate and quartz arenite occur at the base and as rare intercalations within this volcanic pile.

The Grauwater Formation, lies conformably above the Nückopf Formation (Table 1). This 1500 m thick heterolithic unit also consists primarily of felsic volcanic rocks, but coarse clastic sediments are more commonly intercalated. The chemical and mineralogical composition of the felsic volcanics and the type of conglomerate and quartz arenite of the Nückopf and Grauwater Formations are very similar.

The Gamsberg Granite Suite intruded the region northwest of Klein Aub more or less simultaneously with the accumulation of the Nückopf Formation, while its youngest members intruded the Grauwater Formation (Schalk, 1970). These intrusions consist essentially of granite, granophyre, aplitic granite and pegmatite, and ages are closely spaced between 1110 Ma and 1059 Ma (Hugo and Schalk, 1974; Burger and Coertze, 1973-74; Malling and Reid, in press).

The Oorlogsende Porphyry, situated in a remote region close to the Botswana border (Fig. 2.1), is considered to be a stratigraphic equivalent of the Nückopf Formation (Hegenberger and Burger, 1985). The tuffaceous ignimbrites and quartz porphyries of this unit occur in a thin thrust slice, which stretches for approximately 100 km and strikes in a northeasterly direction (Fig. 2.1). Quartz- and quartz-feldspar porphyries of the Kgwebe Formation in the Lake N'Gami area are also regarded as equivalents of the Nückopf Formation (Thomas, 1973; Hegenberger and Burger, 1985).

4.2 Mafic Volcanic Rocks, Doornpoort Formation

Significant amounts of basalt occur interbedded with the coarse clastic sediments of the Sinclair Sequence in all segments of the Kalahari Copperbelt (Fig. 2.2) and have been briefly described by Schalk (1970), Toens (1975) and Thomas (1973) from Klein Aub, Dordabis, Witvlei and Lake N'Gami. Ruxton (1981) gave four geochemical analyses of basalt from the Dordabis area, and showed the results in Zr/Ti and $Zr/Ti/Y$ plots. Because he estimated the volume of basalt as less than 1% of the total stratigraphy Ruxton (1981) discarded the scattered distribution of the four data points as 'meaningless' due to the lack of outcrop, the number of samples, and their highly weathered nature. The same basalts from the Dordabis area have been comprehensively studied, geochemically analysed and described by Williams-Jones (1984).

Finally the basalts within the Sinclair Sequence have been ignored by some authors who stated that no volcanic rocks were associated with the clastic succession (Ruxton, 1986, p. 1725; Ruxton and Clemmey, 1986, p. 1739).

In detail, the basalts are intercalated with red beds of the Doornpoort Formation and its equivalents (Fig. 2.2). The stratigraphic volume of the basalts, known from both surface exposure and several boreholes is more than the 1% estimated by Ruxton (1981) and varies from

Plate 4.1: Characteristic lithotypes of the Nuckopf and Grauwater Formations from Farm Kabiras 343 in the Etosha Aub. area. All farm names and farm numbers refer to the Geological Map of SWA/Namibia, scale 1:1 000 000 (Geological Survey, 1980).

(A) Volcanic breccia, composed of sub-rounded quartz porphyry clasts in a quartz porphyry matrix, possibly a vent breccia; hammer for scale (length 31 cm).

(B) Coarse, near-vent fallout deposits consisting of abundant angular pumice lapilli with finer-grained tuffaceous matrix; coin for scale (diameter 38 mm).

(C) Distal pyroclastic fallout deposit with larger pumice fragments in finer-grained tuffaceous matrix displaying crude horizontal layering; coin for scale (diameter 38 mm).

(D) Flow banded, rhyolitic quartz-feldspar porphyry; coin for scale (diameter 38 mm).

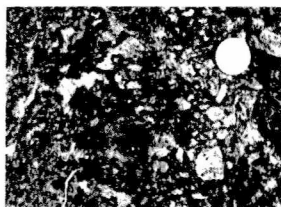
(E) Photomicrograph of welded ignimbrite showing abundant welded pumice shards some of which are incompletely collapsed, plane polarized light.

(F) Photomicrograph of quartz-feldspar porphyry, composed of coarse-grained quartz and feldspar phenocrysts in a fine-grained matrix; crossed Nicols.

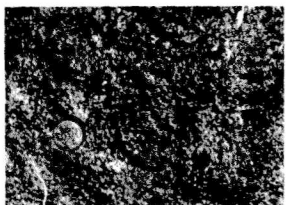
Plate 4.1



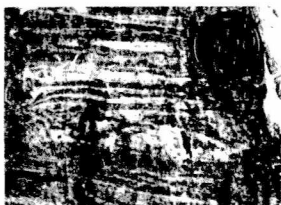
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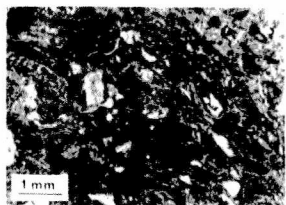
B



C



D



E



F

less than 10% (Klein Aub area) to more than 50% (Dordabis area). In a regional scale gravity data show distinct positive gravity anomalies which follow a line of extension in the areas of exposed Sinclair Sequence (Fig.4.1; Kleywegt, 1967). The gravity differences that define this trend are probably due to dense mafic volcanic rocks, in the volcanic sedimentary troughs of the Sinclair Sequence, flanked by less dense granitic or metasedimentary units. This might also imply the existence at depth of even more mafic rocks than are exposed in surface outcrops and borehole core.

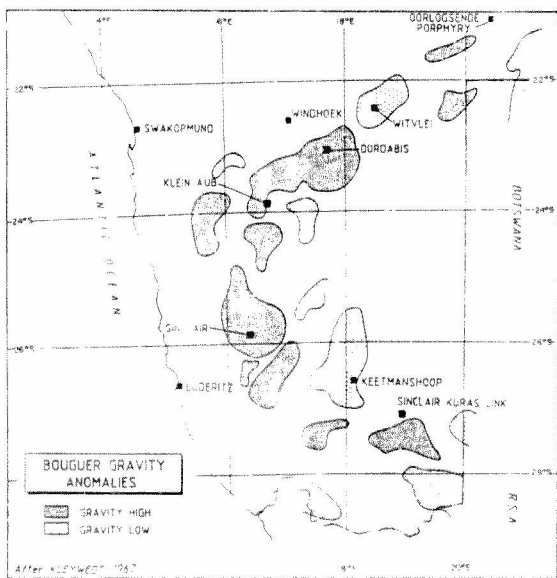


Fig. 4.1. Bouguer gravity map of central and southern SWA/Namibia, displaying areas of positive (gravity highs) and negative (gravity lows) gravity anomalies; after Kleywegt (1967). Note the arrangement of the gravity highs along an arcuate trend, which is probably caused by mafic volcanics of the Sinclair Sequence, flanked by gravity lows, probably the effect of metasedimentary or granitic rocks.

At Witvlei the sediments of the Eskadrön Formation are underlain by subaerially extruded, amygdaloidal basalt of uncertain thickness, forming a local basement high (Loens, 1975). In the Lake N'Gamara a tholeiitic basalt occurs in the Kgwebé Formation and the Toteng Diabase (Thompson, 1973). In bore hole core, the basalts of the Toteng Diabase have a thickness of at least several hundred metres, but a basal contact of the unit has not been intersected.

A suite of 52 surface samples of basalt were selected for petrographical and geochemical studies from the Klein Aub area (Farm Du Plessis Rus 537, 35 km east of Klein Aub), the Dordabis area (Farm Ihenstein 55, 1 km south of Dordabis and Farm Dordabis 98), the Witvlei area (Farms Doornpoort 248 and Okatjepuiko 147, 80 km south-southwest and 30 km north of Witvlei) and the Lake N'Gatai area (Ngwenekau Hills and Toteng, 85 km and 50 km south-west of Maun). The basalts selected from the Klein Aub area occur close to the base of the Doornpoort Formation (Fig 2.2), and due to the limited size of the outcrops on Farm Du Plessis Rus (16°58'30"E, 23°48'50"S) it is possible that the specimens collected may not be from a single lava flow. In the Dordabis area, the stratigraphic position of the basalts within the Sinclair Sequence is still the subject of debate (Williams-Jones, 1984). The selected samples of basalt, and the borehole core are from parts of the Skumok Formation (Williams-Jones, 1984). This representative diamond drill hole ODB 4 from the Dordabis area was logged to clarify the relationships of the interbedding of basalts to interflow sediments (Fig 4.2, Appendix I). The borehole was drilled by FEDSWA Exploration Ltd. in 1973 and is situated on the southern part of Farm Overwacht 270. It was not possible to determine the exact location of the borehole since this information has been subsequently lost.

The units intersected by the 340 m bore hole that was drilled normal to bedding consists of more than 95% basalt. Only rare intercalations of quartz arenite were found and make up the remainder of the core. Based on megascopic characteristics these basalts can be divided into different categories and they are:

- massive, dark grey or dark maroon basalt, which accounts for some 75% of the basalt in borehole ODB 4;
- infrequently scattered flow-banded anhydaloidal basalt which commonly overlies massive domains (Plate 4.2,A);
- brecciated dark red and light green (epidotised) basalt commonly overlying the previous types of basalt (Plate 4.2,B);
- dark reddish-grey sheared and tectonically and hydraulic fractured basalt with epidote- or quartz-filled fractures.

Close examination reveals an intricate relationship between certain basalt categories. Locally the breccias contain a matrix of quartz arenite towards the top. The breccia clasts are generally angular to subangular and show no signs of rounding or transport. In some cases the matrix of quartz arenite fills fractures, penetrating further down into the more massive domains of the flows. The fracture systems are commonly interconnected with the other permeable domains described above. The rocks are sheared in several fault zones intersected by the borehole.

4.3 Volcanic Style and Classification of the Volcanic Rocks

The abundance of coarse pyroclastics, rapid lateral facies changes, and the chemical characteristics of the volcanics suggest that the Nuckopf and Grauwater Formations represent a period of explosive, siliceous volcanism. The location of discrete volcanic centres are indicated by coarse vent breccias, laterally grading into proximal pyroclastic talus breccias and distal ash fall deposits suggestive of caldera-type volcanism. The basalts represent subaerially extruded lava flows, that have massive interiors and often brecciated flow tops. The character of the flows indicate either rapid burial by a new lava flow or subsequent clastic influx that swamped the area of sediment without reworking of the flow tops.

The felsic and mafic volcanic rocks from each area have been sampled and chemically analysed by XRF and data may be found in Appendix III. According to their CIPW norms the felsic volcanics are per-alkaline, calc-alkaline and per-aluminous rhyolites and locally trachytes with a high K_2O/Na_2O (Fig 4.3, Appendix III).

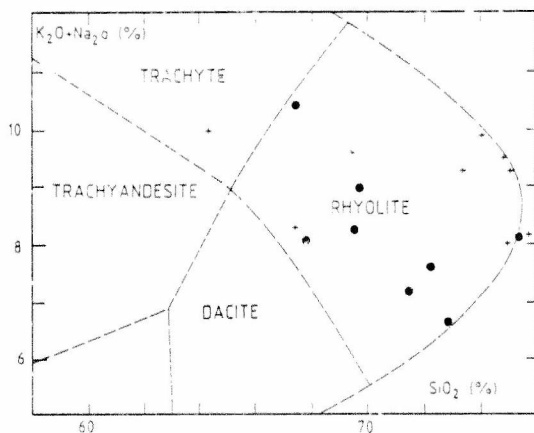


Fig. 4.3. Classification of felsic volcanic rocks, Nückopf and Grauwasser Formations and equivalents, in an alkali-silica variation diagram (after Cox et al., 1979). See Fig. 4.5. for explanation of symbols.

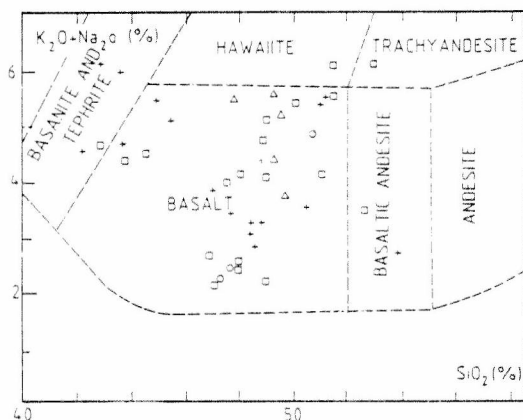


Fig. 4.4 Classification of mafic volcanic rocks, Doornpoort Formation and equivalents, in an alkali-silica variation diagram (after Cox et al., 1979). See Fig. 4.5. for explanation of symbols.

According to the classification proposed by Cox et al. (1979), the mafic volcanics are mainly basalts, with subordinate amounts of basaltic andesite, basanite, trachyandesite and hawaiite (Fig. 4.4). The distinctly bimodal volcanics show a tholeiitic trend which is defined in the ΔFM -diagram of Figure 4.5. Correlation diagrams of Nb/Zr and Nb/Y show that most of the basalts of the Sinclair Sequence follow a narrow differentiation trend (Fig. 4.6, 4.7).

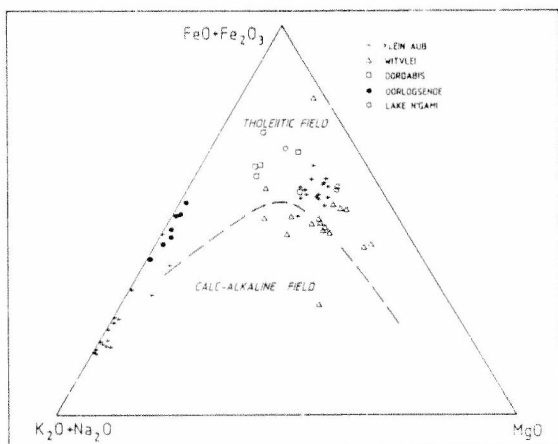


Fig. 4.5. AFM diagram illustrating the tholeiitic trend of the bimodal Sinclair Volcanics between the areas of Klein Aub and Lake N'Gami.

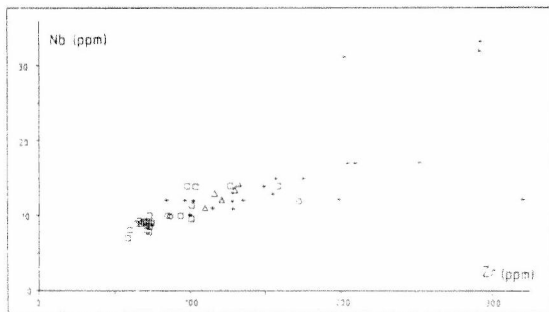


Fig. 4.6. Nb-Zr variation diagram of basalts from the Dorsnpoort Formation in the Klein Aub area and equivalents from Dordabis, Witvlei, and Lake N'Gami. See Fig. 4.5 for explanation of symbols.

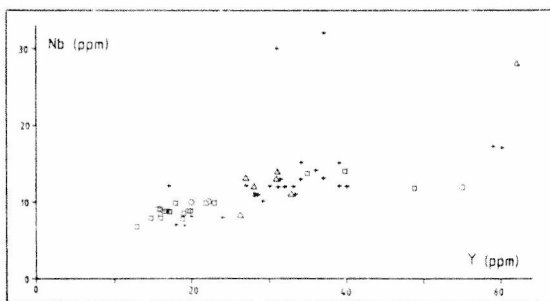


Fig.4.7: Nb/Y variation diagram of basalts from the Doornpoort Formation (Klein Aub area) and equivalents from Dordabis, Witvlei, and Lake N'Gami. See Fig.4.5 for explanation of symbols.

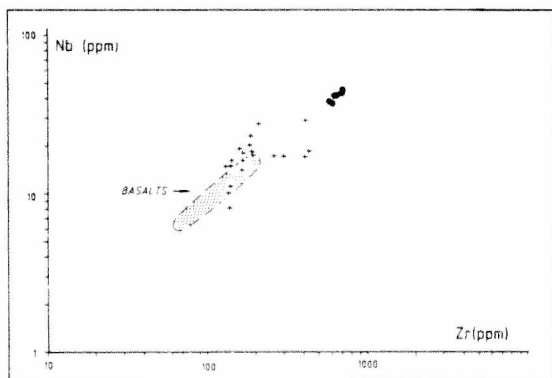


Fig.4.8: Nb/Zr variation diagram of both felsic (crosses and dots) and mafic volcanics (shaded area) from the Sinclar Sequence and equivalents. See Fig.4.5 for explanation of symbols.

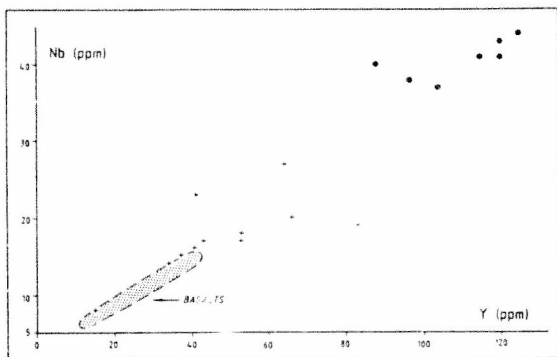


Fig. 4.9: Nb/Y variation diagram of both felsic (crosses and dots) and mafic volcanics (shaded area) from the Sinclair Sequence and equivalents. See Fig. 4.5 for explanation of symbols.

Plotted together with the felsic volcanics in Nb/Zr and Nb/Y diagrams two distinct groups of volcanics can be distinguished (Fig. 4.8, 4.9). One group, consisting of: most basalts from each area, some felsic volcanics from the Klein Aub, and all felsic volcanics from the Oorlogsende area plot on the same linear trend. A second group of felsic volcanics plots dispersed away from this differentiation trend (Figs. 4.6, 4.7, 4.8, 4.9).

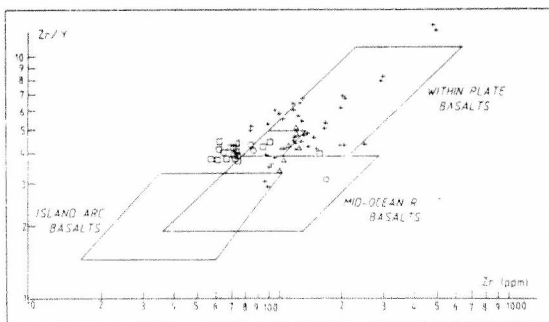


Fig. 4.10: Zr/Y versus Zr variation diagram with fields suggested for modern plate tectonic settings (Pearce and Norry, 1979). See Fig. 4.5 for explanation of symbols.

The basalts were plotted in a Zr/Y versus Zr diagram (Fig. 4.10; after Pearce and Norry, 1979). The data cluster mainly in the field of within plate tholeiites, but many recent studies indicate that empirical discrimination diagrams fail to unambiguously confirm the tectonic setting (e.g. Holm, 1982; Schweitzer and Kröner, 1985). However, concluded with field evidence, these basalt data suggest a subaerial extrusion of the tholeiitic basalts in narrow, fault bounded basins. Based on these relationships it is possible to characterise the tectonic setting of the basalts of the Sinclair Sequence.

From the geochemical signature of the volcanics it is concluded that the region was underlain by thick continental crust during the time of extrusion. The style and chemical signature of the volcanism is comparable to that described from the Afar Depression, Ethiopia (Barberi et al., 1974), the Rio Grande Rift, USA (Chapin, 1979; Elston, 1984), and the Kenya Rift (Barberi et al., 1982). Such an interpretation would be in agreement with Kröner (1977), Mason (1981) and Cahen et al. (1984) that deposition of the bimodal volcanics of the Sinclair Sequence occurred in an intracratonic rift setting.

An interpretation of magma sources and magma evolution must take into consideration that the felsic volcanics generally occur towards the base of the Sinclair Sequence and are overlain by the mafic volcanics. Essentially two different explanations can be envisaged (Fig. 4.11):

Increased mantle convection underneath thick continental crust lead to the development of a mantle plume and a steady increase in the local heat flow. Partial melting of continental crust occurred at relatively low temperatures (approximately 800°C) and produced initial felsic melts, characterised by high K_2O/Na_2O ratios and high K, Nb, Y, Zr, Rb and low Sr contents (Fig. 4.11.A). According to Chapell and White (1974) and Wyllie (1977) such high K_2O/Na_2O ratios suggest that this early phase of melting affected mainly metasedimentary material in the lower crust. These early felsic melts also appear to have been enriched in PGE and Au, possibly indicating mantle contamination (this feature will be discussed in more detail in Chapter 8). Continuing plume activity (mantle convection) caused the temperatures to increase further (900°C) and initiated melting of upper mantle material. These first melts that are extracted from the mantle at these temperature, will have a similar major element geochemistry to the earlier felsic volcanics, but will have higher Sr and lower Rb, Nb, Y, and Zr contents than the early melts, producing more 'normal' felsic volcanics. At even higher temperatures of the now fully developed plume (1200°C) additional partial melting of mantle material produced the tholeiitic basalts.

The second explanation envisages the rapid formation of a relatively hot mantle plume that developed underneath thick continental crust. Early melting of continental crust of mainly sedimentary origin produced the early felsic volcanics. This melt was contaminated by early products from the hot mantle plume. Further (more extensive?) melting of crustal material, wherein the contamination from the mantle plume is more diluted, produced the more 'normal' felsic volcanics (Fig. 4.11.B).

During the last phase the hot mantle plume melted the underlying mantle material, producing tholeiitic basaltic magmas.

The author favours the first explanation but the limited data base does not allow a definite decision.

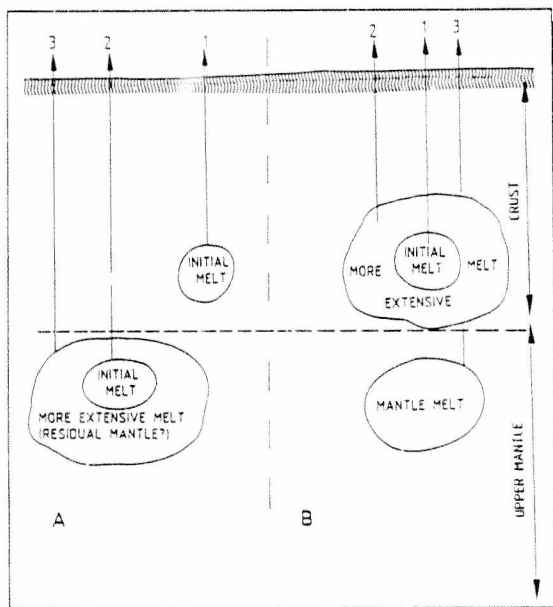


Fig. 4.11: Sketch diagram illustrating two possible explanations of magma generation and magma evolution, both caused by increased mantle convection and plume activity. (1) Basal felsic volcanics of the Nückopf Formation, (2) felsic volcanics of the Nückopf Formation, and (3) mafic volcanics of the Doornpoort Formation.

4.4 Post-Magmatic Basalt Alteration

4.4.1 Petrographic Characteristics

The basalts of the Sinclair Sequence can be subdivided into two separate groups based on their petrographic characteristics. One group consists of massive, dark purplish-grey basalt, generally free of amygdales, occurs as the inner part of lava flows. The basalts are made up of 30% plagioclase (An_{20}) that shows weak to moderate saussuritisation, abundant biotite, chlorite, muscovite, epidote ($< 8\%$), and quartz ($< 3\%$) (Plate 4.2,C). Neither olivine nor pyroxene are preserved; but in some cases chlorite and hematite do form pseudomorphs after these minerals. The mineral assemblage shows the characteristics of lower greenschist facies metamorphism but metamorphism was a static event and the basalts retained their original intergranular texture (Plate 4.2,C). Strong epidotisation associated with good porosity and permeability

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