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The stratigraphy of the Chameis Sub-terrane in the Gariep Belt in southwestern Namibia

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The Chameis Sub-terrane is the uppermost tectono-stratigraphic unit of the allochthonous Marmora Terrane which represents the internal part of the Pan-African Gariep orogenic belt. Based on new field observations and geochemical data, a stratigraphic subdivision of this sub-terrane is proposed, with the term Chameis Group covering all Pan-African stratigraphic units in this sub-terrane. A mainly volcanic Dernburg Formation and a metasedimentary Bogenfels Formation are distinguished in the lower and upper portions, respectively, of the Chameis Group. The former contains a diamictite (Chameis Gate Member) which can be correlated with the Numees Formation in the para-autochthonous Port Nolloth Zone representing the external zone of the belt. Also distinguished within the Dernburg Formation is a dolomitic unit which is derived from stromatolitic reef mounds and from former evaporites that were most likely deposited in an atoll setting (Sholtzberg Member). The Bogenfels Formation is similar to the Holgat Formation in the Port Nolloth Zone, with the calcareous Dreimaster Member at its base correlating with the Bloeddrif Member in the Holgat Formation. The dominantly mafic volcanic Dernburg Formation hosts numerous, largely tectonically dismembered gabbro bodies (Bakers Bay Suite).

Introduction

Two major zones within the Neoproterozoic-Eocambrian Gariep Belt in southwestern Namibia and western South Africa (Fig. 1A) are distinguished based on the recognition of a major structural and lithological discontinuity, the so-called Schakalsberge Thrust. This thrust fault separates the para-authochthonous continental Port Nolloth Zone (PNZ) in the east and southeast from the largely oceanic, allochthonous Marmora Terrane (MT; Hartnady and von Veh, 1990). Structural analysis of the contacts between their mixed volcano-sedimentary Chameis Suite and predominantly siliciclastic Oranjemund Formation (Davies and Coward, 1982) in the south, and the sedimentary Bogenfels Formation (Martin, 1965) in the north led Hartnady and von Veh (1990) to subdivide the Marmora Terrane into three sub-terranes for which the terms Schakalsberge Complex, Oranjemund Complex and Chameis Complex were proposed. Each of these three tectono-stratigraphic units has its own characteristic stratigraphy with the correlation between them remaining uncertain. Discontinuation of the term ‘complex’ for these tectonostratigraphic units is recommended to avoid confusion with the stratigraphic term for a high-grade metamorphic complex, and they will be referred to instead as Schakalsberge, Oranjemund and Chameis Sub-terranes (Fig. 1B).

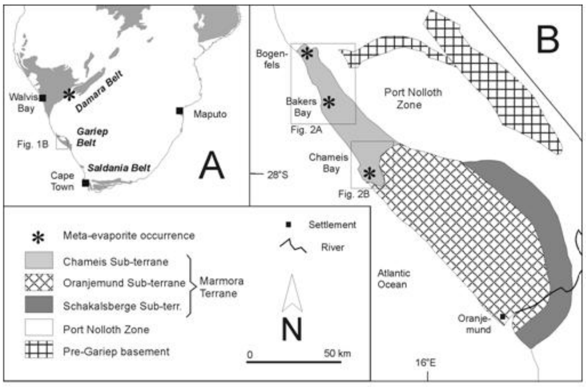

Figure 1: A - Position of the Gariep Belt within the framework of Pan-African Belts in southern Africa; B - Tectono-stratigraphic subdivision of the Gariep Belt; also shown are the localities of Neoproterozoic evaporite deposits documented (Behr *et al.*, 1983; Frimmel and Jiang, 2001).

The tectonically lowest of these units, the Schakalsberge Sub-terrane, consists of the predominantly volcanic Grootderm Formation with a dolomitic, in places stromatolitic and oolitic, cap carbonate (Gais Member). The volcanics of the Grootderm Formation comprise submarine metabasalt, locally with metagabbro and serpentinite, hyaloclastite, agglomerate and tuff beds which are metamorphosed to greenschist. Based on the lithology and the geochemistry of the metabasalt and metagabbro, an oceanic within-plate setting with oceanic islands (or an aseismic ridge) evolving to guyots has been inferred for this sub-terrane (Frimmel *et al.*, 1996a). In contrast, the Oranjemund Sub-terrane is made up of clastic metasedimentary rocks, mainly meta-graywacke, phyllite, quartzite and chlorite schist, all of which are assigned to the Oranjemund Formation.

While the stratigraphic terms for the Schakalsberge and Oranjemund Sub-terranes have been formally recognized (Frimmel, in press), the Chameis Sub-terrane has been regarded as a complex tectonic melange zone (Frimmel and Hartnady, 1992), and no stratigraphic subdivision of the latter has been provided to date. Field work in the Chameis Sub-terrane was carried out intermittently by the author over the last few years. Exposures are found along a narrow coastal strip in the Diamond Area No. 1 between Bogenfels, about 90 km south-southeast of Lüderitz, and Chameis Bay, about 100 km north-northwest of Oranjemund (Fig. 1B). In this contribution a first, preliminary description of the stratigraphy of the Chameis Sub-terrane is given, based on the mapping of selected sections and on geochemical and isotope analyses of key units within the sequence.

Lithology

In spite of isoclinal folding and thrusting which has obscured most of the primary lithological contacts, a volcano-sedimentary succession could be established with a thick sequence of mafic metavolcanic rocks occurring at the base of this succession. The mafic rocks comprise thinly laminated greenschist, mafic hyaloclastites, metabasalt and serpentinized picrite. The very fine-grained greenschist consists of Fe-rich biotite, albite, quartz, epidote, titanite, magnetite and calcite and it displays a compositional layering of dark green, green, grey and light gray bands, reflected by corresponding variations in the modal proportions of the above minerals. The thickness of these layers is in the order of a few millimetres to several centimetres. This highly laminated rock is regarded as being a metamorphosed tuff. It is intercalated with dark green to grey metabasalt, in places displaying pillow structures, and with more aluminous, i.e. mica-rich, dark green tuffitic to dark grey pelitic layers. The typical mineral assemblage found in the metabasalt is syn-tectonic albite, actinolite, chlorite, epidote, titanite, ±calcite, and ±quartz. Locally, a pretectonic assemblage, consisting of edenitic amphibole, plagioclase, biotite, ilmenite and quartz can be distinguished (Frimmel and Hartnady, 1992). Less abundant is metapicrite, interpreted as cumulate, in which all of the olivine is serpentinized with tremolite, chlorite and magnetite as additional metamorphic phases.

Brecciation of the metabasalt is widespread and often associated with the occurrence of hyaloclastites. Unusual modal proportions which are not compatible with any magma composition indicate extensive metasomatism, leading to epidosite, hornblendite, and ophicarbonate made up of epidote, calcite, plagioclase, actinolite and chlorite. Other expressions of metasomatism are the occurrence of albitite and highly oxidized domains rich in magnesioriebeckite and haematite.

Within the laminated greenschist and intercalated phyllite, exotic lonestones or dropstones, up to 1.5 m in diameter, occur at numerous localities. They comprise various granitoids, gneisses, quartzite and dolomite, and display variable degrees of rounding. The fine-grained matrix of this diamictite is either pelitic and dark grey or chloritic and green, and, in less intensely tectonized regions, the original bedding (now foliation) of tuffitic strata appears typically deflected on one side of a given dropstone. A thin black chert band occurs towards the top of this predominantly volcanic unit. The total thickness of this sequence cannot be constrained because the lower contact is not exposed and because of intense isoclinal folding. The relative proportion of the diamictite within the total sequence is estimated to be about 5%.

Metagabbro occurs in the form of lenses and blocks within the greenschist and diamictite, but also with tectonic contacts in the overlying metasedimentary rocks. Most of these bodies, which range in size from a few metres to a few kilometres, have tectonic contacts containing dolomite and albitite. Only at a few localities was an intrusive contact observed, indicated, for example, by the presence of a thin thermal aureole of spotted hornfels in the surrounding diamictite, or by a chilled margin and a thin margin of calcsilicate in surrounding dolomite. The metagabbro is, in places, cross-cut by fine-grained felsic dykes and rarely by plagiogranite dykes.

At one place, an Fe-rich, orange-brown dolomite occurs above greenschist, forming a prominent little hill 6 km north of an old mining camp north of Bakers Bay (Fig. 2A). In strain protected areas, circular stromatolites measuring about 10 cm in diameter are preserved near the base of the carbonates. At a number of other places, such as 5 km north of Bakers Bay and just south of the above-mentioned old mining camp, the greenschist is followed by a sequence of dolomite up to 50 m thick with intercalated pelite which contains tourmalinite layers, lenses and boudins, and albitite. The dolomite is brecciated with white, very coarse-grained, sugary dolomite clasts embedded in a medium grey to pink, similarly coarsely crystalline dolomite matrix. This dolomite breccia typically surrounds tectonically emplaced metagabbro bodies and also contains small fragments of the metagabbro. Evidence of extensive Na- and Mg-metasomatism is widespread in the form of albite-rich dolomite, massive albitite, a high proportion of magnesioriebeckite in a variety of different rock types, and the presence of talc, clinochlore and phlogopite in the dolomite. The mineral assemblage resembles that described from the Duruchaus Formation in the southern Damara Belt (Behr *et al.*, 1983) and is, by analogy, interpreted as being derived from a former evaporite. A detailed description of these unusual, but important, rocks is provided by Frimmel and Jiang (2001). Where the metagabbro bodies are surrounded by tectonic contacts, these contacts contain evaporitic dolomite. The presence of salty layers might have provided most effective glide planes for competent rocks, such as gabbro, to be displaced. Above the locally developed former evaporite follows, in places, a gritstone that is characterized by detrital blue quartz clasts.

The areal distribution of those beds that are interpreted as former evaporites is very limited, confined to nearby occurrences of mafic rocks, and is laterally discontinuous and very scattered due to the intense folding and thrusting. Although their strike length is only a few hundred metres, they occur at a number of places along the whole length of the Chameis Sub-terrane with the best examples exposed south of Chameis Bay and north of Bakers Bay (Fig. 1B).

Regionally more extensive and laterally more continuous is a carbonate sequence which, in all outcrops, overlies the volcanic rocks, including the inferred meta-evaporites and the diamictite. This sequence consists of a basal, laminated, medium grey, limestone or fetid, H_2S-rich dolomitic limestone up to 10 m thick which represents a cap-carbonate to the underlying diamictite where developed. This is followed by a massive, thickly bedded, fine-grained, light creamy white dolomite, fine-grained, medium-grey dolomite, and local ferruginous black chert. At the top of this succession is a dolomite

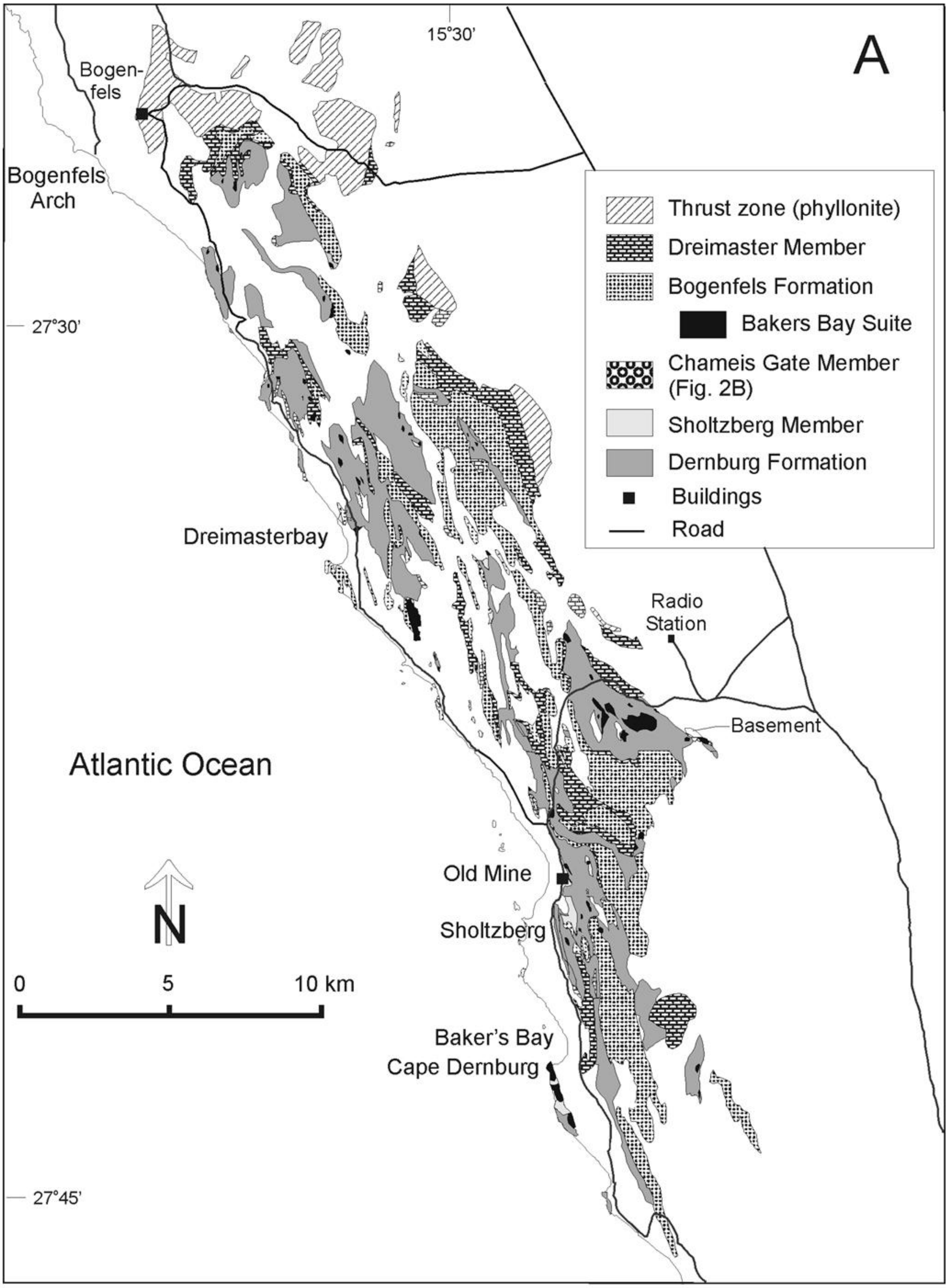

Figure 2A : Distribution of the various stratigraphic units of the Chameis Sub-terrane; northern area. For localites see inserts in Figure 1B.

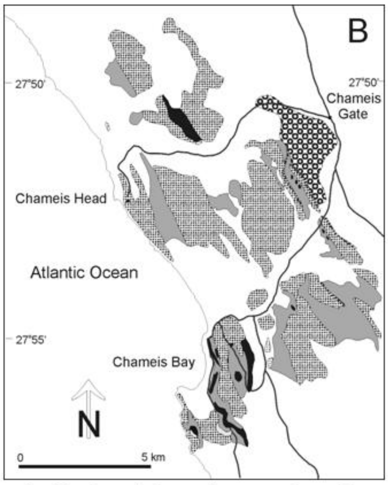

Figure 2B: Distribution of the various stratigraphic units of the Chameis Sub-terrane; southern area. Note that no outcrops exist between the northern (Fig. 2A) and southern (Fig. 2B) areas; for localities see inserts in Figure 1B; legend in Figure 2A.

breccia in which the immediately underlying rock types appear reworked. The total thickness of these carbonates is probably not more than 30 m. In general, the carbonates appear to be more widespread in the northern part of the sub-terrane than in the south.

The youngest sequence overlying the above carbonates is siliciclastic and dominated by feldspathic arenite which is intercalated with quartz arenite, chlorite schist and calcpelite. Abundant faulted contacts and intense folding prevents a reasonable estimate of the thickness from being made. The light brown to yellowish white feldspathic arenite is a medium- to coarse-grained greywacke or arkose with rare graded bedding of turbiditic appearance preserved. Predominantly perthitic feldspar clasts, together with quartz, muscovite and otite clasts are embedded in a recrystallized matrix of phengitic white mica, quartz and ±calcite. The mineral assemblage of the finer grained siliciclastic rocks consists of, in variable proportions, quartz, muscovite, biotite, chlorite, albite and calcite.

Geochemistry

Major, trace and rare earth element (REE) concentrations, and Rb-Sr and Sm-Nd isotope ratios of the various mafic rock types have been determined by Frimmel *et al.* (1996a). In terms of their immobile trace-element distributions and isotope ratios (ε_{Sr} and ε_{Nd}), the metabasalt and metagabbro samples analysed can be subdivided into an alkaline and a subalkaline group. The former bears all the geochemical hallmarks of within-plate basalts, whereas the latter corresponds to mid-ocean ridge basalt (MORB).

Any attempt to correlate the stratigraphic units of the Chameis Sub-terrane is hindered by the lack of absolute age data and of marker fossils. The most useful tool for stratigraphic correlation might therefore be found in geochemical peculiarities of certain strata. To this end, preliminary geochemical data, including Sr, C and O isotope ratios, of the various carbonate rocks are presented here. Inductively Coupled Plasma Mass Spetrometry (ICP-MS) was employed for the determination of trace-element concentrations, thermal ionization and gas mass spectrometry for that of Sr and of C and O isotopic compositions, respectively. All analyses were carried out at the Department of Geological Sciences, University of Cape Town.

Two of the cap carbonate sequences above the greenschist/diamictite and, for comparison, a dolomite that is interpreted as former evaporite have been analysed for their trace-element contents (Table 1). One profile (Profile I) comprising 13 samples (HFG192-204) represents a 26 m thick cap dolomite sequence overlying a greenschist with dropstones at coordinates 27°35.59'S and 15°32.20'E. Sample numbers correspond to progressively lower stratigraphic position with Sample HFG204 coming from 4 m above the contact with the greenschist, and HFG192 representing the top. A second profile (Profile II) was sampled through a carbonate sequence, again on top of greenschist, at coordinates 27°41.58'S and 15°32.48'E. There the cap carbonates start with an 8-m thick limestone (HFG222 and HFG223), followed by dolomite (HFG224). The example of a former evaporite is sample HFG211, a light creamy white, sugary dolomite collected at coordinates 27°39.88'S and 15°32.24'E. For comparison, samples of stromatolitic Gais Member dolomite from the

Table 1: Representative trace element concentrations in carbonates from the Chameis Sub-terrane.

		Profile I			Profile II		
Sample	HFG204	HFG193	HFG192	HFG222	HFG223	HFG224	HFG211
ppm	dolomite	dolomite	dolomite	limestone	limestone	dolomite	dolomite
Li	0.41	1.26	2.09	7.92	9.73	0.75	0.34
Sc	0.94	0.80	1.11	2.86	3.28	0.22	1.97
V	6.99	8.80	10.70	19.90	23.60	1.52	2.38
Cr	3.34	12.00	14.60	20.60	76.60	2.33	1.44
Co	1.27	1.98	2.40	2.81	4.49	1.42	1.98
Ni	7.97	5.55	6.20	9.03	13.10	5.72	9.82
Rb	1.25	11.60	12.40	35.50	39.60	0.17	0.01
Sr	175.00	69.30	71.70	814.00	1412.00	183.00	218.00
Y	6.60	5.57	7.20	9.14	14.30	1.00	3.08
Zr	3.14	28.40	31.50	32.80	102.00	1.34	0.50
Nb	0.25	1.28	1.79	3.69	6.00	0.20	0.14
Cs	0.04	0.17	0.20	1.05	1.52	0.01	0.00
Ba	1.31	82.20	97.60	148.00	148.00	1.65	1.47
Hf	0.04	0.71	0.79	0.87	2.53	0.03	0.02
Pb	2.16	2.20	3.48	1.12	1.27	0.45	0.46
Th	0.11	0.92	1.27	3.79	5.75	0.21	0.01
U	0.22	0.50	0.41	1.53	1.52	0.15	0.03

Analyses conducted on solutions prepared by dissolving 50 mg of -300 mesh powder in a 3:1 HF:HNO_3 mixture in a Savilex beaker heated on a hotplate for 48 hours, followed by two dry-downs in concentrated HNO_3. Each dissolved sample was then analysed as a 5% HNO_3 solution with In and Re as internal standards, using an ELAN 6000 ICP-MS. Standardisation was achieved against multi-element standard solutions. Precision was better than 3% for all elements analysed.

Schakalsberge Sub-terrane (all collected about 12 km northeast of Alexander Bay at coordinates 28°32.5'S and 16°36.0'E) were also included in the stable isotope study.

In general, the limestone samples are richer in trace elements than the dolomite samples (Table 1). Particularly noteworthy are very high Sr, Rb and Ba contents in the cap limestone (up to 1412 ppm, 40 ppm and 148 ppm, respectively). In Profile I, there is a decrease in Sr content of the dolomite from 175 ppm at the bottom to around 70 ppm at the top, which is accompanied by an increase in Rb, Ba, Zr and Nb concentrations. Generally, the carbonate samples display low contents of those trace elements which are typically contained in detrital clasts, such as Zr or Nb, as can be expected for a chemical marine sediment. Compared to the other dolomites, the evaporite-derived dolomite is enriched in Sr and strongly depleted in Rb, Zr, Nb, Th and U.

The relatively high Rb contents in most of the samples preclude the determination of the initial ^{87}Sr/^{86}Sr ratio. A high radiogenic Sr component is reflected by most of the ^{87}Sr/^{86}Sr ratios measured which are typically between 0.710 and 0.718 (Table 2). The radiogenic Sr is ascribed to initially high Rb contents (see Table 1) and/or the syn-orogenic infiltration of a fluid that has reacted with felsic, Rb-rich rocks. The only exception is the dolomite that is interpreted to reflect a former evaporite. Two samples from this bed yielded extremely low Rb/Sr ratios of 0.00004 and 0.00030. The measured ^{87}Sr/^{86}Sr ratios of 0.7088 and 0.7075, respectively, are therefore considered to be close to the intial ^{87}Sr/^{86}Sr ratios.

Profile I was chosen for assessing trends in the C and O isotope ratios from the bottom to the top of the cap carbonate sequence. Near the contacts with the footwall and hangingwall, δ^{18}O values are depressed below 20 ‰, which is taken as indicative of significant post-depositional alteration of the isotope system. No corresponding alteration in δ^{13}C exists, however, in these samples but they follow the general trend in the δ^{13}C values obtained on all the remaining samples which are less altered with respect to δ^{18}O (Table 3). At the contact with the underlying greenschist/diamictite sequence, the δ^{13}C values are negative (around -2.5 ‰). Some 8 m above the contact, the δ^{13}C values approach 0 ‰ and then remain in a narrow range between -1.4 and -0.2 ‰. The stromatolitic dolomite samples analysed all appeared depleted in both ^{13}C and ^{18}O by post-depositional hydrothermal alteration which is manifested by a high Fe-content and widespread silicification. These were not further considered. Some of Gais Member dolomite samples analysed displayed a similar secondary depletion in ^{13}C and ^{18}O and were discarded but three samples with the least hydrothermal overprint were included (Table 3). Their δ^{13}C values range from +0.80 to +2.82 ‰.

Table 2: ^{87}Sr/^{86}Sr ratios of carbonate rocks from the Chameis Sub-terrane.

Sample	^{87}Sr/^{86}Sr	2 s std	Rb/Sr
HFG192	0.71806	0.0010	0.17294
HFG194	0.71799	0.0015	0.16594
HGF199	0.71298	0.0010	0.01111
HFG204	0.71309	0.0009	0.00714
HFG211	0.70880	0.0009	0.00004
HFG213a	0.70751	0.0008	0.00030
HFG224	0.71053	0.0011	0.00093

For analysis hand-picked fragments of clean dolomite or limestone were dissolved in 0.6N HCl and centrifuged. The solution was evaporated to dryness and redissolved in 2.5N HCl. After separating Sr by conventional ion-xchange techniques, it was loaded in 0.5N H_3PO_4 on Ta filaments and its isotopic ratios measured using a VG Sector 7-collector thermal ionization mass spectrometer All measured ^{87}Sr/^{86}Sr ratios normalised to a ^{86}Sr/^{88}Sr of 0.11940 and a ^{87}Sr/^{86}Sr ratio of 0.71023 ± 0.0009 obtained for the NBS-SRM987 standard.

Depositional environment

Based on the existing geochemical data for the mafic rocks, an oceanic within-plate setting is inferred. Submarine extrusion of the mafic volcanic rocks is indicated by the existence of pillow lavas, whereas relatively shallow water depths are implied by the occurrence of hyaloclastites and mafic breccias. Support for a shallow marine environment also comes from the geochemistry of the cap carbonates. The high Sr contents found in the immediate cap carbonates, especially the limestone, are explained by aragonite having been the sedimentary carbonate precursor phase which constrains the water depth of carbonate formation at less than the aragonite compensation boundary. Furthermore, the presence

Table 3: Oxygen and carbon isotope ratios along profile through carbonates on top of greenschist/diamictite in Chameis Sub-terrane and from silicified stromatolitic dolomite in the Schakalsberge Sub-terrane.

Sample	δ^{13}C	δ^{18}O	Member	Metres above contact
HFG192	-1.08	19.69	Dreimaster	18
HFG193	-1.39	20.40		17
HFG194	-0.70	21.17		16
HFG195	-0.75	21.54		14
HFG197	-0.95	21.25		13
HFG196	-0.70	20.56		12
HFG198	-0.29	21.80		11
HFG199	-1.07	22.02		10
HFG200	-0.26	21.94		9
HFG201	-0.18	22.17		8
HFG202	-2.35	21.56		7
HFG203	-2.58	20.57		6
HFG204	-2.37	17.46		4
HFG137	1.02	22.93	Gais	
HFG138	2.82	22.68		
HFG140a	0.80	24.78		

Isotope ratios collected following the techniques described by Al-Aasm *et al.* (1990); all d^{18}O and d^{13}C values reported in per mil, relative to standard mean ocean water (V-SMOW) and the *Belemnitella americana*, Pedee Formation, standard (PDB), respectively.

of stromatolitic dolomite on top of the mafic volcanics suggests the build-up of reef mounds above the top surface of a guyot leading to the formation of an atoll.

The distribution of those trace elements which are typically concentrated in continental detrital phases, such as Zr and Nb, indicate an open marine environment with little continental clastic influence, as these trace element concentrations are all in the range of normal marine carbonate rocks. However, the evaporite-derived dolomite is almost devoid of any continental influence with its Rb, Zr, Nb, Th and U concentrations being an order of magnitude lower than in the marine carbonates. A setting within an atoll with a central basin cut off temporarily from the open sea, is therefore inferred for evaporite deposition. The volcanic activity must have persisted over a period of time during which climatic conditions changed from moderate to warm, reflected by the growth of stromatolitic reefs and formation of evaporites, to cold, as evidenced by the presence of glaciogenic diamictite.

Although some of the siliciclastic material found in the metasedimentary rocks on top of the cap carbonates may be derived from the re-working of the underlying volcanic piles, an increasing continental influence is obvious in these younger rocks. This can be explained by an advancing orogenic front and thus, the youngest rocks in the MT possibly reflect the inversion from extension to collision tectonics in this Pan-African basin.

Proposed stratigraphic subdivision and correlation

The term Gariep Supergroup has been suggested to embrace all Neoproterozoic stratigraphic units within the Gariep Belt (Frimmel, in press). The major differences in the stratigraphy of the PNZ and the MT are accommodated by ascribing all the Neoproterozoic rocks that make up the PNZ to the Port Nolloth Group and distinguishing this group from the stratigraphic units of the MT. In spite of some similarities between the rock types of the three tectono-stratigraphic units of the MT, they are sufficiently different to warrant different stratigraphic names for the individual successions in the Schakalsberge, Oranjemund, and Chameis Sub-terranes. In contrast to the former two, for which a stratigraphic terminology has been proposed (Frimmel, in press), no such terminology exists for the Chameis Sub-terrane. A new stratigraphic subdivision for this sub-terrane is therefore proposed here with the term Chameis Group used to embrace all Pan-African rocks that make up this sub-terrane (Fig. 3). The areal distribution of the various units of the Chameis Group is shown on Figures 2A and B.

The oldest exposed unit in the Chameis Sub-terrane is the sequence of mainly mafic volcanic rocks with intercalated diamictite described here. Compared to previous stratigraphic nomenclature for the area, the mafic rocks correspond to the “Chlorit-schiefer Formation” of Kaiser (1926) and to the Lower Marmora Beds of Martin (1965). The stromatolitic and meta-evaporitic, mainly dolomitic units were ascribed to the “Untere Konkip Formation” of Kaiser (1926) and to the Upper Marmora Beds of Martin (1965). As the term “Marmora” is used for the whole terrane, a new name for the corresponding stratigraphic units appears appropriate to avoid confusion. Therefore, the term Dernburg Formation is proposed for this sequence which includes all the mafic and ultramafic volcanic rocks, metatuffs, diamictite, chert, stromatolitic dolomite, and the sugary dolomite, albitite and tourmalinite that are interpreted as former evaporites. The name is derived from Kaap Dernburg, a rocky cliff on the southern end of Bakers Bay (Fig. 2A), where the metavolcanic rocks are particularly well exposed along a coast-parallel ridge. The diamictite, being a very conspicuous and laterally extensive unit within this subgroup, is distinguished as the Chameis Gate Member, named after a check point, some 104 km north of Oranjemund on the main road through the Diamond Area No. 1 (Fig. 2B). To the west and northwest of the gate, the diamicite is exposed in wind-blown surfaces. All of the rock types of the Dernburg Formation were, in places, intruded by mainly gabbro and all those rocks which are intrusive into the Dernburg Formation are assigned to the so-called Bakers Bay Suite, named after the Bakers Bay, where they are well exposed.

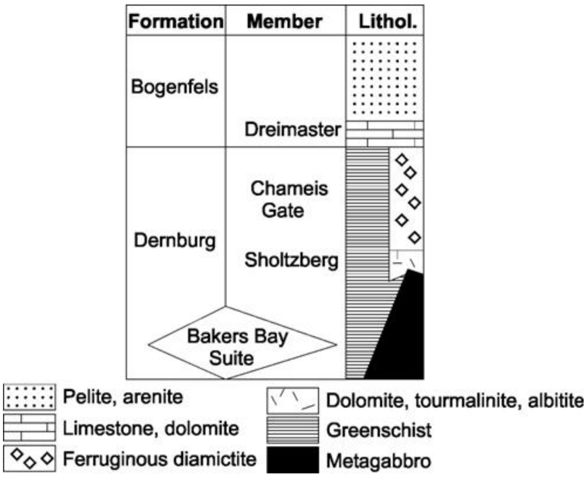

Figure 3: Stratigraphic subdivision of the Chameis Group in the Chameis Sub-terrane.

The stromatolitic dolomite, which is developed only very locally, is included in the Dernburg Formation. Although its exact position within the formation remains unclear because of the lack of primary contacts with the overlying strata, it does not form the basal part of the formation as it overlies mafic volcanics, and it is believed that it occurs somewhere in the middle part of the Dernburg Formation but below the diamictite of the Chameis Gate Member. The name Sholtzberg Member is proposed for the succession of evaporite-derived sugary dolomite, albitite and tourmalinite, usually associated with the mafic rocks, named after a conspicuous hill 1 km south of the abandoned mine camp north of Bakers Bay (Fig. 2A) where the best exposure of this palaeo-evaporitic sequence is located.

The igneous rocks of the Dernburg Formation show strong lithological similarities to the Grootderm Formation of the Schakalsberge Sub-terrane. Although the majority of the mafic volcanics in both formations has very similar geochemical characteristics - in both alkaline tholeiites of oceanic within-plate character dominate - there are significant differences between the two formations. The ε_{Nd} -values for the Dernburg Formation are higher than for the Grootderm Formation and only in the former were mafic rocks with MORB affinity found (Frimmel *et al.*, 1996a). A further similarity between the two formations lies in the presence of stromatolitic dolomite towards the top of the oceanic volcanics. Only from the Dernburg Formation, however, are former evaporites, the Sholtzberg Member, known.

The sequence of carbonates and siliciclastic rocks which follows above the Dernburg Formation constitutes the second major stratigraphic unit within the Chameis Sub-terrane. This sequence bears striking similarities to the Holgat Formation in the PNZ. It starts with cap-carbonates, which are in most places recrystallized fetid limestone, markedly rich in H_2S and characterized by a marked Sr enrichment, suggesting precipitation originally as aragonite. The term Dreimaster Member is proposed for the carbonate sequence, named after the Dreimaster Bay which is located at the northern end of coastal exposures of these rocks. The quartzites of the Dreimasterpunt, a conspicuous outcrop which marks the southern end of the bay, are flanked on both the eastern and western sides by carbonates of this formation. The carbonate sequence begins with limestone or dolomite depleted in ^{13}C (Table 3). In recent studies, this depletion has been found in effectively all carbonates that overlie a glaciogenic diamictite horizon in the Pan-African sequences in southwestern Africa (Fölling *et al.*, 1998; Hoffman *et al.*, 1998) and in itself is in fact a reliable indicator of the glaciogenic origin of the underlying diamictite. Both lithologically and geochemically, the cap carbonates above the Dernburg Formation compare very well with the Bloeddrif Member on top of the Numees Formation diamicite in the PNZ. In both cases the cap carbonates display similar trends in $\delta^{13}C$ with negative values (-2 - 4 ‰) at the bottom contact rising to values around 0 ‰ through the rest of the sequence. This trend is markedly different from that observed in the carbonates above the Kaigas Formation diamictite which are characterized by a strong positive $\delta^{13}C$ excursion (Fölling *et al.*, 1998). By analogy, the diamicite within the Dernburg Formation is correlated with the Numees Formation diamictite in the PNZ (Fig. 4). Further support for such a correlation comes from the Sr isotope data obtained on the evaporite-derived dolomite of the Sholtzberg Member underneath the Chameis Gate Member (Frimmel and Jiang, 2001). Considering the lack of significant continental influence on the inferred evaporite deposit and the extremely small Rb/Sr ratio, the lowest measured $^{87}Sr/^{86}Sr$ ratio of 0.70751 is taken as being close to that of the contemporaneous seawater. During the Neoproterozoic erathem, such a $^{87}Sr/^{86}Sr$ ratio was typical for the period between the Sturtian and the Varangian glaciations. In contrast, post-Varangian cap carbonates have significantly higher $^{87}Sr/^{86}Sr$ ratios (Asmerom *et al.*, 1991; Kaufman *et al.*, 1993). A Vendian age of the Chameis Gate Member would also explain the enriched $\delta^{13}C$ values found in the Gais Member of the Schakalsberge Sub-terrane which is believed to be a stratigraphic equivalent of the Sholtzberg Member in the Chameis Sub-terrane. The C isotopic composition of the Sholtzberg Member itself may not be conclusive because of the unusual, relatively restricted depositional environment postulated for it. The least altered $\delta^{13}C$ values obtained for the Gais Member compare well with those of the uppermost Hilda Subgroup (Dabie River Formation) immediately below the Numees Formation diamictite in the PNZ (Fölling *et al.*, 1998).

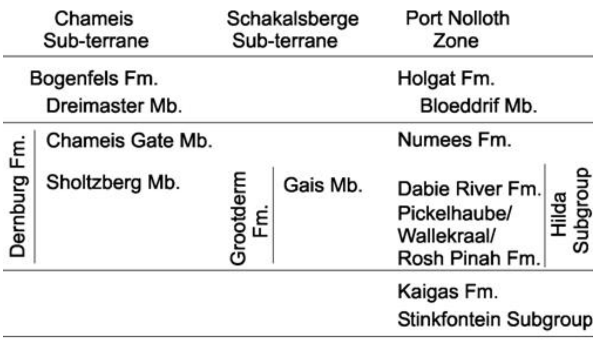

Figure 4: Proposed stratigraphic correlation between the various formations (Fm.) and members (Mb.) of the Chameis and Schakalsberge Sub-terranes in the Marmora Terrane, and the Port Nolloth Zone.

The term Bogenfels Formation has been proposed by Martin (1965) for those rocks which had previously been described by Kaiser (1926) as "Folded Nama" and which correspond to the cap carbonate sequence and overlying siliciclastic succession. It is suggested to retain the term Bogenfels Formation, but to use it in a different context. As no distinction has been made between a PNZ and MT at that time, Martin (1965) used the term Bogenfels Formation for rocks in both tectonic zones. He recognised that the continuation, both lithological and structural, of his Bogenfels Formation can be traced to the area west and northwest of Rosh Pinah. Thus, his Bogenfels Formation is part of the PNZ and should have an equivalent in one of the stratigraphic units of the Port Nolloth Group. Martin pointed out similarities between his Bogenfels Formation and the Hilda Subgroup but such a correlation still needs to be substantiated with sedimentological and geochemical work. All of Martin's Bogenfels Formation which is exposed in the PNZ should be re-assigned to the Port Nolloth Group. However, for that part of Martin's Bogenfels Formation which occurs in the MT, the stratigraphic name and rank shall be retained. The re-defined Bogenfels Formation is thus confined to the MT where it comprises the cap carbonates (Dreimaster Member) and siliciclastic rocks above the Dernburg Formation. It should be noted that the scenic Bogenfels arch on the coast is within the PNZ and consequently does not form part of the re-defined Bogenfels Formation. However, the diamond mining camp "Bogenfels" is within the MT and was built on rocks belonging to the Bogenfels Formation as defined here. On the grounds outlined above, a correlation between the Bogenfels Formation in the MT and the Holgat Formation in the PNZ appears most likely (Fig. 4).

Finally, if the stratigraphic correlations between the Sholtzberg and Gais Members in the PNZ and the upper Hilda Subgroup in the MT, between the Chameis Gate Member and the Numees Formation and between the Dreimaster Member and the Bloeddrif Member are correct, the formation of oceanic crust in the MT would have been taken place at the same time as the deposition of platform carbonates, which followed felsic rift volcanism at around 741 Ma (Frimmel *et al.*, 1996b) in the PNZ. Eruption of oceanic basalts would have continued during the global Vendian (Varangian) glacial epoch at about 590-600 Ma. Such syn-glacial submarine volcanic activity might then explain why the Numees Formation diamictite, in contrast to the older Kaigas Formation diamictite, is in places highly ferruginous and associated with banded iron formation (von Veh, 1993; Frimmel and von Veh, 1999).

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