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GEOLOGY AND ALTERATION-MINERALIZATION IN THE GAMIGAB AREA, NORTH OF THE BRANDBERG

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ABSTRACT

The stratigraphy at the Gamigab Sn prospect consists of two mainly schistose units separated by a thick marble unit which have been correlated with the Orusewa Formation, the Karibib Formation and the Kuiseb Formation respectively. Four phases of folding affected the lithologies with the south-south-west trending F_2 folds defining the main structures in the region. The grade of metamorphism is in upper greenschist facies and to the south-east and west the effects of contact metamorphism are seen in the form of cordierite pseudomorphs and biotite spots. Cassiterite is hosted within east-west trending quartz veins that cross-cut previously altered country rocks. Hydraulic brecciation is spatially associated with the mineralization and alteration. These breccias occur in antiformal structures within the marble and developed in response to a sudden pressure release due to a build up of fluids at the contact between the Orusewa and Karibib Formations. Two Karoo-age intrusions penetrated the metasediments north of the mineralization. One is a ferruginized porphyry plug and the other is an altered dolerite plug. It is possible that the same hydrothermal system was responsible for the alteration of the intrusions, the brecciation and the alteration-mineralization, indicating a possible Karoo-age for the hydrothermal activity.

1. INTRODUCTION

The vein-hosted Gamigab tin prospect is located in the south-eastern corner of the farm Vegkop 528, some 15 km north of the Brandberg granite intrusion (Fig. 1). It occurs in the northern parts of the Southern Kaoko Zone (SKZ) (Miller, 1983) of the Damara Orogen. Within this region of the SKZ there are four areas of known mineralization, one of which is Gamigab. The three other areas include Brandberg West (vein-hosted Sn-W), Frans Prospect (vein-hosted Sn) and the Goantagab Mining Area (vein-hosted and replacement-type Sn) (Pirajno and Jacob, 1986, 1987).

Freyer (in prep, as cited by Petzel, 1986) has further subdivided the SKZ into three structural domains, the Ogden Rocks Domain (ORD), the Lower Ugab Domain (LUD) and the Goantagab Domain (GD) (Fig. 2). The ORD is confined to the region immediately adjacent to the coast and is described by Freyer and Hälbich (1983). The LUD covers the central parts of the SKZ (see Miller *et al.*, 1983), and hosts the mineralization at Brandberg West and Frans. The GD forms the eastern boundary of the region and it is in this domain that the Goantagab Mining Area and the Gamigab prospect occur.

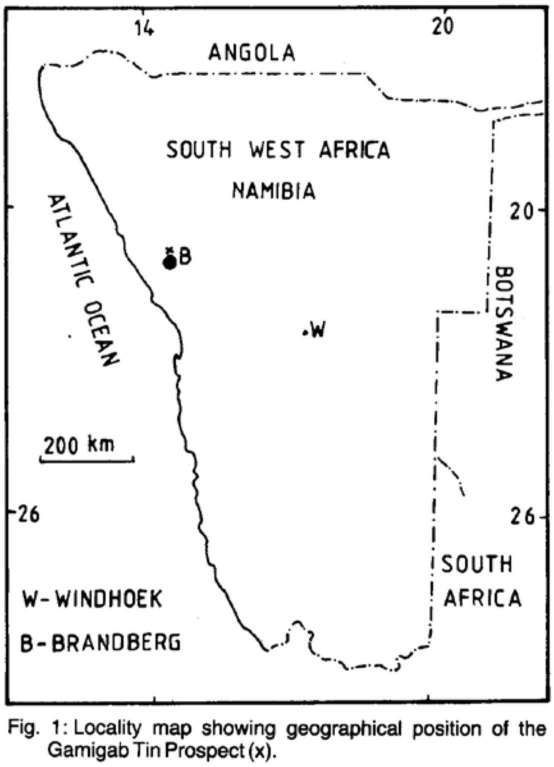


Fig. 1: Locality map showing geographical position of the Gamigab Tin Prospect (x).

Previous work done in the GD has been essentially on a regional scale. The first major study of the area was done by Hodgson (1972) who mapped the area from the Brandberg intrusion northwards to include the post-Karoo Doros pluton. The region south of Hodgson's area was mapped by Jeppe (1952) who covered an extensive area from the coast to the Brandberg granite complex south of the Ugab River. More detailed regional work which included almost all of the GD was completed by Osborn (1985).

In the Gamigab area, the mineralization was first investigated in 1953 by the South West Africa Company (SWACO). Three sampling trenches were dug perpendicular to a set of mineralized quartz veins (which were subsequently assayed for tin and tungsten). A reconnaissance geological map was also completed. Mapping by Le Roux (1982) and Osborn (1985) extended the area mapped and located two igneous intrusions some 500 m north-east of the trenches.

2. GEOLOGY

2.1 Regional Geology

The marbles and schists in the Goantagab Domain form part of the Damara Sequence, and are intruded by a mafic complex of Damaran age and by syn- to post-tectonic granites. The metasediments are unconformably overlain by undeformed interbedded sedimentary rocks and lavas of Karoo age and are cut by numerous Karoo dolerite dykes.

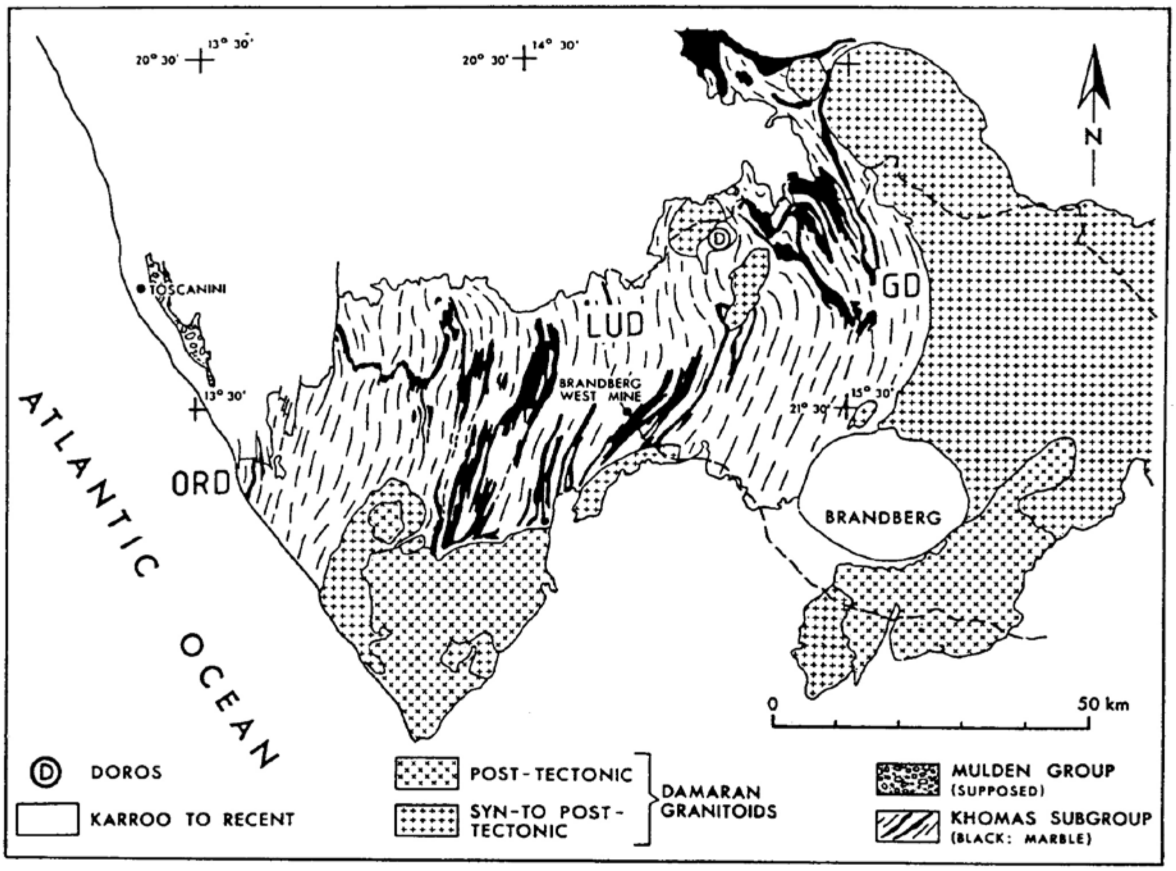


Fig. 2: Simplified geological map of the northern parts of the SKZ, showing the subdivision into structural domains. ORD = Ogden Rocks Domain; LUD = Lower Ugab Domain; GD = Goantagab Domain. Modified from Porada *et al.* (1983).

Osborn (1985) correlated the lithologies with those of the Swakop Group and suggested a subdivision into the Orusewa, Chuos, Karibib and Kuiseb Formations (Table 1). As can be seen from Table 1, the Chuos Formation has been correlated with the Ugab Subgroup whereas, according to SACS (1980), the Chuos Formation should be at the base of the Khomas Subgroup.

In general, the stratigraphy proposed by Osborn (1985) agrees with that of Hodgson (1972) except for those regions to the south and west of Goantagab mining area (hereafter referred to as Goantagab). In these regions Hodgson (1972) interprets the schists as 'Upper Schists' which overlie the Karibib Formation, whereas Osborn (1985) places them beneath the Karibib marbles. This discrepancy may be because of a regional shear zone across which structural and stratigraphic change occurs (Osborn, 1985). This shear separates a north-eastern continental shelf-type environment from a south-western, distal, deep water basin (Osborn, 1985).

2.2 Lithostratigraphy

2.2.1 Orusewa Formation

At Gamigab the stratigraphy is slightly different from that at Goantagab and, according to Osborn (1985), the lithologies in the Gamigab area may be correlated with those at Goantagab. The oldest unit at Gamigab is a strongly foliated, generally homogeneous, fine-grained quartz-biotite schist which is correlated with the Orusewa Formation. The schist is generally not very well exposed because of an extensive 2-3 m thick calcrete cover, but improves in river beds and valleys. Thickness of the beds is difficult to measure because of the isoclinal folding. Toward the contact with the overlying marble, thin (10-20 cm thick) carbonate bands are interbedded with the schist, and are hydrothermally altered near the mineralized area. The schist has been both sericitized and ferruginized whereas the marble has only been ferruginized (see section 5.2).

2.2.2 Karibib Formation

The Karibib Formation at Gamigab differs from that at Goantagab in that in place of two marble units separated by a schist, only one thick (150 m) marble sequence is present. It comprises a thickly banded calcitic and dolomitic marble sequence interbedded with lensoid quartz-biotite schist.

It is important to point out that the banding in the marble is not bedding but is a transpositional banding

TABLE 1: Lithological and stratigraphic subdivisions of the Damara Sequence in the Goantagab Domain.

		OSBORN (1985) GOANTAGAB DOMAIN	THIS WORK GAMIGAB AREA
KHOMAS SUBGROUP	KUISEB FORMATION	Rhythmically interbedded calcareous schist with impure marble, calc-silicate bands and feldspathic quartzite. Basal gritty calcareous schist.	Interbedded marble and schist with calc-silicate bands and basal platy marble and schist.
	KARIBIB FORMATION	Two massive marble units separated by sericite-biotite-quartz schist. Lower blue-grey marble becoming interbedded with schist toward contact with overlying schist. Upper marble contains granitic boulders and becomes interbedded with schist toward contact with Kuiseb Formation.	Single marble sequence consisting of interbedded calcitic and dolomitic marble layers. Lensoid quartz-biotite schist. Marble is blue-grey in colour at the base and at the contact with the Kuiseb Formation.
UGAB SUBGROUP	CHUOS FORMATION	Lensoid mixtite unit with tillite, conglomerate, schist and BIF.	NOT PRESENT
	ORUSEWA FORMATION	Black schist, biotite-sericite-quartz schist.	Quartz-biotite schist with interbedded marble close to contact with Karibib Formation.

which is related to the earliest phase of folding of the rocks. Generally the banding is parallel to the contacts between schist and marble and so may be easily confused with bedding. Bedding is still preserved in a few places where the transposition has not totally obliterated the evidence. At the base of the unit is a thick (20 m), blue-grey, massive marble band. The true banded character of the unit is clearer in the marble overlying the blue-grey marble where pale yellow, blue-grey, yellow-brown, black and white marble bands occur. The thickness of the bands varies between 1 m and 10m. A band of 'streaky marble' occurs at several localities between calcitic and dolomitic marble bands and contains lenses of yellow-brown dolomitic marble (usually a few centimetres long) set in a matrix of white calcitic marble. The streaky marble may be traced for several hundred metres along strike but eventually pinches out and hence cannot be used as a reliable marker horizon.

Interbedded with the banded marble unit is a lensoid quartz-biotite schist which is approximately 0,5 m thick and occurs toward the top of the unit. Dark coloured, resistant quartz-rich lenses may be found within the banded unit and do not seem to be concentrated in any specific band. These may represent original sedimentary chert lenses which were deformed and recrystallized in response to deformation and metamorphism.

2.2.3 Kuiseb Formation

The base of the Kuiseb Formation in the Gamigab area is represented by a 5 m thick quartz-biotite-muscovite schist which in turn is overlain by a gritty calcareous schist (2-3 m thick), locally termed platy marble. The remainder of the formation is represented by dark brown, quartz-biotite-chlorite schists with interbedded marble and calc-silicate bands (<10 cm thick) containing radiating aggregates of actinolite and dark red grossularite garnet. In the eastern parts of the area much of the Kuiseb Formation is covered by recent sand and calcrete cover.

3. STRUCTURE

The region around the Gamigab prospect has been subjected to four phases of deformation. The earliest phase (D_1) is represented by the banding in the Karibib Formation and by a strong axial planar schistosity in the metapelites. The banding is a result of transposition of the original bedding, which can still be seen in places. Minor intrafolial folds (F_1) with vertical axes are preserved at several localities. Intraformational shearing, in response to flexural slip, produced a streaky marble

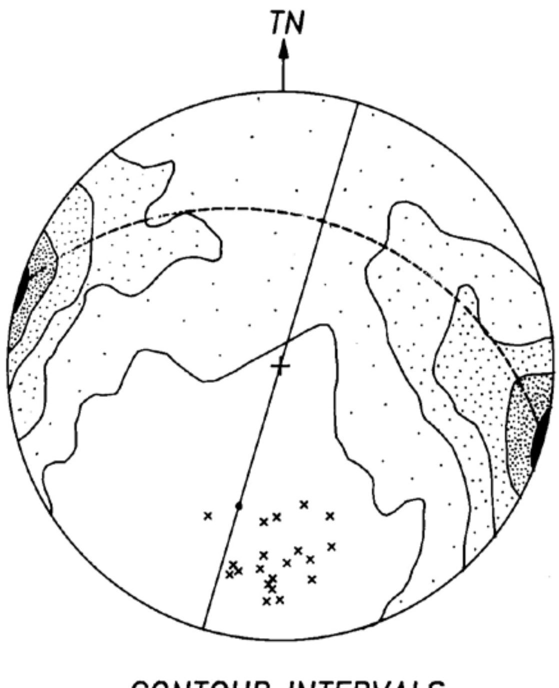


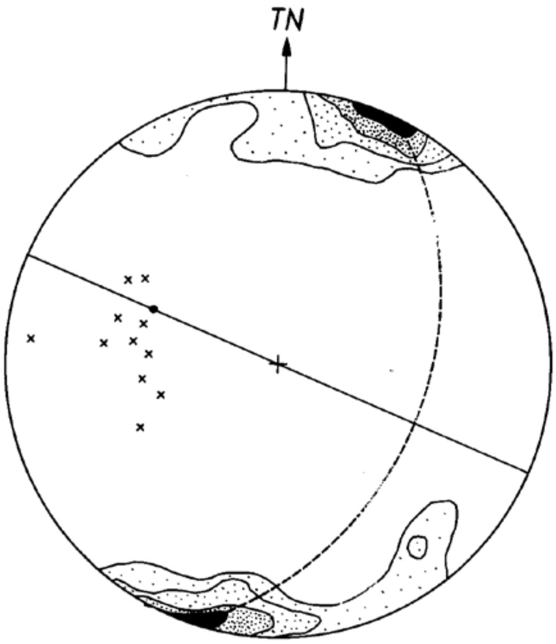
Fig. 3: Poles to banding and schistosity, and measured lineations (x). Filled-in circle = average plunge of the F_2 axis. Contour intervals at 13, 8, 5, 3, 1, per 1 % area. N > 1 000.

between layers of contrasting competence (i.e. dolomitic marble and calcitic marble).

The F_2 structures are the main structures in the area and are represented by megascopic and mesoscopic southerly-plunging (30°-50°) folds. Axial planes are generally vertical, although a few are slightly overturned towards the west. Away from the closures, the limbs of these folds parallel each other indicating that they are isoclinal. The F_2 closures are only really seen when the marble-schist contact is traced around the fold, and at these closures further transposition effects may be seen. The s_2 direction parallels the banding (s_1) in the marbles (along the fold limbs), and it is not always clear in the schist whether the schistosity is s_1 or s_2. Hence, the regional schistosity is locally termed $s_{1,2}$. Fig. 3 is a structural diagram showing poles to the banding and schistosity. From the diagram an average plunge and plunge direction for the F_2 folds may be determined (45° toward 195°), as well as an average trend for the $s_{1,2}$ fabric (195°). Associated b lineations plot in the same vicinity as the F_2 fold axis.

D_3 was responsible for the major change in strike of the lithologies between the Goantagab Mining Area to the north and Gamigab. The structures around Goantagab trend approximately south-south-east whereas those at Gamigab trend south-south-west. The F_3 fold axis trends approximately north-east and is located several kilometres north of Gamigab.

Superimposed on the earlier fold phases are crenulations and kink bands (F_4) with an associated, albeit weak, crenulation cleavage (S_4). The crenulations are best expressed in the pelitic rocks but are seen as a gentle warping of the banding in the marbles. Fig. 4 is a structural plot of the poles to the F_4 axial planes and shows that these structures trend 291° with a plunge of some 45° to the west.



CONTOUR INTERVALS
20,15,9,3 per 1% AREA

Fig. 4: Poles to F_4 crenulation and kink band axial planes, x = fold axes. Contour intervals at 20, 15, 9, 3, per 1 % area. N = 40.

In the Gamigab area several east-west trending faults were mapped. Three such faults lie several hundred metres east of the mineralization, and are associated with ferruginized marbles, suggesting that these lines of weakness acted as conduits for hydrothermal and/or meteoric fluids. The sense and amount of movement in the faults is uncertain because of the alteration effects.

4. METAMORPHISM

The rocks in the mapped area underwent low to medium grades of regional metamorphism with conditions probably in the region of transition from greenschist to amphibolite facies. Syn- to post-tectonic contact metamorphic effects overprint the regional metamorphic fabric. The pelitic rocks have chlorite, muscovite, biotite and quartz as stable assemblages which are typical of greenschist facies, i.e. low grades of metamorphism.

The grossularite in the calc-silicate lenses appear to have formed by the reaction between quartz and zoisite (only a single grain of zoisite was seen in contact with actinolite, suggesting that it was present prior to the reaction with quartz). According to Winkler (1979) the grossularite-forming reaction takes place at temperatures around 500°C.

The presence of tremolite in the marbles implies high X_{CO2} conditions, since the reaction between dolomite and quartz to form tremolite occurs between 480°-500°C at 2 kbar (Slaughter *et al.*, 1975). At higher pressures the reaction may take place at higher temperatures and lower X_{CO2} (Slaughter *et al.*, op. cit.).

Pseudomorphs of cordierite consist of chlorite, biotite and muscovite which overprint the regional fabric south-east of Gamigab. The porphyroblasts are elongated indicating that they were generated syn-tectonically (probably during D_2). Coarse biotite spotting of the schists to the west of Gamigab also suggests contact metamorphism in these parts. Under thin section the spots are seen to consist of a coarse-grained, recrystallized core of quartz wrapped around by coarse, unstrained biotite. The D_4 crenulations appear, in places, to be overprinted by these spots, although in other examples the biotite seems to be aligned in the S_4 direction. This suggests that the spots are late- to post-tectonic in age.

5. HYDROTHERMAL ACTIVITY

5.1 Mineralization

The cassiterite mineralization is hosted in a single set of east-west trending quartz veins emplaced into the schists of the Orusewa Formation. The thickness of the veins is variable, ranging between 10 cm and 3 m. In most instances the veins have been fractured perhaps in response to further pulses of fluid movement. The fractures have been infilled with calcite and/or siderite and haematite.

Generally the veins are sub-vertical, dipping both to the north or south. The cassiterite is present as fractured grains within the veins and fine-grained fresh pyrite and chalcopyrite are also present in accessory amounts. The cassiterite fragments have been cemented together with haematite indicating that the mineralization pre-dates the haematization phase of alteration.

The wall rocks adjacent to the veins have been tourmalinized and there appears to be no direct relationship between thickness of the veins and extent of tourmalinization. Preliminary fluid-inclusion work on quartz vein samples collected suggests a fluid temperature of 245°C with a fluid composition of $KCl + H_2O$ and a salinity of approximately 10 wt. % NaCl equivalent (Pirajno and Smithies, unpubl. data). Since the amount of overburden during vein emplacement is not known, a pressure correction is not possible.

5.2 Alteration

In the mineralized area the host quartz-biotite schists have been pervasively altered, whereas the marbles are only weakly altered and probably acted as a barrier to the hydrothermal fluids. Zoning of the alteration is indicative of several phases of metasomatism and the general paragenesis is sericitization, tourmalinization and haematitization. A late-stage calcitization is also present.

5.2.1 Sericitization

This process was the first to affect the rocks and everywhere within the antiform the original quartz-biotite schists have been sericitized. The sericite is developed as fine-grained lepidoblastic laths together with fine-grained recrystallized quartz and minor tourmaline. The sericite probably replaced the original biotite and feldspar of the schist without affecting the metamorphic texture to any great extent. In places coarser grained (1-2 mm), poikiloblastic muscovite cross-cuts the foliation. Associated with the mica is fine-grained, untwinned calcite which developed during a carbonatization phase after the sericitization.

5.2.2 Tourmalinization

Tourmalinization strongly affected the wall rocks adjacent to the quartz veins. In these rocks fine-grained (<0,1 mm) disseminated tourmaline laths occur with their long axes lying almost parallel to the foliation, and are seen as inclusions completely and partially within the muscovite. In the vein margins the tourmaline laths become coarser grained (1-2 mm), randomly orientated, distinctly pleochroic (pale yellow to almost colourless) and exhibit colour zoning. The metamorphic texture in these rocks has been obliterated. Microprobe analyses show that tourmalines are magnesium-rich (dravite). In places where the quartz veins intrude into the marble, the marble has also been tourmalinized.

5.2.3 Haematization and late-stage calcitization

Haematite was introduced into the rocks with calcite in veinlets which cross-cut all the previously mentioned alteration assemblages. Haematite is present in the veinlets and is also developed as red replacement spots within the wall rocks and as fracture fillings in tourmaline and cassiterite.

5.3 Brecciation

Hydraulic breccias, confined to the marbles, were seen at 20 localities in the mapped area. The size of the breccias is variable with some being a few square metres in surface area, while others crop out over several hundreds of metres along strike. The breccias are spatially associated with altered host rock which is pervasively ferruginized in the vicinity of the breccias, but ferruginization becomes less intense and vein-controlled away from the breccias.

Common characteristics of the breccias are the angular, unrotated, folded fragments of marble. The breccia fragments range in size from a few centimetres to 2 m along their long axes, and have been ferruginized along their rims. The fragments are set in a coarse-grained calcite matrix which in some places has been ferruginized. One kilometre south of the trenches the breccia matrix consists in places of fine-grained recrystallized quartz and calcite with minor fine-grained tourmaline. In outcrop this matrix is black in colour and is resistant to weathering.

It is apparent from field observations that the marble fragments did not move from their original stratigraphic positions. This suggests *in situ* fragmentation of the marble at favourable localities in response to stress release at depth. The nature of the matrix and associated hydrothermal alteration indicates that the sudden pressure release was in response to a build up of hydrothermal fluids at the contact between the schist and the marble. This hydrothermal system is perhaps related to the same system responsible for the mineralization and associated alteration.

6. IGNEOUS ACTIVITY

Two intrusive, dyke-like bodies are present some 500 m north-east of the mineralization. Although different in composition they are both amygdaloidal in places, hydrothermally altered and distinctly cross-cutting.

6.1 Porphyry plug

In the field this intrusion is red in colour due to extensive ferruginization. In places the rock is brecciated and contains fragments of unaltered marble. In thin section this igneous rock is porphyritic with feldspar phenocrysts set in a fine-grained, highly ferruginized matrix of feldspar. In places it exhibits a glomeroporphyritic texture with aggregates of cloudy alkali and plagioclase feldspar phenocrysts. The twinned phenocrysts are euhedral in shape, commonly a few millimetres in length and show some sericitic alteration.

The matrix is microcrystalline and consists of fine-grained feldspar laths and possibly devitrified glass. Unfortunately pervasive ferruginization makes it difficult to identify the phases present in the matrix. Where present, the amygdales have been infilled with secondary minerals and are commonly zoned. The zoning is from quartz at the rims to zeolite and calcite in the centre of the amygdales.

Although misleading, the term trachyte has been applied to the intrusion (De Waal, 1985). The rock resembles a trachyte texturally but field evidence indicates an intrusive rather than extrusive origin.

6.2 Dolerite plug

A dolerite plug outcrops 200 m north of the porphyry plug. This body is larger than the porphyry plug and is altered and friable in hand specimen. Although the rock has been extensively altered, the original igneous texture is retained. The texture is subophitic with generally unaltered, euhedral plagioclase laths (1-2 mm long) partially enclosed by anhedral augite which is largely altered to calcite. The finer-grained portions of the rock consists of fine-grained plagioclase and pyroxene. Anhedral opaque sulphide is present and constitutes a few per cent of the igneous rock. The dolerite dykes elsewhere in the Gamigab area have been similarly altered.

Within the intrusion are fragments of undeformed sedimentary rocks. A conglomerate fragment (>2 m^2) contains well rounded quartz pebbles up to 7 cm in diameter, set in a fine-grained matrix of quartz and feldspar. The smaller, angular feldspar grains are cross-hatched microcline and polysynthetically twinned plagioclase, both of which are slightly sericitized. Accessory hornblende, zircon, muscovite and clay minerals are also present in the matrix. A second sedimentary xenolith (an immature feldspathic greywacke) was found a few metres south of the conglomerate. This rock contains both quartz and feldspar grains cemented by a clay-rich matrix. The grains are poorly sorted, variable in size and are angular to sub-rounded.

The marbles into which the intrusions penetrated have been ferruginized but not extensively, since the marbles acted as a barrier to the fluids. In the area around the intrusions small outcrops of breccia are obscured by scree cover. Where visible, these breccias contain rotated and altered marble fragments set in a fine-grained ferruginous matrix.

7. DISCUSSION

The hydrothermal activity responsible for mineralization, brecciation and alteration post-dated the deformation. Both the breccias and mineralized quartz veins occur either in or directly adjacent to antiformal structures. The fluids were able to intrude up into the antiforms in the schist along planes of weakness (possibly a-c joints generated during deformation) and first altered the country rocks before precipitating the cassiterite and gangue minerals.

Both the porphyry and dolerite plugs have been altered and it can be assumed that the same, or a similar hydrothermal system to the mineralizing one, was responsible. The magma which produced the porphyry plug must have been highly charged in volatiles because of its partially amygdaloidal nature. Both plugs have intruded into the folded metasediments, thus they are post-tectonic and possibly even Karoo in age. If so, then one may speculate that the age of mineralization too may be Karoo.

The other deposits in the northern part of the SKZ have distinctive characteristics (see Petzel, 1986) and these differences are attributed to different levels of exposure of the hydrothermal systems with respect to the underlying intrusions (Pirajno and Jacob, 1986). The mineralization at Brandberg West was probably formed close to a hidden cupola, whereas the Frans, Gamigab and Goantagab deposits were formed at relatively greater distances from their respective parent sources (Pirajno and Jacob, 1986, 1987). This model is supported by vein-temperature estimates from fluid inclusion work on samples collected from the various deposits. Homogenization temperatures for Frans are 250-300°C, Gamigab 245°C and Goantagab 180°C (Pirajno and Smithies, unpublished data).

8. ACKNOWLEDGEMENTS

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