Geology and alteration-mineralization of the Brandberg West Sn–W deposit, Damara orogen, South West Africa/Namibia

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Cassiterite, wolframite, and minor base-metal sulphides at Brandberg West occur in a post-tectonic quartz-vein system, located at the intersection of a circular feature and a north northwest-trending fracture. The veins are emplaced within metasediments of the Swakop Group. Hydrothermal alteration-mineralization is related to three stages of ore-bearing fluids. An early greisenization stage was followed by a quartz-sericite alteration stage, and this was followed by a hematitization stage. The presence of a quartz-albitite plug, mineralogy of the veins, character of hydrothermal alteration, and geochemical data suggest that the source of the mineralization may be a buried, highly differentiated granitic intrusion. The mineralization may be related to late- to post-Karoo magmatic activity.

Kassiteriet, wolframiet, en ondergeskikte sulfiede van onedelmetale by Brandberg-Wes kom voor in 'n na-tektoniese kwartsaarstelsel wat gelokaliseer is by die interseksie van 'n sirkelvormige struktuur en 'n breuk met 'n noordwestelike strekkingsneiging. Die are kom in metasedimente van die Groep Swakop voor. Mineralisasie as gevolg van hidrotermale verandering hou verband met drie stadiums van ertsdraende vloeistowwe. 'n Vroeë stadium van greisenisasie is gevolg deur 'n stadium van verandering na kwarts en serisiet, en dit is weer gevolg deur 'n stadium van hematitisering. Die teenwoordigheid van 'n kwarts-albitietprop, die aard van die hidrotermale verandering en geochemiese data doen aan die hand dat die bron van mineralisasie 'n diepliggende, hoogs gedifferensieerde granitiese indringing mag wees. Die mineralisasie mag verwant wees aan laat- tot na-Karoose magmatiese aktiwiteit.

Introduction and geological setting

The Brandberg West Sn–W deposit is situated in the lower Ugab River area, some 80 km west-northwest of the operating Uis tin mine, and about 45 km west-northwest of the Brandberg alkaline granite intrusion (Figure 1). Mining at Brandberg West commenced in the 1950s, with the underground exploitation of the ore-bearing veins. From 1957, mining continued as an open cast operation, until its final closure in 1980. It is estimated that some 12 000 t of concentrates grading 32 % Sn and 19 % WO_3 were produced (Bowen & Evers, 1985).

The deposit is located in the Southern Kaoko Zone (SKZ), a tectonostratigraphic division in the northern coastal arm of the Damara orogen (Miller, 1983). The geology of various parts of the Zone was mapped and described by Jeppe (1952), Frets (1969), Guj (1970; 1974), Hodgson (1972), Hodgson & Botha (1974), Miller (1973), and Freyer & Hälbich (1983). Other aspects of the geology and structure of the SKZ are discussed by Miller *et al.* (1983), Ahrendt *et al.* (1983), Weber *et al.* (1983), Coward (1983), Porada & Wittig (1983), Porada *et al.* (1983), Weber & Ahrendt (1983), and Porada (1983).

The stratigraphic succession in the study area is shown in Table 1 and the simplified geology in Figure 1. Structurally the area is subdivided into 3 major domains, which are from west to east: Ogden Rocks domain, lower Ugab domain, and Goantagab domain (Freyer, in prep.; Petzel, 1986). Brandberg West is situated in the lower Ugab domain, which consists of north-trending, folded turbidite-facies rocks (metagreywacke and metapelite) with intercalated thin marble bands. These rocks are correlated with formations of the Swakop Group (Table 1) (Miller *et al.*, 1983).

Regional metamorphism in the SKZ is of greenschist to amphibolite facies. This metamorphism is in turn overprinted by contact metamorphism of syn- to post-tectonic granitoids.

The magmatic history of the SKZ and adjacent areas is linked to the tectonic episodes that affected the region during the Pan-African Damara event, and during the later Jurassic-Cretaceous period around the time of re-opening of the South Atlantic ocean. The magmatic products include syn- to post-tectonic Salem-type granitic rocks (Miller, 1983), mafic lavas and dykes of the Karoo sequence, and late- to post-Karoo, alkali ring-type complexes. The eastern portions of the area depicted in Figure 1 are underlain by the Omangambo granitic pluton, intruded during a D_2 deformation, and ranging in composition from adamellite to granite. Miller & Burger (1983) regard these rocks as occupying a key position at the junction of the coastal and intracontinental arms of the Damara orogen. The U-Pb zircon age of the adamellites is 589 ± 40 Ma (Miller & Burger, 1983). The Omangambo pluton was intruded by the post-tectonic Sorris-Sorris granite, whose whole-rock Rb-Sr isochron age is 495 ± 15 Ma, (Miller, 1980; Miller & Burger, 1983). Other syn- to post-tectonic granitoids outcrop west of the Omangambo plutons, south of the Brandberg intrusion, and along the coast.

Rocks of the Karoo Sequence include the predominantly basaltic lavas of the Etendeka plateau in the north, and basaltic lava flows around the Brandberg intrusion and in the south (Figure 1). The Doros complex (K/Ar age of about 125 Ma obtained by Siedner & Miller, 1968) and the Brandberg alkali granite intrusion are part of a series of anorogenic ring-type alkali complexes, which penetrated the Damara orogen during the opening of the South Atlantic ocean and the

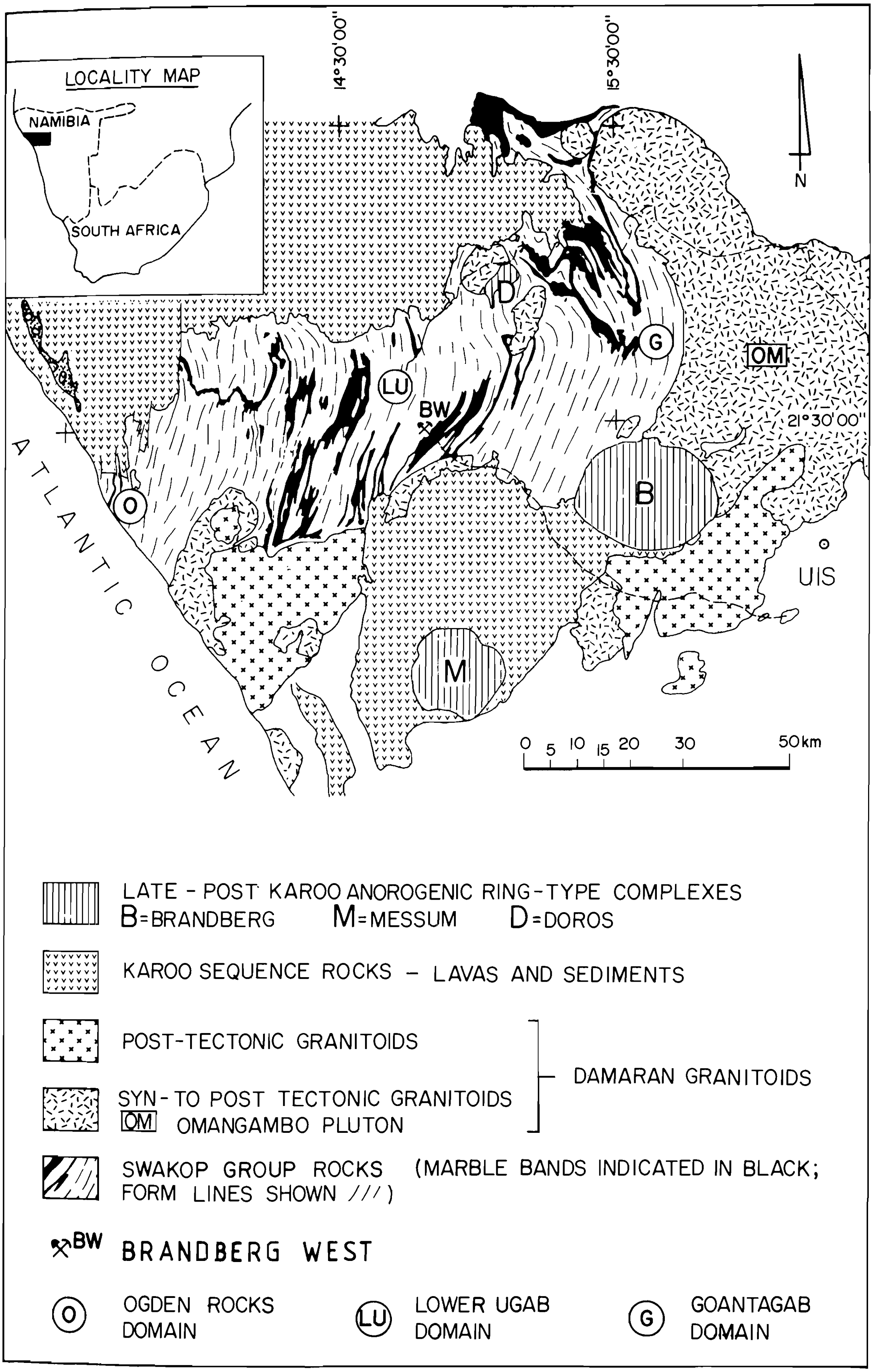


Figure 1 Locality map and schematic geological map of the Southern Kaoko Zone. Adapted from the Geological map of South West Africa/Namibia (1:1 000 000 scale) and from Porada (1983).

Table 1 Stratigraphy of the area around Brandberg West (from Miller *et al.*, 1983)

Swakop Group	Khomas Subgroup	Amis River Fm	Schistose siliceous turbidites, consisting of metagreywacke bases and metapelitic tops	Correlates Kuiseb
		Gemsbok River Fm	Turbidite limestones, impure limestones, schists; yellow to brown in lower $^1/_2$ to $^2/_3$, blue and foetid in upper $^1/_3$	Karibib
		Brak River Fm	Schistose siliceous turbidites, mainly metagreywackes; local conglomerates, isolated boulders	Chuos
	Ugab Subgroup	Brandberg West Fm	Turbiditic limestones, yellow and brown at base, becoming blue at top	Rössing
		Zebrapütz Fm	Schistose siliceous turbidites, mainly metagreywackes	Okonguarri

break-up of Gondwana. These within-plate anorogenic complexes are aligned along northeast trends which are thought to represent old re-activated transform faults (Marsh, 1973). The importance of these complexes in terms of Sn–W metallogeny is discussed by Pirajno & Jacob (1987).

Three major groups of tin deposits are recognized in the Damara orogen (Pirajno & Jacob, 1987). The Northern Group contains the Brandberg West deposit, which is one of several in an area informally named the Brandberg West–Goantagab Sn–W belt. Here, hydrothermal Sn–W and Sn deposits occur in quartz veins and Fe-rich replacement bodies (Pirajno & Jacob, 1986). These authors noted the spatial association of many of the mineralized localities with circular structures and suggested a late- to post-Karoo age for the mineralization. The circular structures are topographic lows and they are marked by zones of brecciation and quartz and carbonate veins. They are being studied currently and are tentatively interpreted as resulting from degassing of igneous intrusions at depth.

This paper outlines the results to date of geological field work, and mineralogical, petrological, and geochemical studies carried out by the authors and post-graduate students from Rhodes University. Their data were augmented by the results of detailed mapping by geologists employed by Gold Fields Namibia Ltd. (Bowen & Evers, 1985).

Brandberg West mining area

Lithology and structure

The Brandberg West quartz-vein system extends for about 4 km in a general northeasterly direction. It was mapped in detail over a distance of 2,5 km (Bowen & Evers, 1985). The open pit is located at the intersection of two circular structures and a north northwest-trending fracture (Figure 2).

The lithologies at Brandberg West consist of two schist units (Zebrapütz and Brak River Formations), separated by a marble unit (Brandberg West Formation) (Table 1). The base of the sequence is the Zebrapütz Formation (also referred to as the Lower Schist, about 500 m thick), which consists of quartz-biotite schists with minor calc-silicate and quartzite layers. This is followed by the Brandberg West Formation, which includes the Lower Marble (about 10 m), overlain by the Brak River Formation (Middle Schist, 350 to 500 m), correlative of the Chuos Formation (Miller *et al.*, 1983) consisting mainly of metagreywacke with intercalated calc-silicate bands.

The Zebrapütz quartz-biotite schist is made up of fine-grained (0,02–0,04 mm) quartz, microcline, plagioclase, and coarser-grained (0,1–0,15 mm) biotite, which defines the schistosity. Mineralogical banding is common as indicated by alternations of biotite-rich and quartz-rich laminae. The thickness of the laminae ranges from 0,05 to 5 mm, and those with dominant biotite may reflect original clay-rich sedimentary partings. Chlorite, calcite, zircon, and muscovite are present in accessory amounts.

Quartzite layers occur within the schist and consist of aggregates of quartz grains (0,05–0,01 mm) with decussate to radiating aggregates of actinolite needles. The quartzites exhibit gradational contacts with the schists.

Calc-silicate rocks, also present within the schist, usually form resistant marker bands. They consist of poikiloblastic diopside, quartz, microcline, plagioclase, and minor to accessory amounts of epidote, sphene, apatite, and calcite.

The marble of the Brandberg West Formation is bluish-grey in colour, medium- grained and massive. It consists of a mosaic of calcite grains averaging 0,05 mm

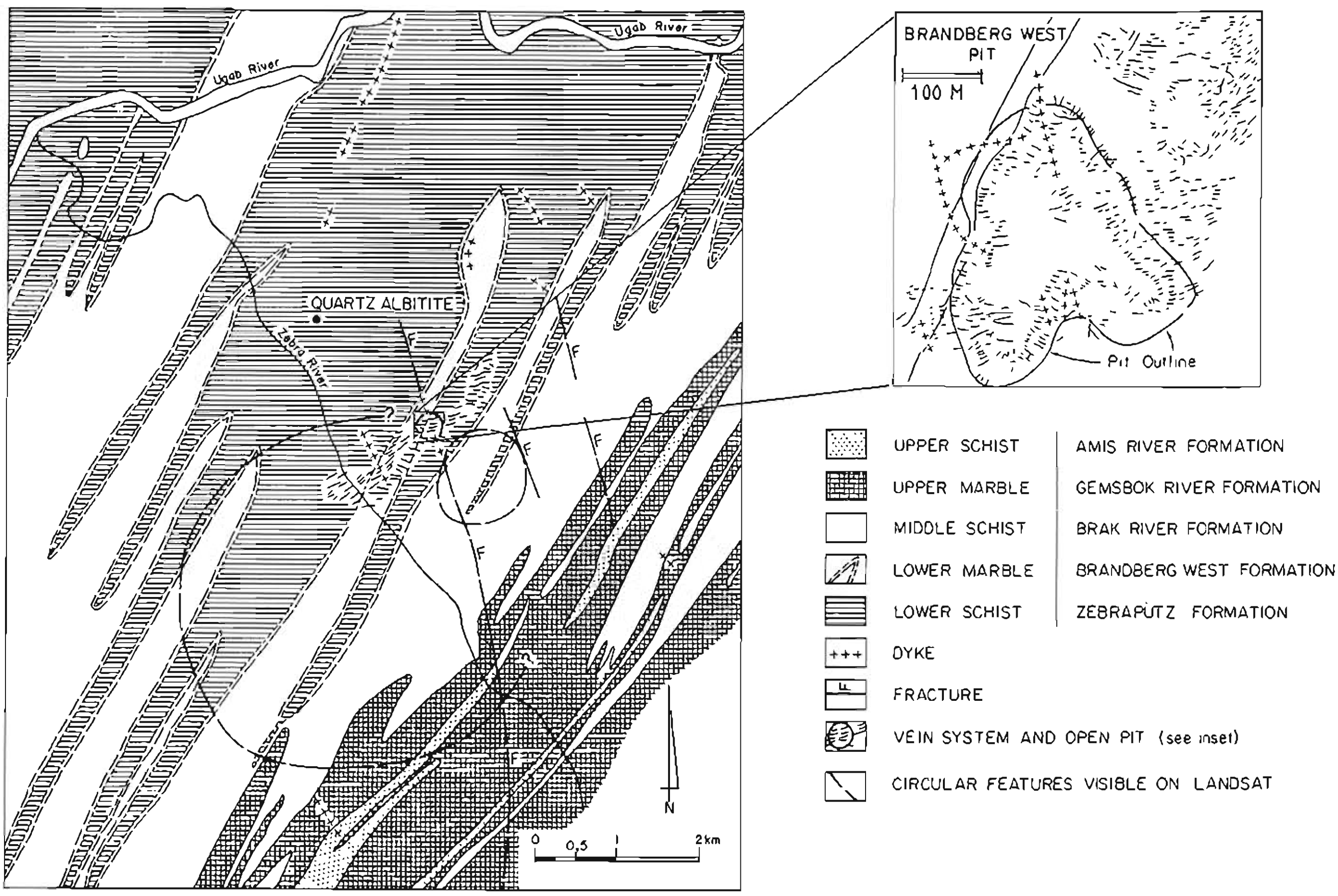


Figure 2 Schematic geological map of the area around Brandberg West, showing the mineralized vein system. Adapted from Petzel (1986).

in diameter with quartz, white mica, epidote, and diopside as accessory minerals.

About 2 km northwest of Brandberg West open pit is a small outcrop originally described as an acid lava pipe (Jeppe, 1952). This rock is in fact a quartz-albitite, which probably results from the late- to post-Karoo magmatism. The quartz-albitite 'plug', consists of a felted mass of albite with anhedral quartz grains and perthitic K-feldspar, which is largely replaced by albite. The rock has numerous miarolitic cavities. In places these contain euhedral K-feldspar along the margins, but generally contain quartz and calcite (Figure 3). These features (replacement by albite and presence of cavities) are indicative of Na-metasomatism followed by CO_2-rich volatile activity within a continuously evolving system associated with a cooling magma.

The regional structure of the lithologies at Brandberg West is shown in Figure 2. The folds are tight, isoclinal in places, and are generally overturned towards the west (a feature of the SKZ — Miller, 1983). Axial planes trend approximately NNE. Freyer (in prep.) has recognized at least 3 folding phases in the Lower Ugab Domain, where the major NNE trending folds are of D_1 age. In places these are deformed by the D_2 folding which produced folds of similar trend but different axial-plane dip. Although no F_2 folds are observed in the Brandberg West area the associated axial-plane foliation, S_2, is developed as a crenulation cleavage. Late F_3 folds can be recognized on regional geological maps and LANDSAT imagery as open *en echelon* east to northeast-trending flexures (Miller, 1983). The open pit area is located on the western limb of an F_1 antiformal structure (Figure 4).

Wall-rock alteration

The open pit area provides a 'window' into the effects of hydrothermal alteration-mineralization on the host lithologies. Textural evidence from thin- and polished

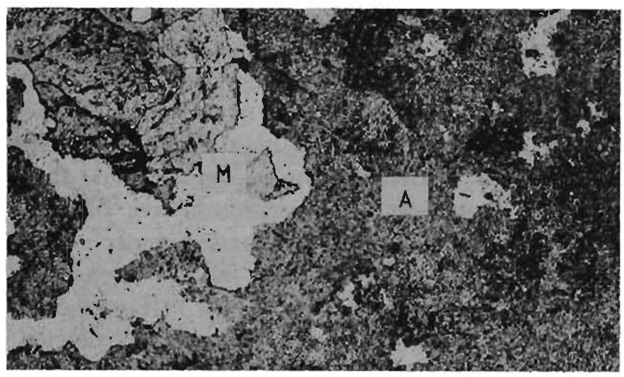


Figure 3 Photomicrograph of quartz-albitite. This rock is made up of a fine-grained felted aggregate of albite + quartz (A) and miarolitic cavities filled with carbonate and quartz (M). Width of field is approximately 3,5 mm. Crossed nicols.

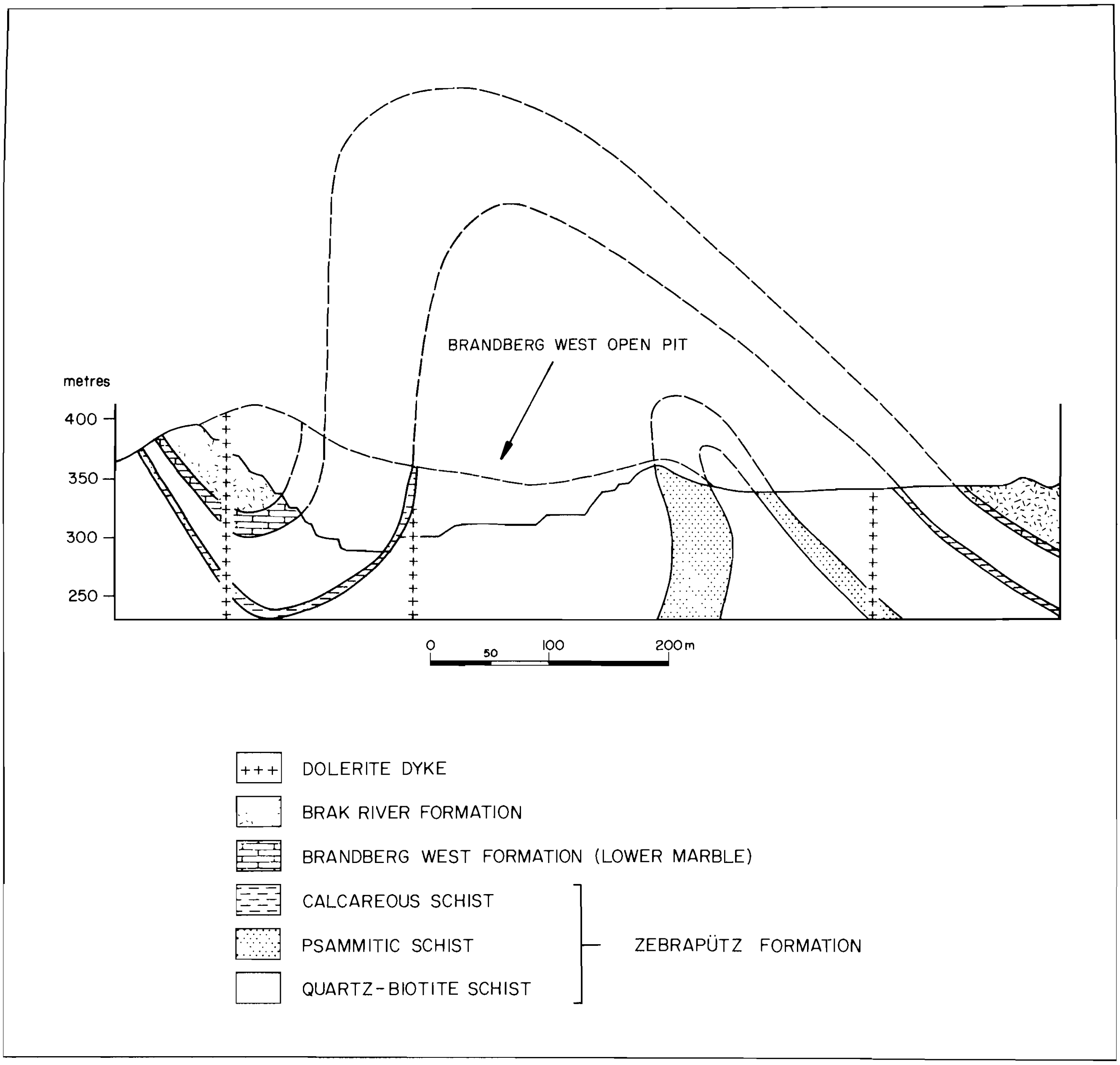


Figure 4 East-west cross-section across Brandberg West open pit. Modified after Townshend (1985).

thin-section studies reveals the presence of a number of temporally distinct events, which have resulted in diverse alteration and ore mineral assemblages. In order to avoid confusion, these have been classified according to the predominant minerals present. The distribution, in the open pit, of the 3 main types of alteration is shown in Figure 5. Although the alteration-mineralization events resulted in overprinting in most places, three areas were chosen as being representative of these alteration types, based on the predominance of the relevant mineral assemblages. These areas are designated 1, 2, and 3 and are shown in Figure 5 A. Quartz-biotite schists are the rocks most affected, whereas the marbles are altered only weakly as they probably acted as a barrier to the hydrothermal fluids. Alteration of the marbles is present only at the base, and along zones of weakness, where talc, tremolite, and locally hematite, are developed.

A tentative sequence of events is summarized in Table 2 and briefly discussed below. The oldest event is the emplacement of early quartz veins with tourmalinization of the wall rocks. These may be related to granites of Damara age because they show evidence of Damaran deformation (vein set 1 in Table 3). At some later time this was followed by a post-tectonic thermal event that produced dark spots, containing biotite and perhaps Fe oxides. The dark spots overprint all previous strain fabrics in the rocks. This type of thermal metamorphism is possibly related to intrusion of a granitic body, which could also be the source of the mineralizing fluids. Wall rock alteration commenced with the development of biotite poikiloblasts around fractures, which were latter filled by quartz veins (Figures 6 and 7). These biotite poikiloblasts also overprint all strain fabrics, and they are interpreted as the result of K-metasomatism. It is worth noting that in other parts of the Brandberg

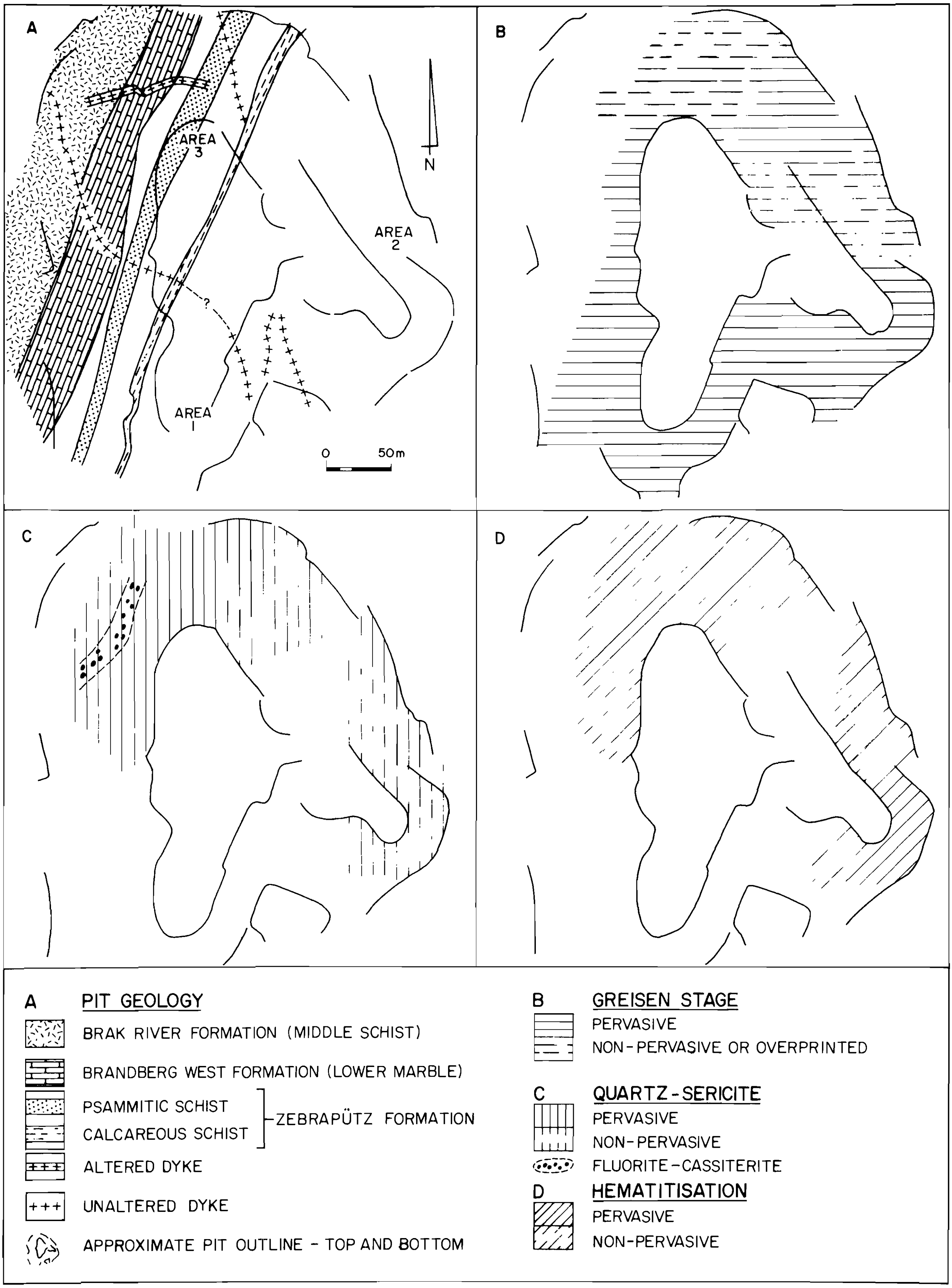


Figure 5 Sketches of the Brandberg West open pit showing geology (A), and patterns of surface alteration (B, C, and D). Modified after Elliott (1985).

Table 2 Sequence of alteration-mineralization at Brandberg West, based on mineralogical and petrological studies and field relationships

Event	Mineral assemblages and remarks
A. Early veins	Quartz + tourmaline + muscovite
B. Thermal metamorphism	Spotting of quartz-biotite schist; local recrystallization
C. Stages of alteration-mineralization	
1. K-Metasomatism	Fracture-controlled biotite poikiloblasts overprint all previous fabrics
2. Greisen stage	
a. Wall rocks	Commonly muscovite and tourmaline growths Fracture-controlled
b. Vein and vein margins	Quartz + muscovite ± wolframite ± cassiterite (?)
Fracturing and dyke emplacement along E–W trends	
3. Quartz-sericite stage	
a. Vein re-opening	Quartz + muscovite ± tourmaline ± cassiterite
b. Wall rocks	Quartz + sericite ± cassiterite ± fluorite
4. Hematite-sulphide stage	
a. Vein re-opening and wall rocks	I Hematite ± cassiterite ± tourmaline II Sulphides, graphite
b. Vein and wall rocks	Carbonates
Dyke emplacement along northerly trends cross-cutting all veins and altered wall rocks	

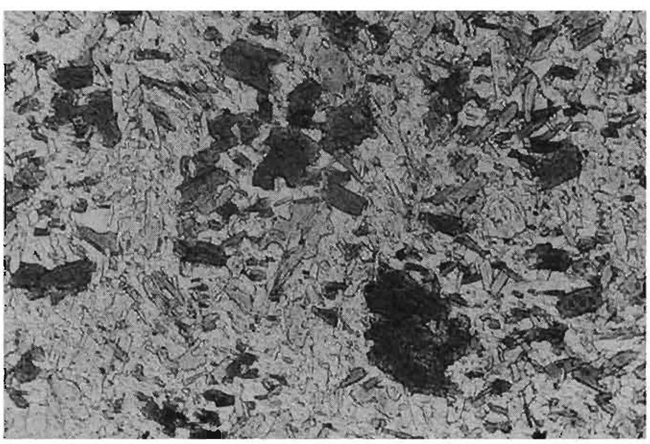


Figure 6 Biotite poikiloblasts in quartz-biotite schist. Width of field is approximately 3,5 mm. Plane polarized light.

West–Goantagab area both post-tectonic thermal metamorphism (spotting) and K-metasomatism (biotite growth) are spatially associated with the circular structures mentioned earlier (Pirajno & Jacob, 1987).

Growth of biotite was followed by hydrothermal alteration which produced an assemblage mainly consisting of quartz, muscovite, and tourmaline. This is regarded as a greisenization phenomenon and referred to as the greisen stage in Table 2. In Area 1 (Figure 5 B) the greisen stage assemblages are largely unaffected by later alteration. This alteration is fracture controlled and generally confined to within a few metres of the vein margins. However, the width of the alteration halo has no relation to the width of the veins. A diagrammatic representation of this alteration is depicted in Figure 7. Veins were emplaced during a later pulse and these have a selvage of muscovite and contain wolframite and cassiterite as large crystals (Figure 7). Greisenization is a process which is also commonly accompanied by sodium metasomatism in Sn–W systems (e.g. Taylor, 1979). This is not a feature of the alteration-mineralization at Brandberg West at the present level of exposure. However, evidence of albitization may be found in the quartz-albitite plug referred to earlier.

A fracturing event followed this stage and was particularly intense in the northern part of the pit. The fractured wall rocks, being more permeable, allowed the influx of hydrothermal fluids, with further vein emplacement and re-opening of older veins. Two hydrothermal alteration stages can be recognized. The first and older (stage 3, Table 2), is characterized by pervasive (Area 3) and non-pervasive (Area 2) quartz + sericite alteration (Figure 5 C, and Figure 8). In Area 3, pervasive sericitic alteration is accompanied by disseminated cassiterite and fluorite, particularly near and along the marble-schist contact (Figure 9). These minerals can be observed to replace the earlier greisen assemblage along grain boundaries, cleavages, and microfractures in areas of non-pervasive alteration.

Stage 4 is represented by pervasive (Area 2) and non-pervasive (Area 3) hematitization (Figure 5 D). Hematite veinlets in Area 3 cross-cut the quartz + sericite assemblage and also contain tourmaline and

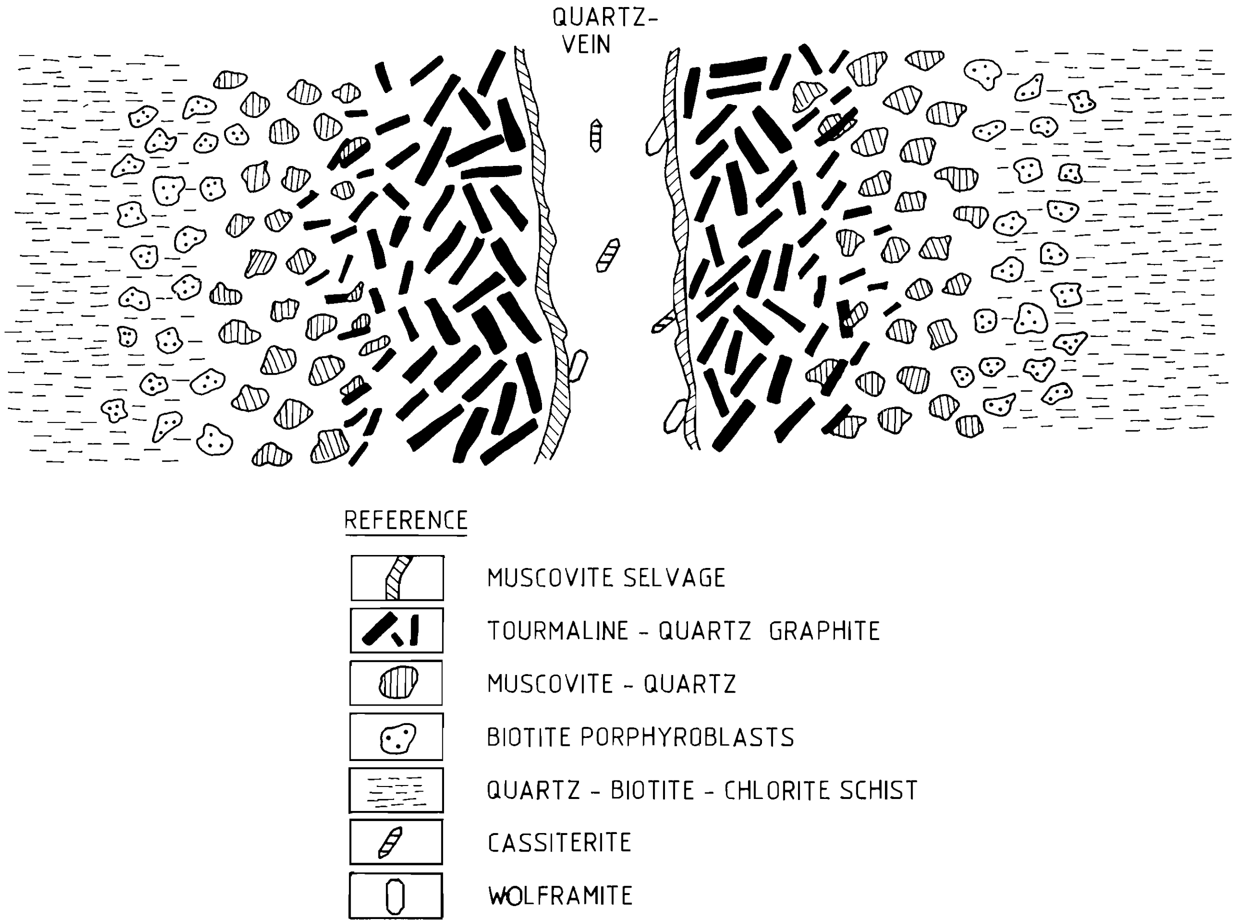


Figure 7 Diagrammatic respresentation of the alteration of quartz-biotite schist adjacent to a mineralized quartz vein.

cassiterite crystals. In a later pulse, sulphides and graphite were deposited in the fractured veins and wall rocks. Sulphides predominantly occur in Area 3, whereas graphite appears to be dominant in Area 2, where it occurs both in the vein quartz and in the vein margins, together with tourmaline. The last pulses of hydrothermal activity are represented by late cross-cutting carbonate veinlets.

This reconstructed and tentative sequence of events was punctuated by at least two episodes of fracturing and mafic dyke emplacement. The first followed the greisen stage, with the emplacement of an east west-trending dyke, which was subsequently affected by hydrothermal stages 2 and 3 (Figure 5 A, Figure 10). The later dolerite dykes with a northerly trend (Figure 5 A) cut across all stages of alteration-mineralization and quartz veins.

Quartz veins and mineralization

Mineralization is predominantly associated with sheeted vein systems, which, in the area around the pit (inset, Figure 2), were traced by detailed mapping along a zone some 900 m long and 300 m wide (Bowen & Evers, 1985). The quartz veins generally occur in the quartz-biotite schist of the Zebrapütz Formation, and most terminate against the overlying lower marble unit (Brandberg West Formation; see also Figure 2, inset). The quartz veins have variable strikes, lengths, and thicknesses, and frequently the same vein set can be seen to be refracted when cutting through different lithologies. Five vein sets were recognized, whose general features are summarized in Table 3. The table is based on mineralogy, morphology, orientation, age relationships, and detailed structural and geological mapping (Bowen & Evers, 1985; Townshend, 1985; Petzel, 1986). One set is of Damara age (quartz + tourmaline) and is not mineralized. The other four sets all cross-cut Damara strain fabrics and are mineralized to varying degrees. The veins were formed during at least 3 pulses of ore-bearing fluids and are related to the alteration stages described earlier. Correlation between vein sets and individual alteration-mineralization stages is difficult, because the same sets were re-opened during subsequent stages. The greisen stage generally accounts for most of the vein sets (II to IV, Table 3). Set V is the youngest and was formed during the hematite stage.

The vein mineralogy is varied and complex. Quartz constitutes from 70 to 95 per cent of the vein minerals, it is usually highly fractured, and accompanied by muscovite, K-feldspar, tourmaline, fluorite, graphite, beryl, apatite, and sulphides (pyrite, chalcopyrite, sphalerite, stannite, pyrrhotite, galena, and marcasite). Oxide ore minerals are cassiterite, wolframite, scheelite, hematite, and goethite. A typical ore-bearing quartz vein is usually, though not always, bounded by a selvage

Table 3 Details of vein sets at Brandberg West

Vein set	Attitude	Host rock	*Mineralized †Unmineralized	Description
I	Strike 005–015	Best development in schist units	†	Veins usually occur as vein swarms and range in thickness between 2 m and 2 cm. They are boudinaged by extension parallel to foliation, and may be folded on a minor scale. Typically they comprise mainly quartz and minor muscovite, and tourmaline.
II	NE–SW trend	Schist	*	Veins generally less than 1 cm. The most distinctive feature is the presence of cross-cutting tourmaline-filled dilation features, giving the veins a laddered appearance. A halo of up to 1 m of wall rock tourmalinization occurs next to the vein.
III	Strike 045–075 dip 70 SE–60 NW	Quartzite units	*	The veins are 10–40 cm thick and contain quartz, fluorite tourmaline, calcite, various secondary Cu and Fe minerals ± wolframite, ± scheelite. A muscovite-rich selvage is generally present.
IV	Strike 025–045 dip 65 SE–80 NW	Schist	*	Veins have similar characteristics to vein set II.
V	Strike 118 dip 72 NE	Mainly schist units	*	Veins are in general thin, cross-cut vein systems III and IV, and are therefore younger. They run parallel to the main shear system which is also exploited by dolerite dykes. Carbonate-filled shears follow the same direction. The vein mineralogy varies along strike of the individual veins from a siderite + calcite assemblage to a quartz-hematite-tourmaline ± cassiterite assemblage. Tourmalinization is well developed in the host rock adjacent to the veins.

zone, up to 0,2 m thick, consisting of muscovite and quartz. Fluorite, topaz, hematite, and cassiterite may also be present. The selvage zone generally grades into the wall rock through a tourmaline-rich zone consisting of poikiloblastic tourmaline and quartz, (Figure 7). Lithogeochemical work over the entire length of the Brandberg West vein system (see Figure 2) by Bowen & Evers (1985), established a zonation from low Sn:W ratios in the northeast to high Sn:W in the southwest.

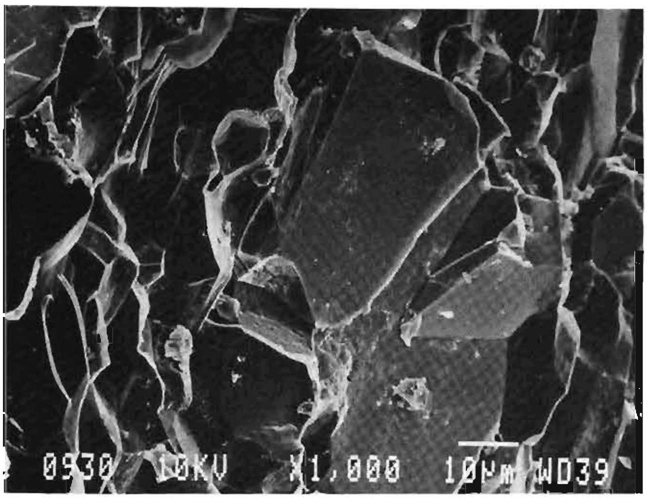
Wall-rock geochemistry

Samples were taken from selected 'vein traverses' [vein, immediate wall rock (i.e. vein margin) and wall rocks up to 6 m away], for geochemical analyses of major and trace elements.

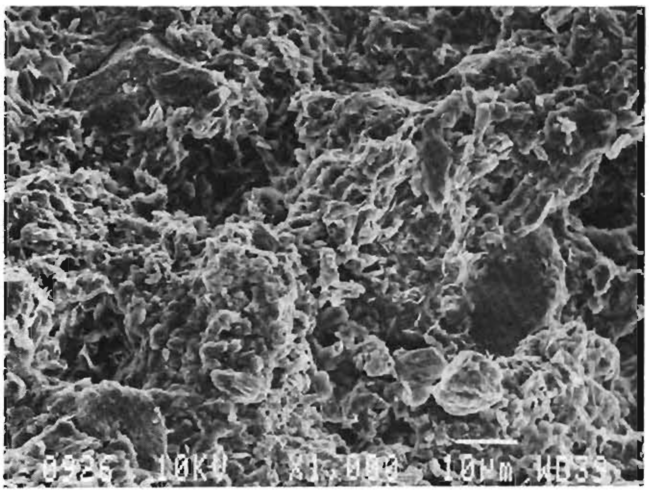
Results are presented in Figures 11 and 12 as diagrammatic summaries of element variations. Whole-rock analytical data are presented in Table 4 and semi-quantitative mineral analyses in Table 5. The mineral analyses aid in the interpretation of whole-rock geochemical variations.

Figure 11 depicts variations in major oxides, and trace elements respectively around mineralized veins formed during the greisen stage in Area 1, which here represents a single-stage alteration effect.

Geochemical trends from wall rocks towards vein margins and vein selvages (from weak to strong greisenization) are characterized by depletions of Na_2O, Fe_2O_3, Al_2O_3, MgO, and TiO_2, and by enrichments in SiO_2, MnO, CaO, K_2O, and P_2O_5. These variations may be accounted for by the decrease in biotite and tourmaline and increase in quartz and muscovite from the wall rocks towards the vein selvages. The CaO enrichment is readily explained by the presence of fluorite in the vein margins and selvages. The distribution of trace elements (Figure 11 B) indicates a general enrichment of the metallic elements from the wall rocks towards the mineralized veins. Pb and Zn are concentrated at the vein margins, in contrast to Bi, Cu, W, and Sn which attain their highest values in the vein quartz. F and Rb enrichment at the vein margins and selvages is due to fluorite and muscovite, respectively. Y is also enriched at the vein margins and selvages, and this too may be due to the presence of fluorite, since Y is an element which has a pronounced affinity for P and F (note also the P_2O_5 peak in the same area).



(A)



(B)

Figure 8 SEM photomicrographs of unaltered quartz-biotite schist (A) and quartz-sericite altered schist (B).

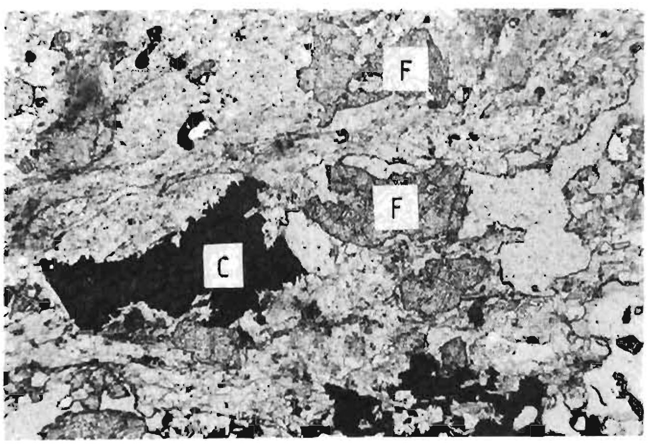


Figure 9 Quartz-sericite rock with fluorite (F) and cassiterite (C). Width of field is 3,5 mm. Plane polarized light.

A plot of Na_2O versus K_2O is shown in Figure 12. This diagram shows that each alteration stage is characterized by distinctive fields. The greisenized rocks show Na_2O and K_2O enrichment relative to the sericitized rocks. The latter display a great variation in their K_2O content at more or less constant Na_2O. High Na_2O in the greisenized rocks is probably a reflection of tourmaline content. The range in K_2O in the sericitized rocks is a function of modal quartz and sericite.

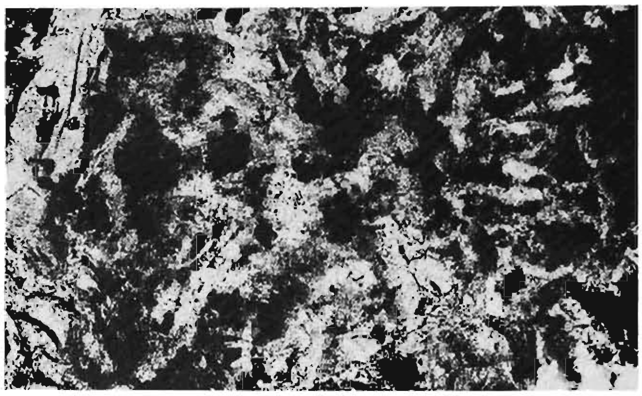


Figure 10 Altered mafic dyke. Plagioclase laths are entirely replaced by sericite and groundmass by hematite mainly. Width of field is approximately 1,0 mm. Crossed nicols.

Conclusions

A feature of the Sn–W mineralization in the Brandberg West–Goantagab area is the common association of the mineralization with circular structures (Pirajno & Jacob, 1987). The Brandberg West deposit exemplifies this. The extent of the Brandberg West vein system (Figure 2) indicates that hydrothermal acitivity must have been operative on a large scale. The northeast-trending vein system transgresses the lithologies (Figure 2) and was formed mainly during the greisen stage (Table 2). Stages 3 and 4 of the hydrothermal activity are best developed in the open pit and were controlled by the intersection of the north northwest-trending fracture, the circular structure, and the north northeast-trending marble band of the Brandberg West Formation, which acted as a barrier to the fluids.

The character of the alteration-mineralization is consistent with a granitic source. The phenomenon of greisenization is associated particularly with highly differentiated and geochemically 'specialized' granitic intrusions. During this process a series of geochemical and mineralogical changes occur in both the granites and surrounding host rocks. The main feature of greisenization at Brandberg West is the alteration of quartz-biotite schist into an assemblage of quartz, muscovite, and tourmaline. This type of greisenization presumably occurred above a hidden body of greisenized granite (endogreisen). There is no clear indication of the depth of this body at this stage. However, alteration stages 3 and 4 (Table 2) in the northern part of the open pit and the decreased Sn:W ratio towards the northeast indicate that this part of the vein system is closer to the granitic source. Further evidence of a granitic source for the vein system is provided by the quartz-albitite plug.

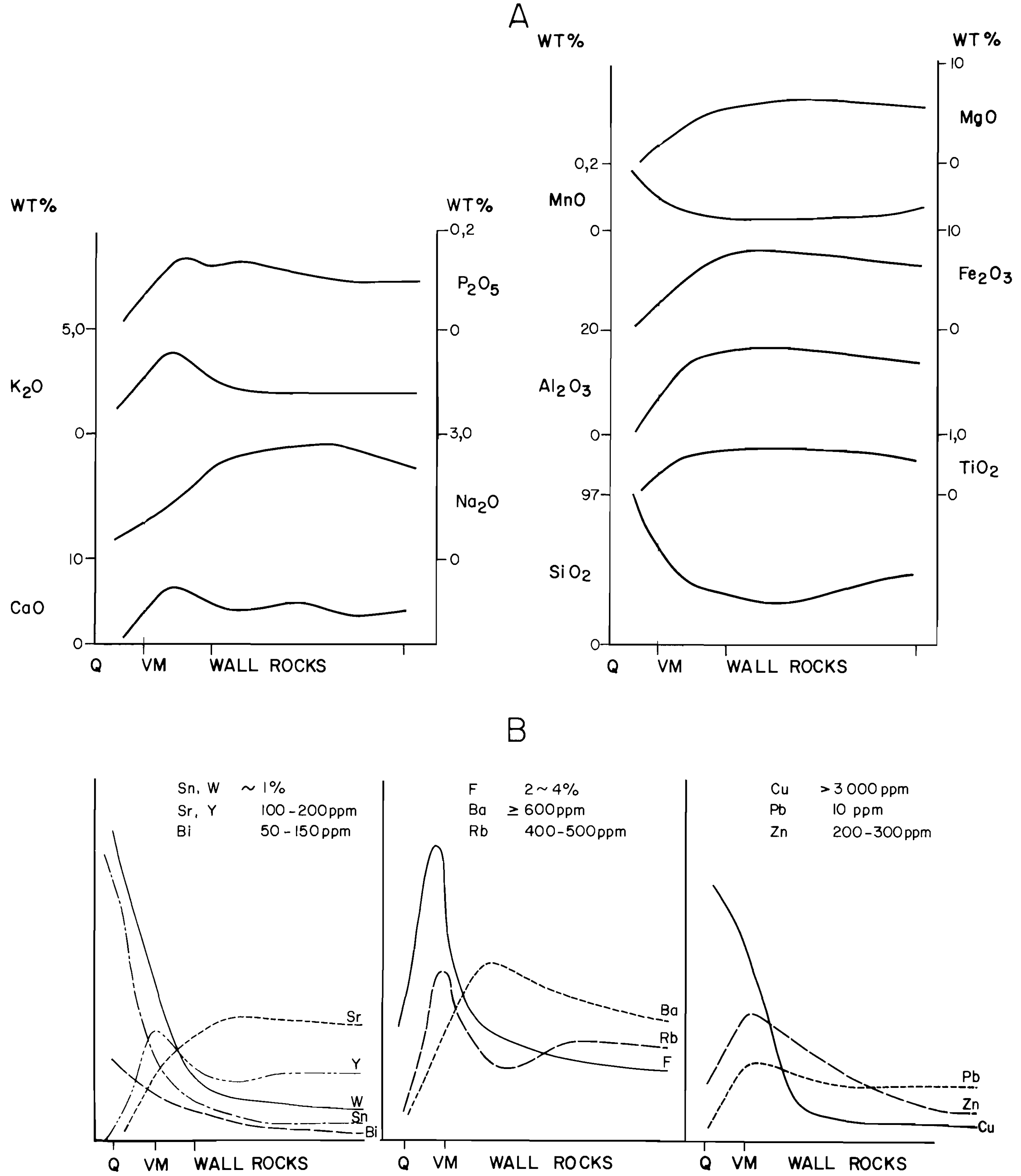


Figure 11 Diagrammatic summary of (A) major-element, and (B) trace element distribution trends around mineralized veins, based on averages of 3 sampling traverses in Area 1 (greisen stage). Element concentrations in diagram (B) indicate approximate peak values for each element. Q = quartz vein ; VM = vein margin.

Albitites are commonly associated with Sn–W bearing, highly differentiated igneous intrusions (Taylor, 1979). Elsewhere in the Damaran orogen, albitites containing W ± Sn mineralization occur as part of a boron-rich granitic phase of the Erongo caldera complex, which is of late- to post-Karoo age.

The Brandberg West mineralized veins and late thermal metamorphic overprinting are post-tectonic with respect to Damara strain fabrics. There are only two possible magmatic events that can account for those features. One would be a post-tectonic Damara granite and the other a late- to post-Karoo granite, which would

Table 4 Major and trace element analyses of vein (QV), vein margins (VM), and wall rocks (WR) in area 1. Major elements expressed in weight per cent; trace elements expressed in parts per million, unless otherwise stated.

Sample No	7821	7822	7823	7824	7825	7826	7827	7808	7809	7810	7811	7812	7813
Area	1	1	1	1	1	1	1	1	1	1	1	1	1
Rock type	QV	VM	WR	WR	WR	WR	WR	WR	WR	WR	WR	VM	QV
SiO_2	97,30	56,20	56,40	55,40	51,00	56,50	57,00	56,00	56,30	53,20	54,00	53,10	78,20
TiO_2	0,00	0,74	0,86	0,84	0,77	0,84	0,80	0,81	0,80	0,73	0,81	0,70	0,10
Al_2O_3	0,12	16,50	17,50	17,60	20,50	17,60	16,70	18,30	17,50	16,20	18,60	18,10	7,93
Fe_2O_3	0,92	6,90	8,24	8,22	8,75	8,64	8,33	7,47	7,55	7,45	8,01	5,79	2,90
MnO	0,02	0,14	0,04	0,04	0,03	0,02	0,10	0,13	0,15	0,04	0,15	0,14	0,94
MgO	0,30	4,30	5,40	5,80	5,80	5,80	5,50	5,10	5,00	4,80	5,20	4,20	1,00
CaO	0,17	6,72	3,87	4,13	4,01	2,76	3,50	2,43	2,85	5,12	2,34	7,31	4,85
Na_2O	0,00	0,80	2,00	1,70	2,20	2,40	2,10	1,70	1,70	1,30	1,50	0,20	0,00
K_2O	0,02	3,83	3,76	3,65	4,30	3,83	3,32	3,72	3,67	3,76	3,85	5,20	2,21
P_2O_5	0,00	0,20	0,19	0,20	0,19	0,16	0,17	0,15	0,16	0,16	0,18	0,16	0,04
L.O.I.	0,47	2,87	0,98	2,00	1,28	1,31	2,21	3,43	3,51	6,40	4,48	4,29	2,48
Total	99,32	99,20	99,24	99,58	98,83	99,86	99,73	99,24	99,19	99,16	99,12	99,19	100,65
Cu	3600	1310	70	60	150	45	50	80	70	50	45	525	360
Pb	10	11	10	9	8	6	9	10	7	13	11	12	8
Zn	55	185	175	150	180	160	140	155	150	1410	160	100	75
Sn	449	240	15	15	84	15	15	21	13	15	33	219	129
W	8700	311	98	90	60	18	25	20	25	35	100	140	54800
Bi	117	19	19	15	18	17	14	14	14	15	14	20	46
Sr	18	126	202	213	227	193	177	152	158	136	165	69	49
Rb	5	432	176	189	274	253	247	286	282	302	334	503	283
Ba	30	358	600	559	714	587	473	538	554	455	497	595	195
Zr	26	147	170	147	188	144	151	162	148	143	149	144	34
Y	15	130	70	71	98	93	86	96	92	102	110	155	124
F	420	41500	980	1000	4900	980	920	2250	2050	1550	2200	29800	16500

Trace element analyses of samples 7808 to 7813, 7821 to 7827 performed by Scientific Services Ltd., Windhoek. All other analyses performed by Bergström and Bakker, Johannesburg. The sum total of Bergström and Bakker analyses includes F. Analytical techniques used were: XRF on fusion disc for major elements; XRF on pressed disc for trace elements; F was analysed by specific ion electrode. All Fe expressed as Fe_2O_3.

be part of the anorogenic magmatism related to the Gondwana break up (Figure 1). Evidence at Brandberg West indicates that the greisen stage mineralization occurred before the emplacement of dolerite dykes which are acknowledged to be of Karoo age. Alteration of Stages 3 and 4, however, postdates the hydrothermally altered east west-trending dyke and is in turn cut by north northwest-trending dykes. Ages of Karoo dyke emplacement in South West Africa/Namibia range from about 190 to 125 Ma (Siedner & Miller, 1986). We conclude that the Brandberg West mineralization may be related to the late- to post-Karoo anorogenic magmatism.

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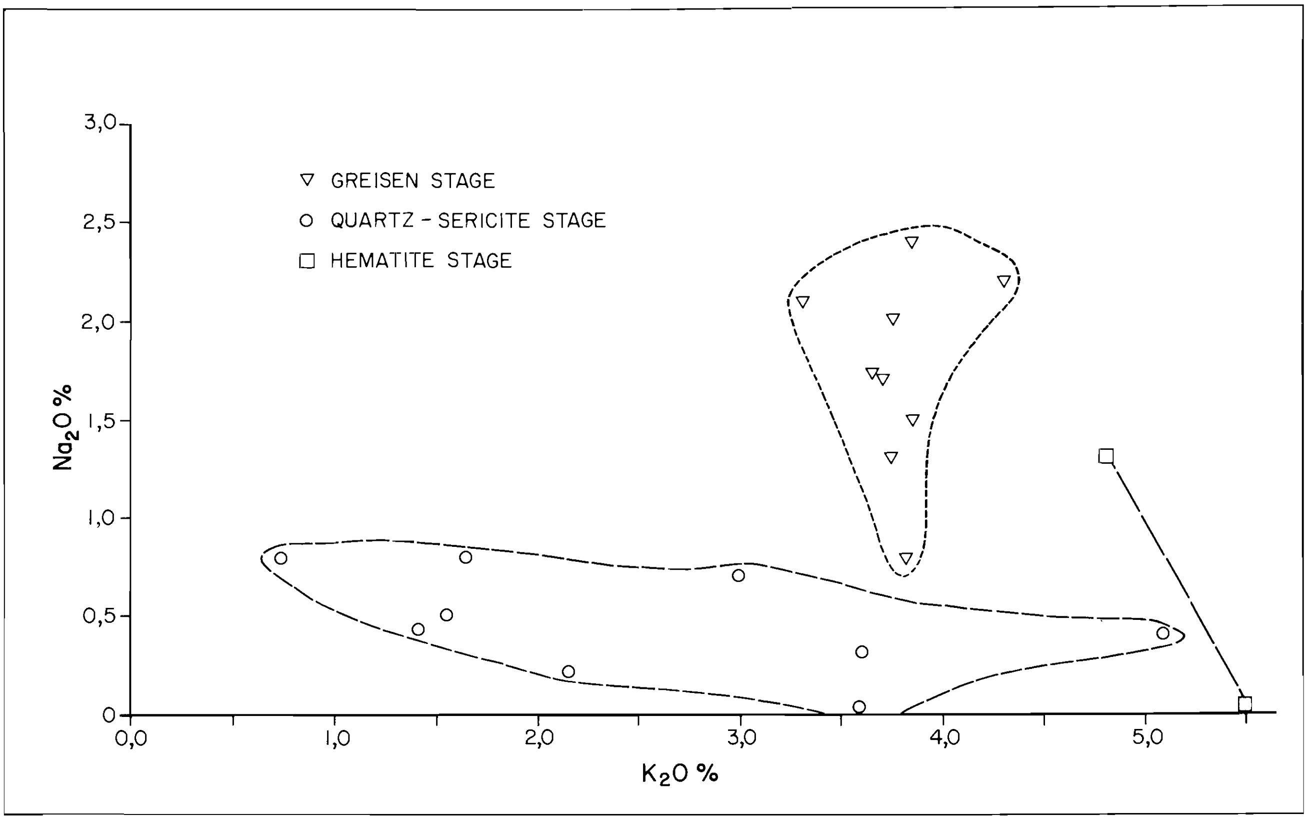

Figure 12 Plot of Na_2O versus K_2O for altered wall rocks at Brandberg West.

Table 5 Semiquantitative spectrographic analyses of selected vein minerals. After Markham (1959)

WT%	+10%	1–10%	0,1–1%	>0,1%
Muscovite	Al, Si	Fe, Mg	Ca, Sn	Bi, B, Cr, Cu, Pb, Mn, Mo, Ag, Sr, Ti, W, Cl
Tourmaline	Al, Si, B	Ca, Fe, Mg	Mn, Sn, Ti	Be, Cr, Cu, Pb, Li, Ni, Sr, Zn
Fluorite	Ca, F	Fe	Al, Cu, Si, Sn	Be, Bi, Pb, Mg, Mn, K, Ag, Sn, W, V
Cassiterite	Sn	Fe	Al, Ca, Mg, Si, Ti	As, Ba, Be, B, Cr, Cu, Mn, Sr, W, V
Wolframite	Fe, W	Mn, In	Ca, Cu, Mg, Si	Al, Ba, Cd, Au, Mo, Nb, P, Ag, V, Zn
Scheelite	Ca, W	–	Al, Cu, Fe, Mg, Si	Be, Bi, B, Cr, Au, Pb, Mn, Mo, P, Sr, Ta, Sn, V

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