4. The Lebowa Granite Suite.

4.1. Field Relationships.

The Lebowa Granite forms a sheet-like composite pluton which underlies the Stavoren Granophyre and overlies the layered mafic rocks. In this area it is composed of various Klipkloof Granite types and the Nebo Granite. The Klipkloof types of granite are best developed in the northern and north-western sector, whereas Nebo Granite occurs throughout the larger part of the area. This is therefore an ideal area to study the relationship between Nebo- and Klipkloof Granite, and the relation of these granites with the overlying granophyres.

The variety of rock types which form part of the Lebowa Granite Suite in this area are listed in Table 4.1.

4.1.1. The Nebo Granite.

The Nebo Granite with an age of 2052 ± 48 Ma (Walraven 1982) intrudes the Stavoren Granophyre dated at 2084 ± 62 Ma (Walraven et al. 1981). This intrusive relationship was observed at various localities, e.g. in a riverbed (29°30'W, 25°15'S) on Rietkloof 166JS. The contact of Nebo Granite with Stavoren Granophyre is sharp, but may be gradational in places, as for instance on Mooiplaats 121JS, where a coarse-grained granophyric granite marks the transition between the two rock types.

The escarpment of the Sekhukhune Plateau is formed by Nebo Granite, overlain by granophyre and then by felsite. Where mafic rocks are present, Nebo Granite is not developed beneath the Stavoren Granophyre.

Due to a lack of outcrop in the low-lying areas, the exact contact between the Nebo Granite and the rocks of the Layered Suite on Weltevreden 165JS could not be found.

Table 4.1. The various rock types of the Lebowa Granite Suite in the area, listed in chronological order.

LEBOWA GRANITE SUITE	Klipkloof Granite	**Fine- to medium-grained:** (a) <u>aplite dykes</u>: Intrusive into all the Klipkloof Granite types as well as the Nebo Granite. Extremely leucocratic, fine-grained and albitized granite. Fluorite contents is variable. Contains pegmatite lenses and tourmaline spheroids. Sharp contact with other varieties. (b) <u>aplite sheets</u>: Developed at different horizons in upper part of the Nebo Granite. Tourmaline spheroids are present if the granite is albitized. Clots of biotite and pegmatite lenses are developed. The amount of fluorite varies. Granophyric intergrowth is common. Intrusive into Nebo Granite.
		Porphyritic: Perthite(2-8 mm) and quartz(2-5 mm) phenocrysts in a fine-grained groundmass. Grey to red coloured. Granophyric intergrowth present. High concentration of white fluorite. Gradational contact with aplite sheets and sharp contact with aplite dykes.
		Medium- to coarse-grained: Leucocratic granite with high fluorite content. Always red coloured. Mafic minerals altered to chlorite. Interlocking quartz grains. Pegmatite lenses. Gradational contact with Nebo Granite.
	Nebo Granite	Coarse-grained grey to red granite with red varieties common in the upper parts of the sheet. Decrease in mafic mineral content and grain size from bottom to top in the sheet. Increase in biotite/hornblende ratio and fluorite content from bottom to top. Intrusive into Stavoren Granophyre. Intrusion breccia in Rustenburg Layered Suite.

Hereabout the lowest stratigraphic portion of the Nebo Granite in the whole area is exposed. On the farm Tussenin 21JS in the north-western part of the area the stratigraphically highest portion of the Nebo Granite occurs.

A mineral gradation characterizes the Nebo Granite sheet, wherein the amount of hornblende, the hornblende to biotite ratio, and the total mafic mineral content all decrease from bottom to top. The amount of free quartz and fluorite displays a concomitant increase, whilst the grain size shows a corresponding decrease upwards through the Nebo Granite sheet.

An intrusion breccia of a medium-grained hornblende granite into mafic rocks of the Layered Suite on Rietkloof 166JS (Fig.4.1) probably represents the least differentiated Nebo Granite magma recognized in the area (Chapter 6).

4.1.2. The Klipkloof Granite.

The Klipkloof Granite, the youngest member of the Lebowa Granite Suite in the area mapped, has been dated at 2036 ± 50 Ma (Walraven et al. 1981). Several different textural types are present. They include fine- to medium-grained equigranular and porphyritic types, which are reddish, grey or white coloured and may contain clots of biotite and pegmatite lenses. These granites are closely related to the Nebo Granite and seem to constitute a highly fractionated aplitic phase of the latter.

The Klipkloof Granite occurs in the stratigraphically higher portions of the Nebo Granite sheet, where it forms undulating flat-lying sills as well as dykes and veins which are intrusive into Nebo Granite (Fig.4.2). An extensive outcrop of Klipkloof Granite is also present between the Nebo Granite and the Stavoren Granophyre, where it forms dykes and sills intruding the latter rock type.

Fig. 4.1.: The intrusion breccia of granite into the Rustenburg Layered Suite on Rietkloof 166JS. Different rocktypes are present, viz. gabbro, gabbronorite, norite, anorthosite, magnetite-gabbro and magnetite. Large quantities of a fine-grained mafic rock, probably a sill of critical zone composition (Sharpe, pers. comm.), constitute the largest number of the fragments (large block at handle of hammer).

4.1.2.1. Fine- to medium-grained Klipkloof Granite.

This rock type forms the largest part, by volume, of the Klipkloof intrusives. It occurs as aplite sills, dykes and thin veins in the Nebo Granite or as second-generation aplite dykes or veins in the Klipkloof aplite sills (Fig.4.3). The dykes and veins dip steeply and terminate abruptly. Klipkloof Granite sills are developed at different horizons within the upper parts of the Nebo Granite sheet: at each level dykes and veins originate which may terminate at or intrude overlying Klipkloof Granite sills.

The rock is always leucocratic and contains only minor amounts of chloritized biotite, which forms clots in some localities. Primary, magmatic fluorite is ubiquitous and the grain size varies, being fine-grained in dykes and veins and fine- to medium-grained in sills. This rock type resembles the Lease Granite of the Zaaiplaats area (Crocker, pers. comm.; authors observation).

Associated with the dykes and sills are plug-like bodies of albitized Klipkloof Granite (Fig.4.4). These are reddish in colour when albitization is not advanced and white if a high degree of albitization has occurred.

Tourmaline spheroids with a diameter of 4 to 15 centimetres and a concentration of one to three spheroids per square metre occur in both the reddish and white albitized Klipkloof Granite (Fig.4.5). The majority of spheroids are nearly perfect spheres enclosed by granitic rims depleted in mafic constituents. Some spheroids contain visible 1 to 2 centimetre long tourmaline crystals of the schorl type.

4.1.2.2. Porphyritic Klipkloof Granite.

This rock type invariably forms a marginal phase to the other types of Klipkloof Granite wherever these are in contact with Nebo Granite. Contacts with other Klipkloof

Fig. 4.2.: The contact between Nebo Granite and an overlying Klipkloof Granite sill (white arrows). Roadcut on Varschwater 23JS.

Fig. 4.3.: Two aplite dykes intrude Nebo Granite. The steeply dipping dyke carried the mineralizing fluids, which were trapped by the overlying Klipkloof Granite sill. The molybdenite mineralization occurs both as massive and disseminated ore in the aplite dyke and the surrounding Nebo Granite. Roadcut on Varschwater 23JS.

Fig. 4.4.: The round, pluglike outcrop of white albitized Klipkloof Granite is clearly recognizable at the centre of the photograph. Tussenin 21JS.

Fig. 4.5.: Two merged pairs of tourmaline spheroids in white albitized Klipkloof Granite. Tussenin 21JS.

Granite varieties are gradational, as is illustrated by the decrease in phenocrysts in the rock.

The rock type is characterized by phenocrysts of quartz and perthite, up to 8 millimetres in diameter, with quartz phenocrysts usually smaller than the perthites. Mafic minerals are chloritized and the fluorite content is relatively high; however, being white-coloured, the fluorite is difficult to recognize in handspecimen.

4.1.2.3. Medium- to coarse-grained Klipkloof Granite.

This generally red coloured rock type is extremely leucocratic with minor amounts of chloritized biotite. The quartz grains are interlocking and both quartz and perthite grains are typically about 4 millimetres in diameter. The appearance of this rock type resembles that of the Bobbejaankop Granite of the Zaaiplaats area.

The contact of the sheet with the underlying Nebo Granite is difficult to locate because of the poor outcrop and the small difference in grain sizes. This granite is, however, different from the Nebo Granite in that it is generally finer grained, more leucocratic, has a much higher contents of fluorite and chloritized biotite, and contains quartz-rich pegmatite lenses.

4.2. Petrography of the Nebo Granite.

The Nebo Granite is an equigranular coarse-grained rock with hornblende and biotite forming the major mafic minerals. It has a grey colour in the lower part of the sheet and displays a red colour in its upper part.

Quartz, perthite, plagioclase, hornblende and biotite are the major rock-forming minerals. Plagioclase and perthite were the first major phases to crystallize in the least differentiated Nebo Granite. Nebo Granite higher in the sheet is more differentiated and here quartz appears to be the first major mineral to crystallize. Hornblende and biotite always occur as interstitial grains indicating that they were late in the crystallization sequence.

4.2.1. Perthite.

All the primary K-feldspars are perthitic. Some are macroperthitic, but most are microperthitic. They are slightly zoned and partially seritizised.

Interlocking-, string-, vein-, patch- and microcline perthites are developed. The perthite is usually rimmed by albite, which is in optical continuity with the albite component of the perthite grain, except where the albite rim is developed between perthite and plagioclase when the albite is in optical continuity with the plagioclase. A peculiar situation arises if two albite rims are developed around adjacent perthite grains, where the rim surrounding one grain appears to acquire the optical orientation of the albite component of the adjoining perthite grain (Fig.4.6).

4.2.2. Plagioclase.

Plagioclase is less abundant than perthite and accounts for 5 to 7 per cent of the modal composition. The grains are strongly zoned and saussuritization of the core is common. Two types of plagioclase occur in the Nebo Granite. Firstly, early-formed crystals of oligoclase that are sometimes twinned according to pericline law and secondly, relatively late-formed grains of oligoclase composition which are interstitial between quartz and perthite.

The anorthite content of late-formed plagioclase cores is about 10 to 15 per cent in undifferentiated rocks, but below 10 per cent in more differentiated counterparts, with

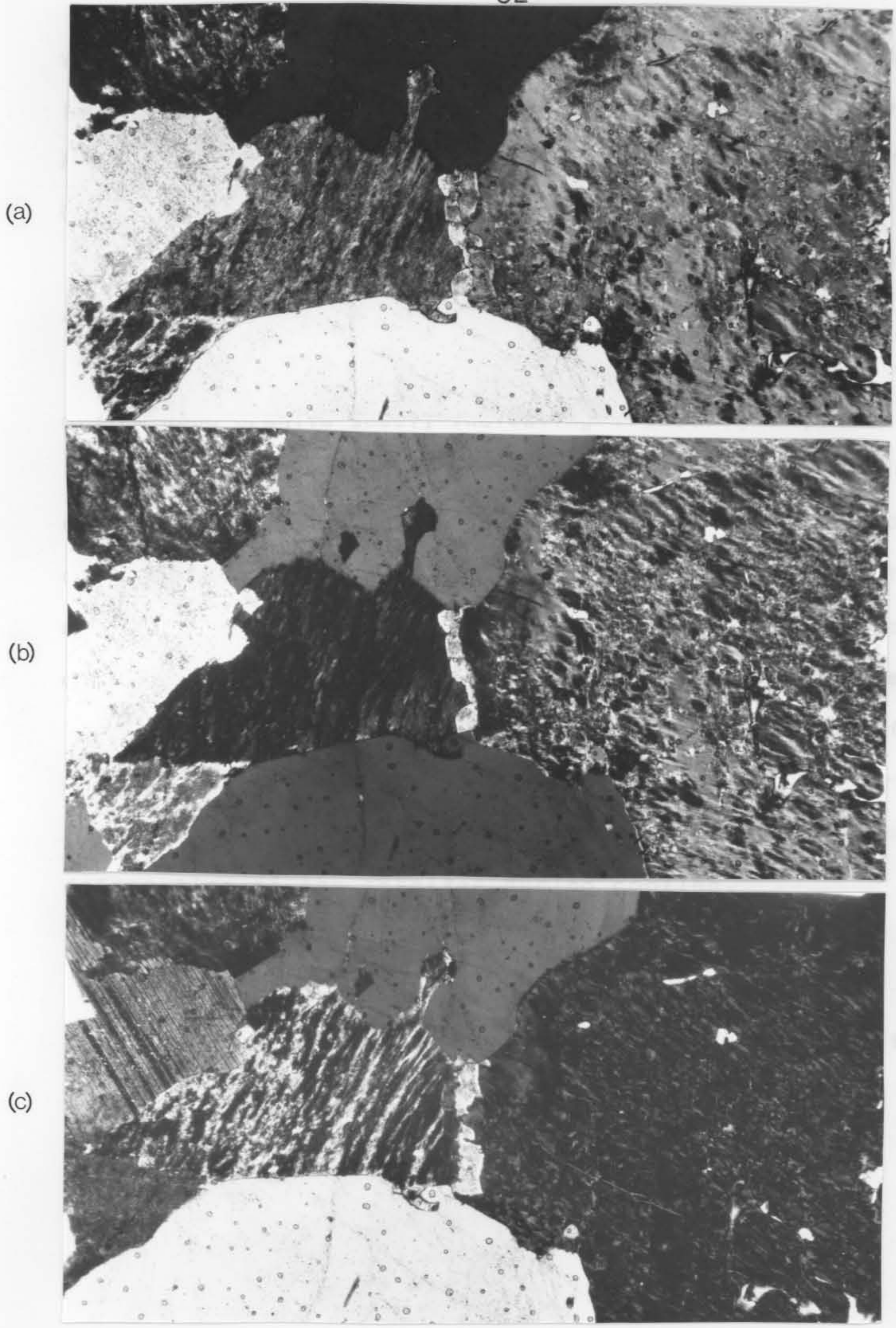

Fig. 4.6.: Two albite rims are present in Nebo Granite if two perthite grains are in contact (a). "Swapped rims", ie. the rims are in optical continuity with the albite component of the adjoining grains. The large perthite grain on the right is of the interlocking variety (b). With rotation of the stage through 180°, the other albite rim is now in optical continuity with the adjoining perthite grain (c). GN-12. X-Nicols. 25x. Varschwater 23JS.

values as low as An_{1-5} in the most differentiated varieties (Appendix 1). There is therefore a marked decrease in the An content of plagioclase with differentiation of the Nebo Granite magma.

4.2.3. Quartz.

Quartz forms subidiomorphic crystals in the upper parts of the Nebo Granite sheet, indicating its early crystallization. In the lower parts of the granite body, no subidiomorphic quartz grains are present and feldspar crystallized before quartz. Clusters of quartz of variable orientation are common in the Nebo Granite, especially in the upper parts of the sheet. This feature was considered by Hara et al. (1980), who investigated the origin of granites of Japan, as being a secondary feature produced by dynamic recrystallization of large single quartz grains caused by high-temperature deformation of the granites during cooling.

Sagenitic quartz, containing opaque needles, possibly rutile, occurs in some specimens.

Myrmekitic textures are developed at perthite grain boundaries; these textures usually occur in one of the two albite rims referred to earlier (Section 4.2.1.).

4.2.4. Hornblende and Biotite.

The major mafic minerals in the lower part of the Nebo Granite comprise mainly hornblende with minor biotite. The abundance of biotite increases upwards through the granite sheet, with a concomitant decrease in total mafic mineral content.

Hornblende and biotite occur interstitially to quartz and feldspar, indicating their late crystallization. Hornblende has the absorbtion formula X= brown green, Y= olive green and Z= dark olive green. According to the terminology of

Leake (1978), the amphibole is a ferro-edenite (Appendix 1) belonging to the group of calcic amphiboles with the end-member formula $NaCa_2Fe_5Si_7AlO_{22}(OH)_2$. The $Mg/(Mg+Fe^{2+})$ ratio is low and has a value of 0,04. Zircons, opaque minerals, apatite and other accessory minerals are enclosed by hornblende, again confirming its late crystallization.

Biotite, present as small flakes, has the absorption formula X= brown, Y= Z= dark brown. The biotites of the Nebo Granite are annite-rich (Appendix 1.). Annite is an uncommon biotite (Eugster and Wones, 1962) because a certain amount of substitution of Mg for Fe^{2+} is usually present.

4.2.5. Zircon.

Zircons are comparatively abundant and occur in three settings. The majority of zircons are enclosed in hornblende grains, together with opaque minerals and apatite. Some zircon crystals are enclosed in quartz, perthite and plagioclase, and a few zircons are situated along grain boundaries between quartz, perthite and plagioclase. Zircons crystallized early and were evidently dispersed throughout the melt. Crystallizing quartz and feldspar grains do not readily include the zircon crystals because of the large difference in surface tension between them (Spry 1979, p 171); this explains why the majority of zircons are found in the late crystallizing hornblende.

Most zircons are zoned and secondary overgrowths on the primary zircon are common. The overgrowth results in pleochroic halos in hornblende, as it is reasonable to assume that the late overgrowths probably contain the highest U and Th concentrations.

Pupin (1980) states that zircon crystallization is not confined to the first stages of crystallization of a magma, but continues to the hydrothermal stage. This is substantiated by the development of late overgrowths, which may distort the cleavage of late biotite grains (Fig.4.7), thereby indicating that the overgrowth formed when the silicates had already crystallized.

4.2.6. Accessory minerals.

Accessory minerals that occur in the Nebo Granite are allanite, apatite, calcite, fluorite, magnetite, ilmenite, sphalerite, galena, arsenopyrite, chalcopyrite, molybdenite, thorite, sphene and tourmaline. Allanite, ilmenite and magnetite are the most abundant accessories.

Allanite from the lower parts of the sheet is lighter in colour than that from the upper parts. Subidiomorphic allanite is rare and irregular grains are more common.

Thorite is a rare constituent. Due to its high Th content, it produces a halo in the host mineral.

4.3. Petrography of the Klipkloof Granite.

4.3.1. Fine- to medium-grained and porphyritic Klipkloof Granite.

Quartz, perthite, minor plagioclase with a low An content (Appendix 1), biotite and accessory amounts of hornblende form an equigranular 0,5 to 1,5 millimetre matrix. Phenocrysts of quartz, perthite and rarely plagioclase, between 5 and 8 millimetres in diameter, occur evenly distributed in the fine- to medium-grained matrix.

Microcline-, string- and patch perthites are the predominant types of perthite forming both phenocrysts and groundmass. Swapped albite rims are present between perthite grains.

Quartz phenocrysts are smaller than the perthite phenocrysts and have subidiomorphic crystal outlines. They are frequently surrounded by a thin rim of granophyric intergrowth, the quartz of which is optically continous with the phenocryst (Fig.4.8).

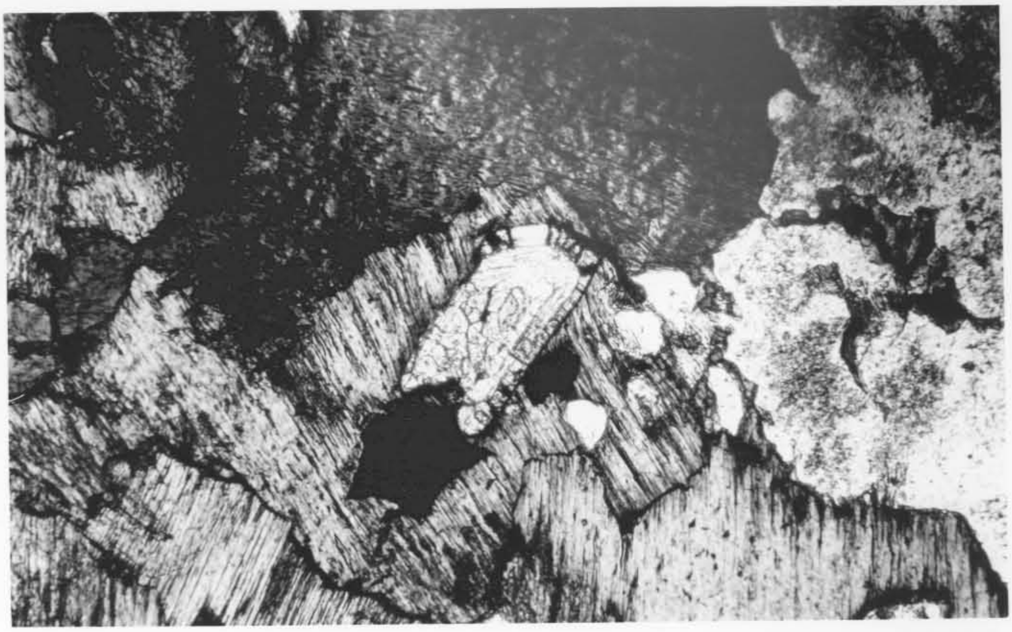

Fig. 4.7.: A zoned zircon crystal with secondary overgrowth in late crystallizing biotite. It is evident that secondary overgrowth formed very late in the crystallization sequence, because it disturbs the cleavage of biotite. GN-16. 125x. Varschwater 23JS.

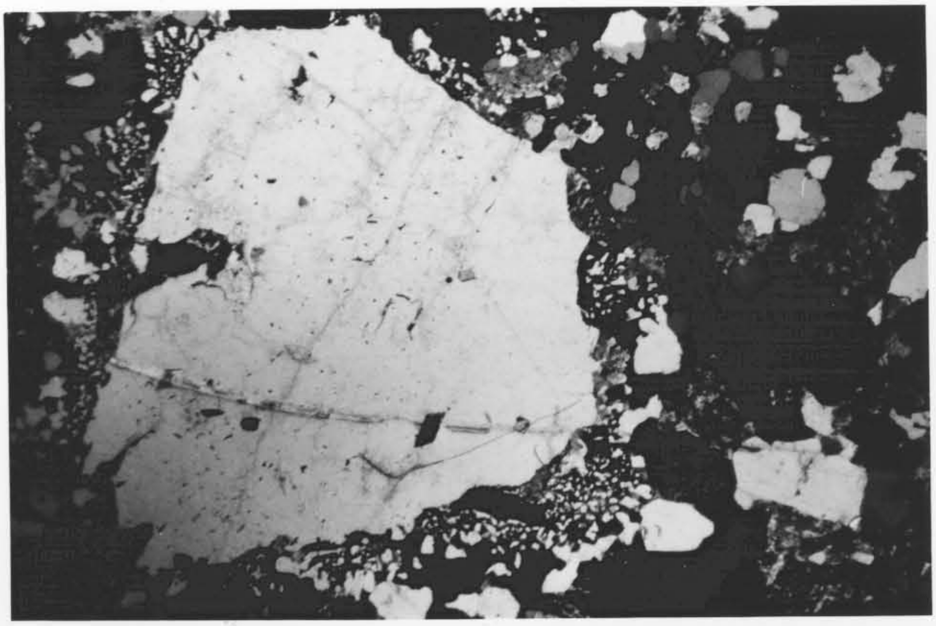

Fig. 4.8.: The small quartz domains are in optical continuity with the large quartz phenocryst. GK-29. X-Nicols. 12,5x. Varschwater 23JS.

Granophyric intergrowth around perthite phenocrysts and in the groundmass is common. The majority of these intergrowths have the appearance of an exploding bomb (Fig.4.9). Schloemer (1962) showed that mixtures of quartz and K-feldspar in a water medium at 400°C produce intergrowths of quartz and feldspar resembling the exploding bomb texture. This may suggest the possibility of hydrothermal activity in the granite.

Biotite is generally altered to chlorite and occurs interstitially to quartz and perthite. The chlorites are Mg-poor, Fe-rich varieties of thuringite which are dark green and nearly opaque (Appendix 1). Parry and Downey (1982) found that chloritic alteration in the Gold Hill quartz monzonite in Utah took place at about 200°C, and that Mg, Fe^{3+}, H^+ and Mn are added to the rock, whilst K, Fe^{2+}, Ti, F and Cl are lost to solution. The same process evidently occurred in the Klipkloof Granite.

Accessory minerals include abundant fluorite, as well as zircon, ilmenite, thorite, monazite, allanite, muscovite, arsenopyrite, galena, chalcopyrite, sphalerite, molybdenite, rutile and tourmaline.

Zircons are extremely zoned and characterized by secondary overgrowths (Fig.4.10).

The following minerals in Klipkloof Granite were identified with the aid of the scanning electron microscope:

1) Th,Y silicate - yttrialite, which occurs next to and intergrown with zircon.
2) $ThSiO_4$ - thorite, closely associated with zircon.
3) Ce,La,Y,Ca,Th(PO_4) - cheralite, where Ca and Th are substituting for REE.
4) Ca,Fe,Al,Ce,La silicate - allanite.
5) Th,Ce,Y,Ca, fluorsilicate - tritomite?
6) La,Ce silicate - cerite?

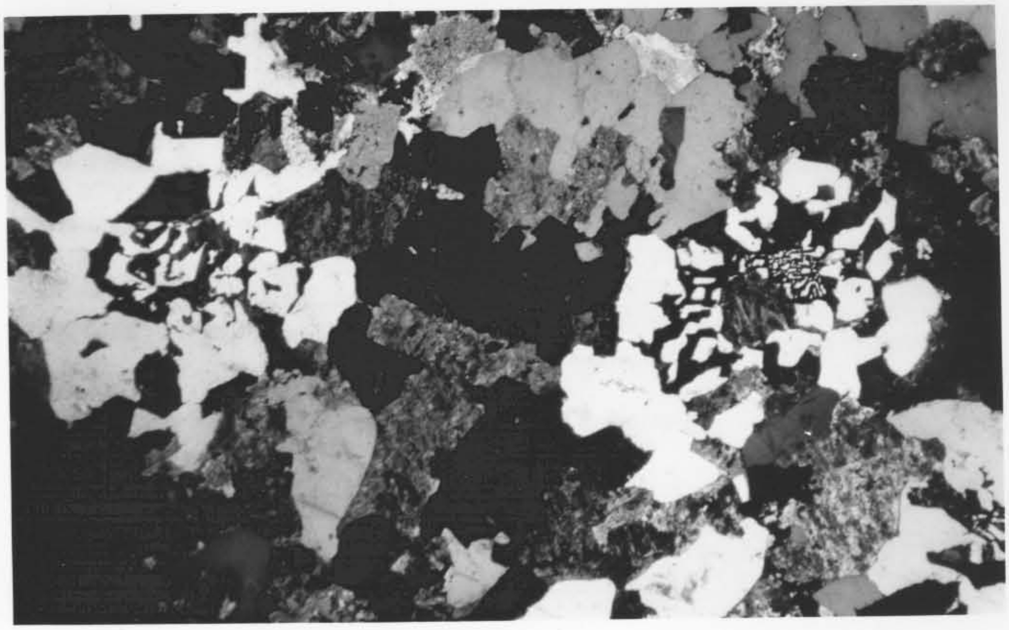

Fig. 4.9.: Exploding bomb texture in Klipkloof Granite. GK-17. X-Nicols. 12,5x. Varschwater 23JS.

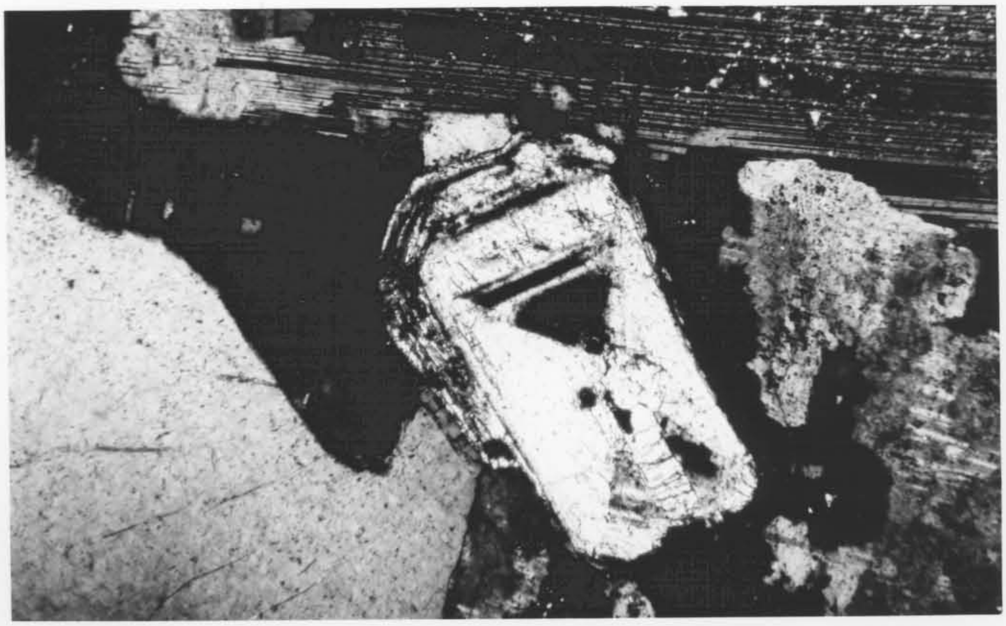

Fig. 4.10.: Secondary overgrown zircon crystal with sector zoning. GK-17. X-Nicols. 125x. Varschwater 23JS.

7) Ca,La,Ce silicate - beckelite?

8) $(Zr,Th)SiO_4$ - zircon and thorite solid solution.

9) $(Ce,La,Di)PO_4$ - monazite.

10) Ca,Ce,Fe silicate.

11) Ca,Ce,Ti,Y silicate.

12) $(Th,P)SiO_4$ - auerlite, because of P in the lattice.

Most of the above-mentioned minerals are very minute and therefore difficult to identify with a petrographic microscope. They occur mostly in hornblende. Some of them were found enclosed in plagioclase grains or on grain boundaries of quartz, perthite and plagioclase.

4.3.2. Medium- to coarse-grained Klipkloof Granite.

This type has a grain size of 2 to 4 millimetres with interlocking quartz grains and a high fluorite content. Mafic minerals are generally chloritized and the feldspars are reddish and very altered.

Subidiomorphic grains of quartz were the first to have crystallized (Fig.4.11). The amount of plagioclase is lower compared to the Nebo Granite. Granophyric intergrowth was observed in some samples.

The zircons are extremely zoned and secondary overgrowth is common. Other accessory minerals, as listed for the fine- to medium-grained and porphyritic Klipkloof Granite, also occur in this rock type.

4.3.3. Albitized Klipkloof Granite.

Albitization is due to late sodium-rich fluids, which interacted with the rock and changed its mineralogy and chemistry. The albite component of perthite increases in volume and a mesoperthite is formed (Fig.4.12).

Muscovite with slight pleochroism, indicating a celadonite composition, fluorite and tourmaline are important accessory

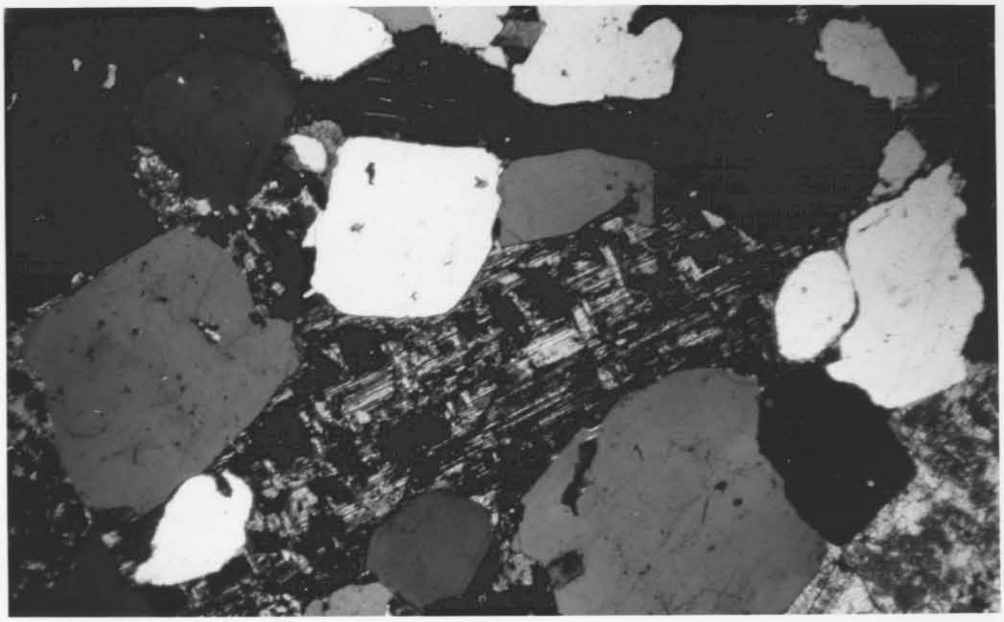

Fig. 4.11.: Subidiomorphic quartz grains which crystallized before perthite in Klipkloof Granite. GGR-362. X-Nicols. 12,5x. Tussenin 21JS.

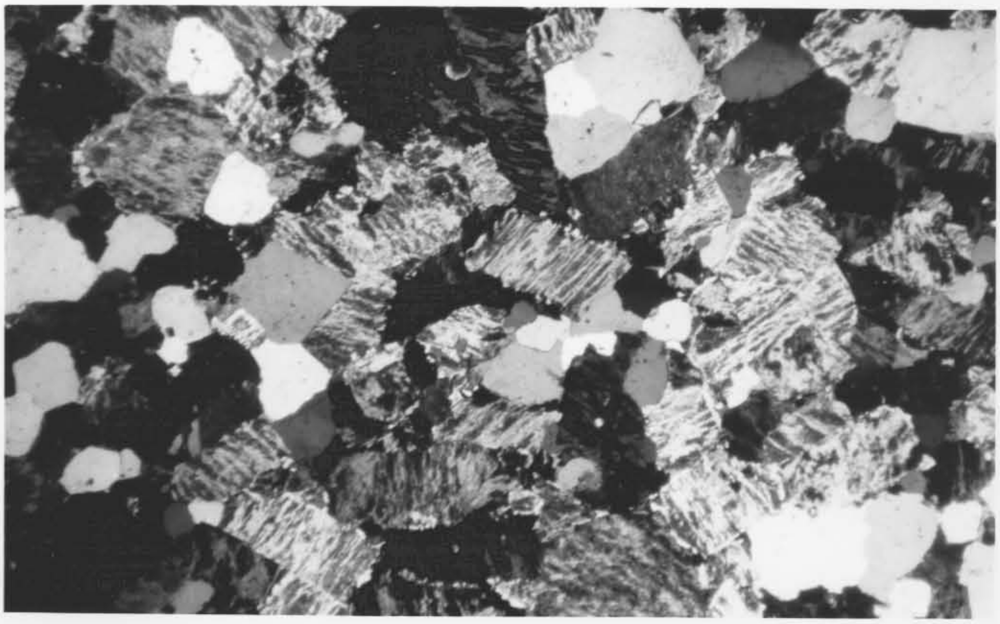

Fig. 4.12.: Albitized Klipkloof Granite is characterized by the large albite components of the perthite grains. GK-14. X-Nicols. 12,5x. Varschwater 23JS.

minerals.

Tourmaline-rich spheroids in the albitized granite are composed of tourmaline (schorl), quartz, plagioclase, perthite and topaz. Quartz occurs as irregular and subidiomorphic grains, enclosed in optically continous patches of tourmaline. Thorite and zircon present are metamict.

4.4. Obliquity of potassium feldspars.

Obliquity values of potassium feldspars of the Nebo and Klipkloof Granite were determined using the separation of the 131 and $1\bar{3}1$ reflections (Smith and MacKenzie, 1955) (Table 4.2).

More than one factor controls the obliquity value of K-feldspar and it is difficult to ascertain the importance of any of these factors. There is a tendency for obliquity values to increase with the silica content and it may therefore be inferred that an increase in obliquity takes place during magmatic evolution, which includes lowering of consolidation temperature or increase of volatile content (Dietrich, 1962).

A range of obliquity values from low towards high values with accompanying intermediate values is an indication of one igneous suite, where the younger parts have the highest values, with pegmatites being characterized by obliquity values above 0,80. Dietrich (1962) also found that most of the Ab content must be exsolved before obliquity values above 0,85 can be fixed.

The obliquity values of K-feldspar are influenced by temperature and volatile content of the magma during crystallization, the amount of albite in solid solution, post-magmatic hydrothermal solutions and cooling rate (Lenthall and Hunter, 1977).

Table 4.2.: Obliquity values of K-feldspar.

Rocktype	Sample No.	Obliquity.
Nebo Granite	GN-56	0,689
Nebo Granite	GN-50	0,735
Medium- to coarse-grained Klipkloof Granite	GGr-146	0,786
Porphyritic Klipkloof Granite	GGr-184	0,783
Porphyritic Klipkloof Granite	GGr-261	0,823
Fine- to medium-grained Klipkloof Granite	GGr-156	0,823
Fine- to medium-grained Klipkloof Granite	GK-51	0,859
Albitized Klipkloof Granite	GK-36	0,833

Nebo Granite sample GN-56 is from the bottom of the sheet, whereas sample GN-50 is from the upper more differentiated parts. The obliquity value of GN-50 is probably higher due to the presence of volatiles, a slower cooling rate and lower overall crystallization temperature.

Obliquity values of Klipkloof Granite are higher than those of the Nebo Granite, which is possibly due to the presence of volatiles, as reflected by the higher fluorite content, or perhaps because the Klipkloof Granite magma cooled more rapidly.

4.5. Tourmaline spheroids in the Klipkloof Granite.

According to Taylor (1979, p 200) many apogranites contain clots and nests of tourmaline, which may contain minor amounts of cassiterite. The tourmaline spheroids in the Klipkloof Granite appear to be an integral part of the rock with no sign of structural control (Fig.4.5).

The tourmaline clusters or spheroids are rimmed by a wide halo of light coloured rock, due to the impoverishment of mafic constituents. The diameter of the light coloured halos are always proportional to the size of the tourmaline spheroids. The hostrock is albitized and leucocratic and total mafic minerals do not exceed three percent. The spheroids are scattered irregularly through the rock and their diameters range from three to twenty centimetres, with the majority having a diameter of about ten centimetres. Most tourmaline accumulations are spherical, but in some instances irregularly shaped clusters of tourmaline were observed.

The chemical analyses of the spheroids, together with the hostrock (GGr-256), are presented in Table 4.3. The spheroids are enriched in Al_2O_3 and FeO, but depleted in SiO_2, CaO, Na_2O and K_2O relative to their hostrock. The amount of K-feldspar in the spheroids is low, explaining the low K_2O content of the analyses. The FeO content is higher, due to its presence in schorl.

The analyses of the tourmaline spheroids do not add up to 100 percent, which is attributed to the presence of B_2O_3. From the two spheroid analyses it can be assumed that the B_2O_3 content amounts to about 2,5 to 3,0 percent, which is a reasonable figure if the modal amount of tourmaline is considered. A modal composition of 25 per cent schorl would result in a B_2O_3 content of about 2,5 per cent.

The spheroids contain about 40 ppm Sn, which is only slightly higher than the 34 ppm in the host rock.

According to Nemec (1975), the origin of tourmaline spots and spheroids may be explained by metasomatic replacement of granite, because the mineral assemblage tourmaline and quartz is also known from greisens and pegmatites, where it developed as a result of the replacement of feldspar by tourmaline, forming a poikilitic texture with quartz. He also suggests that the material required for the development of tourmaline spheroids was imported partly from outside in the case of boron, and partly from the light halos, due to the breakdown of biotite.

Schust et al. (1970) also believe in the metasomatic origin of the spheroids, because they are similar to small

Table 4.3.: Chemical analyses of spheroids (GKSph) and host rock (GGr).

	<u>GKSph-37</u>	<u>GKSph-37A</u>	<u>GGr-256</u>
SiO_2	72,29	72,27	75,55
TiO_2	0,10	0,09	0,06
Al_2O_3	12,82	12,89	12,16
FeO	5,98	5,99	1,56
MnO	0,03	0,03	0,01
MgO	0,00	0,00	0,00
CaO	0,23	0,04	0,65
Na_2O	3,64	3,88	4,16
K_2O	1,27	1,25	4,73
P_2O_5	0,00	0,00	0,00
Cr_2O_3	0,03	0,04	0,04
NiO	0,00	0,00	0,01
LOI	0,76	0,64	0,65
H_2O^-	0,08	0,07	0,20
Total	97,23	97,19	99,78
Ba	5	10	33
Rb	155	163	643
Sr	3	2	9
Y	94	51	158
Zr	226	227	277
Nb	52	63	88
La	28	60	72
Ce	42	103	121
Nd	6	44	55
Th	45	41	63
U	17	10	29
Hf	7	9	13
Ga	46	49	32
Sc	0	0	0
Zn	104	99	19
Cu	1	2	6
Ni	6	4	6
Pb	10	11	30
Mo	1	1	2
W	10	6	14
Sn	45	39	34

greisen bodies. They concluded that the spheroids originated after the granite host had crystallized, because they could find no difference between textures of the host granite and the spheroid on stained varnished rockslabs.

Teuscher (1936) proposes that such spheroids originated in gas cavities, which formed whilst the granite crystallized. Oelsner (1952) believes that they formed as a result of pneumatolitic introduction of boron, while Tindle and Pearce (1981) attribute their origin to a late-stage build up and expulsion of volatiles.

Durasova and Barsukov (1973) suggest a magmatic origin for the tourmaline spheroids. According to them separation of a silicate magma enriched in boron by a mechanism of liquid immiscibility could take place at a late stage in differentiation when the boron has accumulated sufficiently. They showed that it is possible for tin and boron to be extracted from the silicate melt by liquid immiscibility in the system $CaO-B_2O_3-2SiO_2$.

Tourmaline spheroids in the Klipkloof Granite are believed to have originated by metasomatic replacement of K-feldspar by schorl. The iron necessary for the formation of tourmaline was derived from the breakdown of biotite. A build-up of volatiles probably played a role in the importation of boron.

Recknagel (1909) and Strauss (1954) state that the tourmaline nodules present in the Bobbejaankop Granite at Zaaiplaats are genetically related to the pipe-like ore bodies, and that the nodules may mark the transition between the hydrothermal and pegmatite phase. The presence of tourmaline nodules in the albitized Klipkloof Granite on the Sekhukhune Plateau, can therefore be considered as a further indication of the tin potential of these granites in this area.

4.6. The molybdenite mineralization on Varschwater 23JS.

Massive and disseminated molybdenite and chalcopyrite mineralization is exposed in a roadcutting on Varschwater 23JS (Plate 1, back folder). Crocker et al. (1977), the Mining Corporation (report by S. Gain) and Rand Mines (report by I.M. Clementson and P.A. van Straten) have investigated the deposit and surrounding area in some detail.

Three types of ore are recognizable in the deposit, viz. molybdenite-rich, chalcopyrite-rich, and REE-rich ore.

4.6.1. Molybdenite-rich ore.

Molybdenite and fluorite are the major ore minerals, with arsenopyrite, chalcopyrite, galena, sphalerite and ilmenite the accessory constituents. Allanite is generally associated with the ore.

Molybdenite occurs as large elongated aggregates with kinkbands (Fig.4.13) set in a gangue of albite, chlorite and thuringite. Fluorite with minor Y in the lattice is present in large amounts. One yttrocerite grain was identified. According to Dana (1932), yttrocerite can accommodate up to 55 per cent $(Y,Ce)F_3$ in its lattice.

Scheelite was found in some samples, where it occupies gaps between molybdenite kinkbands, whereas a bismuth-telluride (tetradymite-$Bi_2(Te,S)_3$) was found in one sample (Fig.4.13).

4.6.2. Copper ore.

The copper-ore, which consists mainly of chalcopyrite, occurs in a gangue of albite. Arsenopyrite, forming large euhedral grains, galena, covellite and molybdenite are accessory ore minerals. Inclusions of galena (Fig.4.14), iron-poor sphalerite, cassiterite (Fig.4.15), and rarely stannite occur in the chalcopyrite. Inclusions of galena were also found in arsenopyrite (Fig.4.16).

Sulphosalts are common in the copper ore. They include sulpharsenites, sulphantimonites and sulphbismuthites, as well as a Cu,Pb,Bi-sulphosalt (9,8% Cu; 29,1% Pb; 31,1% Bi; 29,4% S and 0,6% Fe). In some samples sulphosalts are present in high concentration as large grains, which are sometimes intermingled with chalcopyrite. They were also commonly observed in the cleavages of altered biotite (Fig.4.17).

Native bismuth, Pb,Bi,S-compounds, Bi-telluride-selenide and Bi-selenide were identified as minute grains in the copper ore.

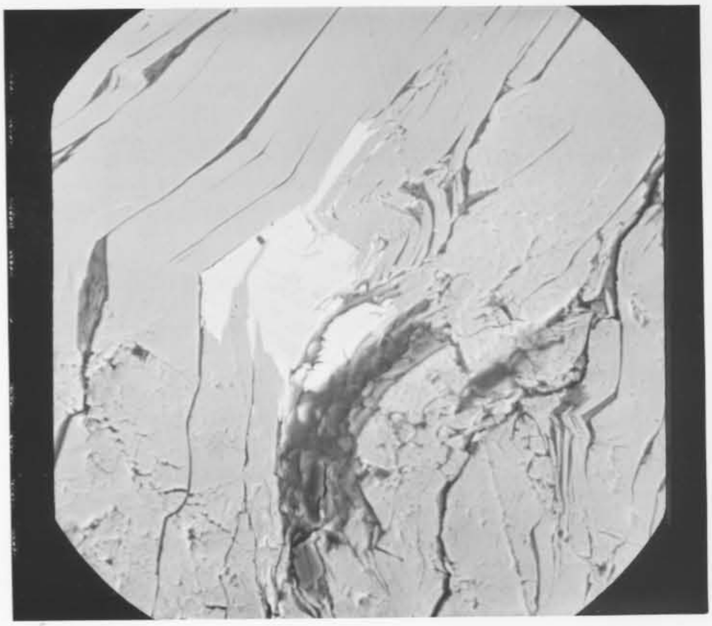

Fig. 4.13.: Kinkbands of molybdenite are characteristic. Bismuth-telluride occurs in the molybdenite ore. 20 kV. 390x. VW-1. Varschwater 23JS.

Fig. 4.14.: Inclusions of galena in chalcopyrite. 20kV. 390x. VW-4. Varschwater 23JS.

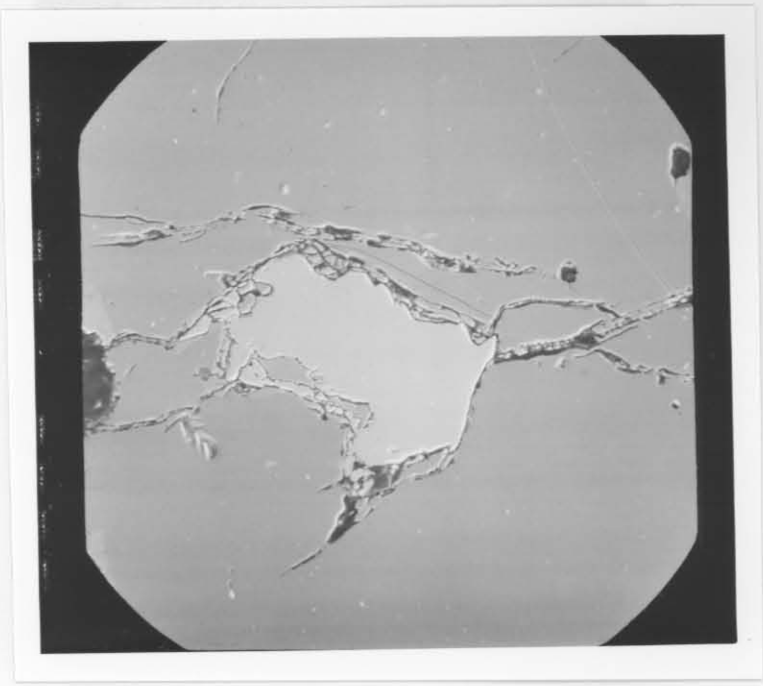

Fig. 4.15.: Inclusion of cassiterite in chalcopyrite. 20 kV. 220x. VW-4. Varschwater 23JS.

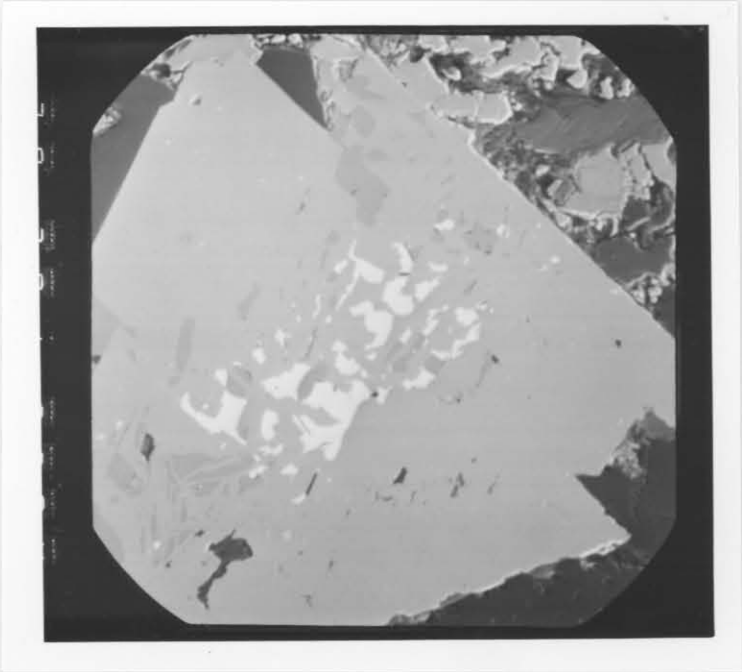

Fig. 4.16.: Inclusions of galena in arsenopyrite. 20 kV. 200x. VW-5. Varschwater 23JS.

Fig. 4.17.: Sulphosalts commonly occur in the cleavages of altered biotite. 20 kV. 110x. VW-3. Varschwater 23JS.

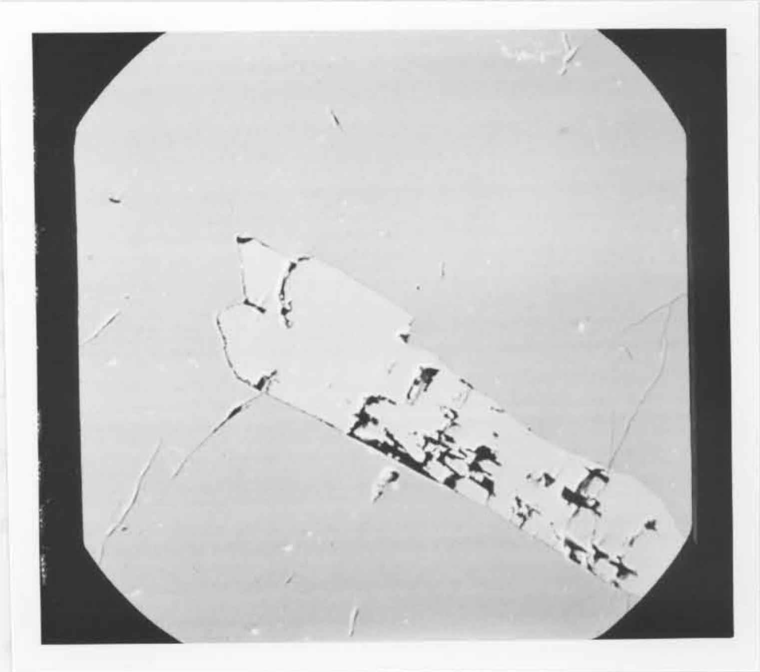

Fig. 4.18.: A well developed grain of loellingite in arsenopyrite. 20 kV. 470x. VW-5. Varschwater 23JS.

Loellingite ($FeAs_2$) commonly occurs as well defined grains in arsenopyrite (Fig.4.18). A continuous substitution of sulphur takes place between the former and latter and any composition between $FeAs_2$ and FeAsS seems possible.

Zircons, characterized by secondary overgrowths, are common. In some instances galena is present in the overgrowth (Fig.4.19). The presence of galena could be due to the radioactive decay of U to the daughter element Pb. Sulphur-rich liquid probably combined with the lead to form galena.

4.6.3. REE-rich ore.

The ores rich in REE (La,Ce,Nd,Sm and Gd) are mainly composed of allanite, which is strongly zoned (Fig.4.20 and Fig.4.21). The zone with the high reflectance is characterized by a high concentration of the heavy REE Nd,Sm and Gd.

4.6.4. The origin of the mineralization.

The mineralization is related to late Klipkloof Granite aplite dykes, which intrude both the Nebo Granite and Klipkloof Granite sills. Some Klipkloof Granite sills therefore intruded earlier than the aplite dykes.

The mineralization is present as disseminations in the Nebo Granite and as small pockets of massive ore, underlying a Klipkloof Granite sill. The mineralization occurs at this particular position because late aplite dykes, intruding the Nebo Granite along structural weaknesses, were enriched in volatiles and ore elements, which were subsequently trapped by the Klipkloof Granite sill. This is obvious from the field relationships (Fig.4.3), where the intruding aplite dyke was impeded by the Klipkloof Granite sill.

Because the Klipkloof Granite sills acted as traps for the mineralizing fluids, it is difficult to identify

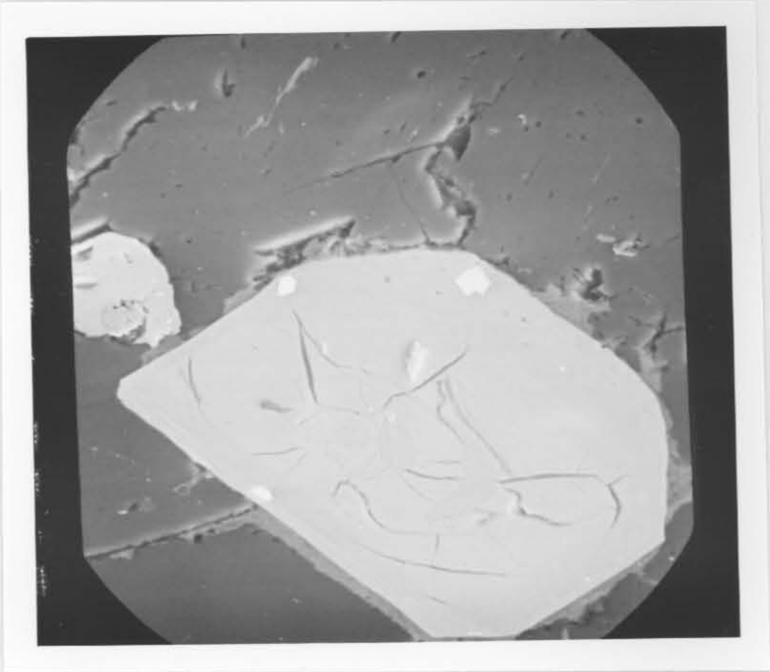

Fig. 4.19.: Grains of galena are present in the secondary overgrowth of zircons. 20 kV. 430x. VW-2. Varschwater 23JS.

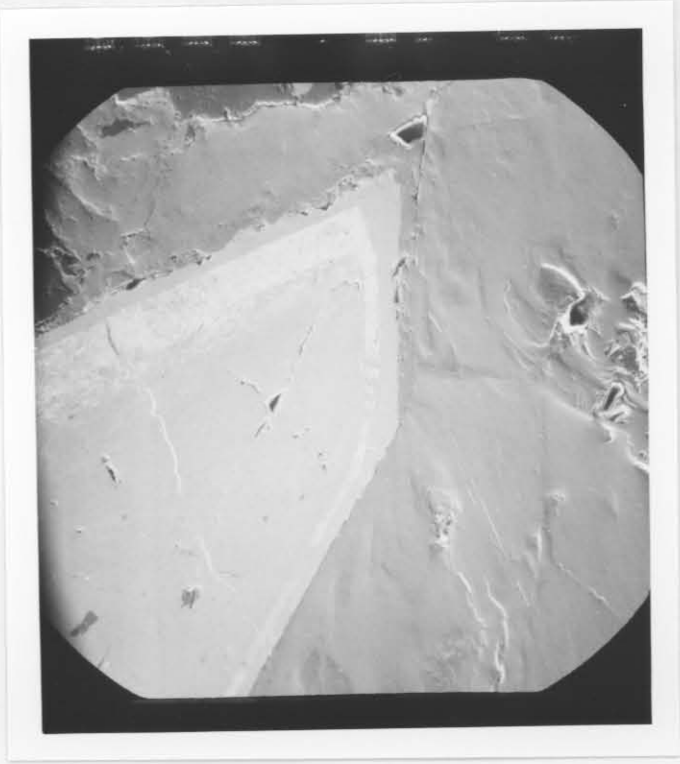

Fig. 4.20.: Strongly zoned allanite crystal. The zone with the high reflectance is characterized by a high concentration of heavy REE. 20 kV. 100x. VW-2. Varschwater 23JS.

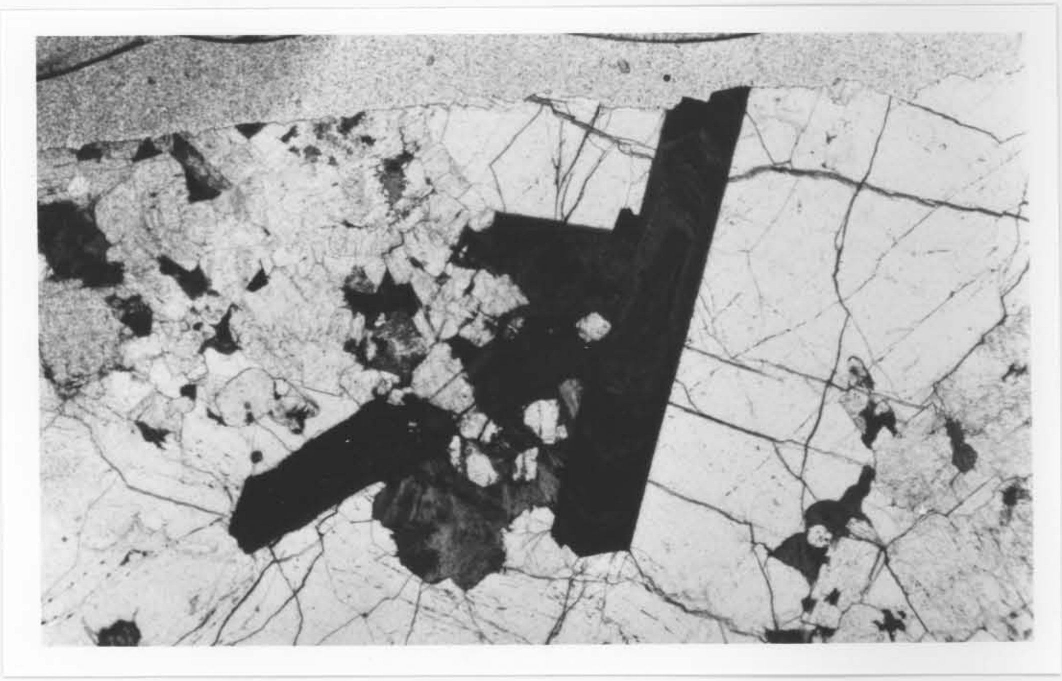

Fig. 4.21.: Zoned allanite crystals in a host of albite. VW-10. 12.5x. Varschwater 23JS.

anomalies above these sills. Detailed geochemical exploration of specialized Klipkloof Granite would probably indicate more mineralized localities. For these reasons, it seems that the Klipkloof Granite underlying the Stavoren Granophyre is a potential target, because the contact with the granophyre is an ideal trap for mineralization.