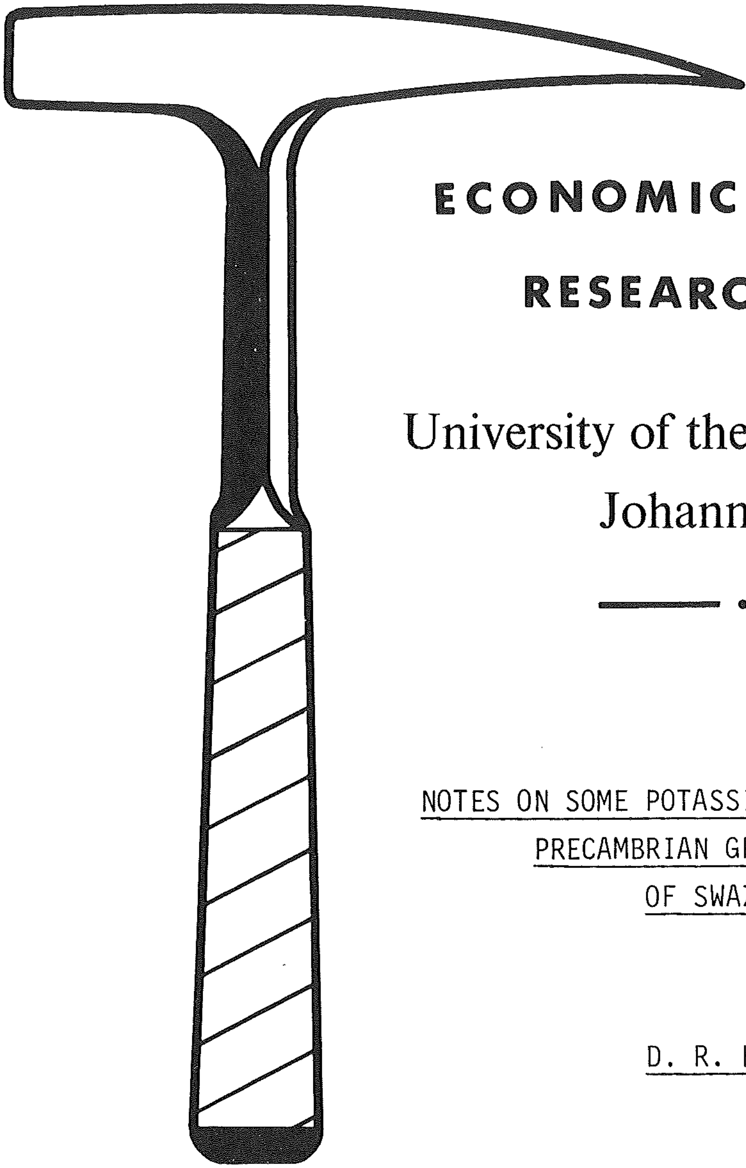

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NOTES ON SOME POTASSIUM FELDSPARS IN THE PRECAMBRIAN GRANITIC ROCKS OF SWAZILAND

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by

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ABSTRACT

The mode of occurrence of potassium feldspars in the various groups of granitic rocks is described. Measurements of the spacing of the (131) and ($1\bar{3}1$) lines of 37 samples of feldspar show that all have high triclinicity values (lowest 0,82; mean 0,94).

Potassium feldspars embay and replace plagioclase grains, but only microcline of high triclinicity and with distinct, cross-hatched twin lamellae effects this replacement. It is concluded that the development of microcline in this structural state is coincident with the act of replacement. This, together with the absence of potassium feldspars with intermediate triclinicity values, is taken as evidence that the microcline did not have a monoclinic ancestry. It is concluded that the granites, at least in part, accumulated slowly under low temperature and hydrothermal conditions.

Myrmekite, microperthite and mantling by oligoclase are all observed in the potassium feldspars. The origin of these features is discussed.

Tin and tantalum mineralization are located in a linear, albitized zone extending northwestwards across the Homogeneous Granite. By contrast columbium minerals are apparently related to a potassic phase of the Homogeneous Granite lying on the northeastern flank of the Tin Belt in the vicinity of Forbes Reef.

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NOTES ON SOME POTASSIUM FELDSPARS IN THE PRECAMBRIAN GRANITIC ROCKS OF SWAZILAND

INTRODUCTION

The Precambrian granitic rocks of Swaziland have been grouped as follows (Hunter, in press) :

4. Granite Plutons of at least two ages
3. Homogeneous Granite
2. Granodiorite Suite
1. Ancient Gneiss Complex

Potassium f eldspars are found in all these groups. In the tonalitic gneisses and associated migmatites of the Ancient Gneiss Complex and the more acid members of the Granodiorite Suite, potassium feldspars are subordinate to plagioclase but, in the Homogeneous Granite and the Granite Plutons, microcline is predominant. Pegmatites of several ages, occurring in varying tectonic settings, are common, except in the Granite Plutons : all the pegmatites are potassic. Potash feldspars mantled by rims of oligoclase are found sparingly in the older Granite Pluton which crops out east of Mhlosheni in southern Swaziland.

A linear belt, some 5 km broad, within which the only known stanniferous pegmatites are located, extends across the Precambrian granitic terrain in a northwesterly direction. Late-stage albitization affects both the pegmatites and Homogeneous Granite host in the Tin Belt.

MODE OF OCCURRENCE OF POTASSIUM FELDSPARS

A. ANCIENT GNEISS COMPLEX

Potassium feldspars are found :

(i) as augen and in felsic layers in banded migmatites

(ii) forming part of the mosaic of the more homogeneous tonalitic gneisses, and

(iii) as the main constituent of pegmatites.

Augen of potassium feldspar are prominent in banded migmatitic gneisses. The augen range up to 25 mm in diameter, and are commonly linked to each other by narrow (paper-thin to 10 mm in thickness) quartz-feldspar veinlets lying in the plane of the foliation. The growth of the augen has been accommodated by the compression of the foliae around the augen, which are built of microcline displaying regular cross-hatching, and are devoid of inclusions of other mineral grains. Perthitic intergrowths are not prominent, but delicate films and veinlets are present.

The microcline in the more homogeneous, tonalitic gneisses develops at a late stage in the disruption of the original gneiss texture accompanying granitization. The pre-granitization, fine- to medium-grained, smoothly interlocking, granular mosaic is destroyed, firstly, by the development of larger plates of oligoclase and, secondly, by the formation of a later generation of quartz in irregular areas, more or less elongated with the foliation. The effect of these processes is to produce a markedly inequigranular mosaic, individual grains having complexly sutured margins. The development of microcline adds to the heteroblastic appearance of the rock. It makes its first appearance as small interstitial patches and streaks, and, thereafter, builds larger plates enclosing, truncating and embaying the remnants of the original gneiss mosaic and the new generation of oligoclase and quartz. The growth of myrmekitic heads accompanies the development of the microcline where this mineral embays the earlier formed oligoclase. The latter mineral becomes turbid except for clear albitic selvedges around the margins of the embayed oligoclase.

Pegmatites are abundant in the Ancient Gneiss Complex. The pegmatites range from those which have diffuse margins, often giving the impression that they have resulted from the coalescence of a cloud of augen, to those which have sharply defined boundaries and which truncate the foliation of the gneisses in which they are found. All the pegmatites, however, are potassic, and are composed of quartz, microcline and plagioclase. The microcline is fresh and has strongly developed grid-iron cross-hatching, in which respect it does not differ from the microcline of the augen.

B. GRANODIORITE SUITE

Potassium feldspars are always subordinate in this Suite, with the exception of a unique occurrence west of Manzini. In the more acid members of the Suite microcline is present as interstitial grains, displaying regular cross-hatching or more streaky undulatory twinning with delicate microperthitic veinlets. Occasionally bulbous myrmekitic heads are developed where larger microcline grains embay grains of oligoclase. The relationships observed in these rocks are similar to those found in the more homogeneous tonalitic gneisses of the Ancient Gneiss Complex.

Microcline is more prominent in a dark coloured, medium- to coarse-grained rock composed of plagioclase (An_{24}), microcline, biotite, hornblende, diopsidic augite and quartz (in that order of abundance) cropping out west of Manzini. The contacts of this rock type with the surrounding quartz diorites are not exposed but there is a suggestion, indicated by the disappearance of the microcline, that it may pass gradationally into the enveloping quartz diorites. All the minerals of this rock, to which the name quartz mangarite has been applied, are fresh and unaltered. The microcline which has fine microperthitic veinlets, is strongly cross-hatched and sometimes builds grains slightly larger than the other minerals. No reaction between microcline and plagioclase has been seen where this mineral is in mutual contact with the oligoclase.

C. HOMOGENEOUS GRANITE

Feldspars build between 60 and 70 per cent by volume of the Homogeneous Granite and of this total the potassium feldspars are normally in excess of the plagioclase.

Typically the microcline occurs as irregularly shaped grains of variable size depending on the texture of the granite in which it is found. Where the granite is porphyritic, it is microcline which builds the insets. The microcline is always fresh and displays regular cross-hatching. The larger individuals show a complex junction with the other constituent minerals, particularly plagioclase. The contact is extremely involved with portions of the plagioclase isolated as islands in the microcline. Often these islands retain optical continuity with the parent plagioclase. The embayment and replacement of the plagioclase by microcline results in the latter containing frequent relics. In addition, the microcline also encloses grains of biotite and quartz. All stages of the digestion of plagioclase can be observed. In some thin sections fresh microcline and turbid plagioclase form granular areas with minute myrmekitic warts growing into the microcline. In other slides a large area of microcline may be found composed of several individuals with relics of plagioclase occurring not only within them but irregularly along the contacts between individuals as well. Small grains of oligoclase enclosed in microcline may develop a clear selvedge of albite around the turbid core.

Microcline porphyroblasts are found growing in gneisses adjacent to the contact of the Homogeneous Granite. Southeast of Mbabane a gradational contact exists between biotite-hornblende gneisses and the Homogeneous Granite. In the outer transitional zone large oligoclase porphyroblasts grow in the gneisses. Closer towards the granite the porphyroblasts are wholly or partially replaced by microcline. No myrmekitic heads nor albitic selvedges have been observed accompanying the alteration.

Large euhedral microcline porphyroblasts are found in gneisses along the contact between the Homogeneous Granite and the Swaziland Sequence on the north bank of the Komati River. In the Motshane valley west of Mbabane, large augen are developed in granitized gneisses of the Swaziland Sequence. These augen have similar features to those found in the banded migmatitic gneisses.

Microcline is abundant in more pegmatitic granite forming part of the migmatite zone which occurs beneath the hood of Homogeneous Granite. This microcline builds large plates commonly with a uniform development of minute, spindle-shaped blebs of film perthite.

Delicate film microperthite and coarser vein microperthite are present in most microcline grains. The last-named intergrowth develops from narrow rims of clear albite which occurs interstitially among the grains, and reaches its maximum development in that part of the

Homogeneous Granite which is coincident with the 5 km wide belt of cassiterite-bearing pegmatites which extends southeastwards from Mbabane to Nyonyane Hill, some 16 km distant.

Myrmekite is a characteristic feature particularly where the potassium feldspar is embayed into and is replacing plagioclase. Myrmekite may form protuberances, attached to the host plate of plagioclase, embayed into the adjacent microcline but in other cases it occurs as a marginal zone between the oligoclase and potash feldspar. It may also be found in granular areas of microcline and plagioclase as minute wart-like growths. In most cases the myrmekite is slightly or moderately sericitized, particularly those grains isolated in potash feldspar individuals. The myrmekite has its convex face embayed into the microcline and cuts sharply across the microperthitic intergrowths.

The quartz in the myrmekite occurs as minute drops or sinuous and vermicular tubes, generally arranged so that their longer axes are at right angles to the convex side of the growth. The quartz may or may not show uniform extinction : the extinction of tubes in one part may be simultaneous with that in another part, and it seems that the presence of the quartz can only be explained by assuming a release of silica during the replacement of the potassium feldspar by the oligoclase, the quartz crystallizing simultaneously with the plagioclase.

D. GRANITE PLUTONS

Potassium feldspar is represented in the porphyritic, coarse-grained granites by prominently cross-hatched microperthitic microcline and by microcline with only limited areas having undulose twinning. Both occur as large subhedral grains enclosing fragments of the groundmass. Such porphyroblastic grains of microcline may have complex margins consisting of a narrow fringe with abundant, but minute inclusions. In addition to these larger grains, microcline forms part of the groundmass.

Coarse perthitic intergrowths are typical, particularly in the larger porphyroblasts. The cores of some microcline grains are occupied by highly corroded, turbid plagioclase which is embayed and replaced by the potassium feldspar. Prominent cross-hatched twinning is a feature of the microcline being more especially prominent in the grains forming part of the groundmass. Some of the porphyroblastic grains of potassium feldspar develop cross-hatching only in vaguely defined areas near the edge of the grain.

The granite plutons cropping out north of Mbabane and astride the Ngwempisi River carry disc-like biotite-rich patches in which large, often euhedral, microcline porphyroblasts grow. In extreme cases, when the melanocratic patches are small, the porphyroblast may replace nearly all the basic material leaving only a biotite-rich selvedge around the microcline grain. The microcline building these porphyroblasts does not differ from that occurring as insets in the granite.

Although potassium feldspar encloses and embays the plagioclase, myrmekitic heads are found only rarely in the corase-grained, porphyritic granites. This relationship differs from that found in the Homogeneous Granite where myrmekite is common.

Mantled feldspars are sparingly found in the pluton cropping out east of Mhlosheni. The granite in which these mantled feldspars occur is very coarsely porphyritic; individual insets ranging up to 30 mm in length and often being so closely packed as to give the rock a pegmatitic appearance. The granite building this pluton is further distinguished from the other plutons by the presence of hornblende in addition to biotite and by the existence of a more medium-grained roof facies which is preserved only in the northern part of the pluton.

The mantled feldspars consist of a large central core of microperthitic microcline in which cross-hatched twin lamellae are sometimes only incipiently developed. Inclusions of plagioclase, biotite, and quartz occur within the grain. Saussuritized twinned plagioclase (An_8) encircles the potassium feldspar core, the mutual boundary being sharply defined. As in the microcline of the granites building the other plutons, myrmekite is rare but coarse microperthitic veining is characteristic, the plagioclase veins often being in optical continuity with each other. More rarely flame-like veins extend into the microcline, the albite of the veins being untwinned. Plagioclase grains included within the microcline are turbid but are encircled by a narrow, clear albite selvedge.

POTASSIUM FELDSPAR TRICLINICITY

Goldsmith and Laves (1954a) used the difference in spacing of the (131) and ($1\bar{3}1$) lines as a measure of the triclinicity or ordering in potassium feldspars :

$$\text{Triclinicity} = 12{,}5\ (d131 - d1\bar{3}1)$$

The structural state of the potassium feldspar can be useful in understanding the petrogenesis of the granites in which they are found.

Thirty-seven potassium feldspars, mainly from the Homogeneous Granite and the Granite Plutons, were studied in this way. The locations of and results obtained from these samples are listed in the Appendix. The samples were finely crushed and exposed to CuKα radiation (Ni filter) at a scanning speed of 0,5° 2θ/min. using a Phillip's diffraction unit. The results were recorded on a chart travelling at 1600 mm/hr. All the potassium feldspars investigated show a high degree of ordering.

All the microclines show regular cross-hatched twinning with the exception of some of the porphyritic grains in the Granite Plutons which display this twinning over only portions of the grain. Microperthitic intergrowths are present in microclines from the Homogeneous Granite and the Granite Plutons. Goldsmith and Laves (1954a) conducted their experiments on relatively pure potassium feldspars but found that the triclinicity can be affected by the sodium content in solid solution, which content is not known for the samples investigated in Swaziland. Kolbe (1966) has demonstrated that insofar as the Cape granites are concerned there is an inverse relation between triclinicity and the total Ab content of the feldspars. Highly triclinic feldspars contain appreciably less Ab. All the Swaziland feldspars reflect a highly ordered state and it would appear from Kolbe's results that the presence of perthitic intergrowths has not markedly affected the values obtained.

Laves (1950) concluded that the typical cross-hatched twinning of microcline is a logical consequence of the inversion of an original monoclinic crystal. Experimental studies (Goldsmith and Laves, 1954a and b) indicate that microcline will convert to monoclinic orthoclase at 525°C, but under laboratory conditions this inversion is not reversible. It is concluded that microcline is not stable under hydrothermal conditions above the experimentally determined inversion point, but that orthoclase or monoclinic potassium feldspar is stable at any temperature.

Alteration by later processes has been invoked to explain increasing triclinicities of originally monoclinic feldspars. Thus Heier (1957) considered that post-magmatic hydrothermal solutions were responsible for converting monoclinic potassium feldspars to the triclinic form in post-orogenic granites on Langy, Norway. Dietrich (1962) believed that the sympathetic increase in triclinicity with the increasing differentiation of the Boulder batholith to be due possibly to an increasing volatile content in addition to a lower temperature of crystallization. Kolbe (1966) noted that in the Cape granites all potassium feldspars with high triclinicity values (with the exception of a pegmatite) are from deformed granites. Kolbe concluded that it was likely "that post-magmatic hydrothermal solutions and/or deformation during a later metamorphic event caused some Na redistribution between the K-feldspar and plagioclase of the granites from some areas (e.g. George) resulting both in anomalously low 'temperatures of formation' and in high obliquity values of their K-feldspars".

The possibility that a later thermal event affected the potassium feldspars of the Swaziland granites cannot be excluded for discordant ages have been obtained on micas from the pluton north of Mbabane. There is no evidence either macroscopically or microscopically that the granites suffered any major deformation which could be held responsible for high triclinicity values.

In both the Homogeneous Granite and the Granite Plutons only the highly ordered microclines are found to be replacing plagioclase. It seems inevitable to conclude that the development of triclinic, twinned microcline was coincident with the act of replacement. Where potassium feldspars which do not display the typical grid-iron cross-hatching have been seen in the Homogeneous Granite (e.g. west of Mankaiana) there is no sign of replacement (see Figure 4). This phenomenon has been observed in other Precambrian granitic terrains and no comparable relationship between orthoclase and plagioclase has been reported (Marmo, 1962). It was not possible to obtain a satisfactory concentrate of the potassium feldspar from the granite illustrated in Figure 4. Myrmekite accompanies the replacement of plagioclase by potassium feldspar, and the myrmekite truncates the delicate, film microperthite suggesting that the growths formed, and hence the replacement took place, at temperatures below that of the exsolution of the microperthite. Furthermore it is reasonable to conclude that, had the triclinic microcline resulted from an inversion from an original monoclinic form, potassium feldspars with intermediate triclinicity values would have been detected.

The lack of replacement phenomena and of cross-hatched twinning on the one hand and on the other the presence of highly ordered microcline consistently embaying and replacing plagioclase suggests that the latter type of potassium feldspar may have been originally triclinic and may not have evolved from a feldspar of original monoclinic ancestry.

While it must be accepted on the evidence of Heier (1957), Dietrich (1963) and Kolbe (1966) that, in some granites, microcline may have originated as a result of later alteration processes, it is considered that highly triclinic microclines in the Homogeneous Granite and the Granite Plutons are an original feature. Experimental studies (Laves, 1951) have so far shown that artificial microcline can only be produced by a replacement of albite by potassium feldspar, which process is in accord with what is observed in nature.

MYRMEKITE, PERTHITE AND MANTLED FELDSPARS

The origin of myrmekite has been the subject of much discussion since Sederholm applied the term to this particular type of intergrowth in 1897. Becke (1908), Eskola (1914) and Sederholm (1916) believed that myrmekite was formed after the greater part of the magma had crystallized and that "solutions and gases derived from more distant parts of the same rock mass still circulated within them" (Sederholm, 1916), the myrmekite being formed by the replacement of potassium in microcline by soda and lime from these late-stage magmatic solutions.

Bugge (1943) has described myrmekite which in some examples is embayed into microcline and which in others is found as highly corroded grains entirely surrounded by the potassium feldspar. Spencer (1945) did not regard the formation of myrmekite as a replacement phenomenon. He considered that myrmekite "originated by the coalescence of the soda-lime component separating by ex-solution from the potash feldspar. Such segregations might form myrmekitic intergrowths with the crystallizing potash-soda feldspar or alternatively collect into blebs, finally to crystallize out from solution as myrmekite". Previously, Spencer (1938) had stated his belief that myrmekite could result from direct crystallization of an albite-rich phase caused by late-stage separation of the magma into two portions, one rich in potassium and the other in sodium.

Shelley (1964) concluded that myrmekite growths result from the concentration of albite exsolved from orthoclase in fractures or along grain boundaries of the orthoclase. The exsolved albite is regarded as growing either on a plagioclase seed in a cataclastic texture or, in structural continuity, on to a neighbouring plagioclase grain, incorporating grains of quartz and thereby exerting a confining pressure on such quartz inclusions. Growth of myrmekite will be towards the source of albite so that the myrmekite heads will be convex towards the potassium feldspar and the confined quartz will develop as rods in this direction.

Hubbard (1966) studied myrmekite in certain Nigerian charnockites and found support for the proposal that a hypothetical silicate, $Ca(AlSi_3O_8)_2$, held in solid solution in the feldspar, would release silica for the myrmekitic growths on its reversion to anorthite.

The explanations of Becke and Sederholm are tantamount to an albitization of the granite. Chemical analyses of Homogeneous Granite (Hunter, in press), in which myrmekite is present, fail to reveal any evidence of albitization in sufficient amount to account for the abundance of the intergrowth. The use of the Niggli value k bears this out : the value for k in a granite in which no myrmekite is present is 0,43, and is 0,44 and 0,51 respectively for two granites in which myrmekite is common. Although microcline replaces an oligoclase porphyroblast in biotite-hornblende gneisses no myrmekite heads develop. Similarly myrmekite is rare in the granites building the high-level plutons.

In the Homogeneous Granite myrmekite heads cut sharply across the microperthitic intergrowths, particularly those with vague ill-defined margins which are believed to result from exsolution. Thus myrmekite must have formed at temperatures below the ex-solution temperature.

Myrmekite in the Homogeneous Granite, in the tonalitic gneisses and, when developed, in the Granite Plutons is confined to those areas where microcline is replacing oligoclase. This coincidence suggests that the sodium and calcium released by the replacement furnished the material necessary for the formation of myrmekite. The potassium released by the replacement of the microcline by the myrmekite could lead to the sericitization of the oligoclase and the myrmekite. The formation of myrmekite follows the reaction :

$$2NaAlSi_3O_8 + K_2O \rightleftarrows 2KAlSi_3O_8 + Na_2O$$

from which it is clear that the way the reaction will operate will depend on the relative concentration of sodium and potassium.

Bugge (1943) has proposed that the development of perthitic feldspars and myrmekite are the responses to the replacement process. Rhythmic crystallization leading to the formation of perthitic feldspars may result if the potash-rich solutions attacking earlier formed plagioclase fail to carry away the dissolved Na and Ca, and, hence, become enriched with respect to these elements. "If crystallization of plagioclase takes place simultaneously with the resorption of potash-feldspar, myrmekite will be formed, which is then again exposed to resorption during the continued crystallization of the potash feldspar".

Myrmekite is not always present in the Homogeneous Granite and is rare in the Granite Plutons where microcline is embaying and replacing the plagioclase. The above explanation would provide the necessary mechanism to account for this phenomenon.

Microperthitic intergrowths are found in most potassium feldspar grains. In the Homogeneous Granite delicate film perthite is the most typical, whereas in the Granite Plutons a coarser vein type of microperthite is found. Of particular interest, however, are the microperthitic intergrowths consisting of flame-like veins leading into microcline grains from an external rim of albite which occurs in minute interstitial areas. This type of perthite was named deuteric by Alling (1938) but has also been known as injection perthite. This type of perthitic intergrowth is found in the Homogeneous Granite confined to the belt, containing stanniferous pegmatites, which extends southeastwards from Mbabane. From the microscopic evidence it would appear that this type of perthite results from the introduction of sodium-rich solutions and their crystallization along minute cleavage and contraction planes, and other lines of weakness. That there has been an increase in the amount of sodium in the granites in which this type of perthite appears is borne out by chemical analyses. The average k value for the Homogeneous Granite in the Mbabane area is 0,4 but in the Tin Belt this falls to 0,29. Similar perthitic intergrowths have been observed in the stanniferous pegmatites.

The presence of mantled feldspars is confined to the coarsely porphyritic granite lying to the east of Mhlosheni. The origin of potassium feldspars mantled by oligoclase has led to lively debate, origins due to metamorphism, feldspathization and basification have all been proposed. In the case of the Swaziland mantled feldspars these growths are confined to granites which carry both biotite and hornblende. This could be used as evidence to support an origin by basification whereby an enrichment in Na and Ca prevented the further crystallization of the potassium feldspar, absorbed the margins of the already formed microcline and resulted in the deposition of a rim of oligoclase around the potassium feldspars.

Experimental work by Tuttle and Bowen (1958) has shown that mantled feldspars could result from the crystallization of a magma, having low contents of lime, according to the system $NaAlSi_3O_8 - KAlSi_3O_8 - SiO_2 - H_2O$. Potassium-rich feldspar, becoming progressively richer in the albite molecule, would crystallize first, and be followed by quartz. With further crystallization of quartz and feldspar the path of crystallization will move along the quartz-alkali feldspar boundary towards the Ab-Or side line accompanied by increasing water content of the liquid and increasing pressure. Provided that "the overburden withstands the pressure being generated by crystallization and concomitant increase in water pressure" the liquid will reach a point where the temperature has fallen to 660°C. At this temperature Tuttle and Bowen (1958) have shown that "the top of the solvus in the binary system Ab-Or will be intersected, and that two feldspars will crystallize together with quartz", but "as the temperature is lowered one will become richer in potassium and the other richer in sodium". As this change is not abrupt "some of the alkali feldspars will be zoned towards oligoclase, and others towards orthoclase".

This explanation is acceptable insofar as the older Granite Pluton is concerned, for only in this pluton is there evidence of the preservation of an original roof, which shows no evidence of having been pierced by the coarser phase of the granite. It would be reasonable to suggest that the roof had sufficient strength to withstand the build-up of water pressure on crystallization.

CONCLUSIONS

The existence of highly triclinic microclines in the Homogeneous Granite, Granite Plutons and the pegmatites and augen associated with the Ancient Gneiss Complex has been indicated and it has been concluded that the structural state of the feldspars is a reflection of original crystallization. The implication of this conclusion is that, at least in part, the crystallization of certain of the granitic rocks in Swaziland took place under hydrothermal conditions. It is pertinent to examine whether other evidence from these rocks is in accord with this view.

Residual metamorphic or "resister" rocks within the Ancient Gneiss Complex indicate that, prior to granitization, regional metamorphism reached the cordierite-amphibolite facies. Migmatites display apparently retrogressive mineral changes (Hunter, 1970) accompanied by an increasing degree of feldspathization. This relation is inconsistent with the view that the retrogressive changes were associated with falling temperature and pressure but suggest that increasing amounts of water accompanied the onset of granitization (feldspathization).

The formation of sediments favours enrichment in potassium but, when the recrystallization of such sediments is considered, the resulting rock is usually granodioritic or tonalitic in composition. The process of recrystallization appears to result in an expulsion of potassium and also of water. Thus hydrothermal conditions can be established (Marmo, 1962). In the light of the retrogressive changes found to accompany the granitization of the Ancient Gneiss Complex wherein a water phase is considered to have existed, this hydrothermal state appears to fit the facts. It is also known that the regional metamorphism and granitization of the Ancient Gneiss Complex was accompanied by strong tectonism. Under these conditions the sites of lower free energy would provide the locations for the collection of the hydrothermal materials to give rise to augen, pegmatites and granitic veins. On a microscopic scale the hydrothermal materials might concentrate at the interfaces between mineral grains attacking and corroding plagioclase grains where these are present.

The field evidence strongly supports the view that the Homogeneous Granite accumulated in sheet-like bodies, overlying the Ancient Gneiss Complex, in a non-orogenic environment (Roering, 1967). The contact between the Homogeneous Granite and the Swaziland or Pongola Sequences is often conformable for long distances with the strike of the country rocks within which the contact metamorphic aureole is restricted to a narrow zone. If the Homogeneous Granite was formed by slow accumulation of material under low temperature and hydrothermal conditions, it would be reasonable to expect that the accumulation, being uncontrolled by tectonic factors, would take place upwards and at sites of low free energy. The interface between the Swaziland and Pongola Sequences above and the Ancient Gneiss Complex below would satisfy, at least in part, this requirement, and the solidifying magma could have a sheet-like disposition.

The Granite Plutons were not forcibly emplaced as is demonstrated by the lack of strong deformation associated with them, and it can be concluded that their emplacement was slow and relatively passive. There is no evidence that the plutons spread out at higher levels in a sheet-like manner. Furthermore they are apparently randomly distributed so that no postulations can yet be made to account for their distribution.

The field evidence is thus not at variance with a belief, based on the structural state of their potassium feldspars, that the Homogeneous Granites and the Granite Plutons could have accumulated under hydrothermal conditions.

The problem of the source of the potassium for the Homogeneous Granite and the Granite Plutons remains unsolved. Both granite types are richer in potassium than the eutectic granite composition. The chemistry of the Swaziland Sequence (Viljoen and Viljoen, 1969) indicates that no suitable source can be found there. Wet granitic melts do not move far and hence it must be concluded that the potassium required was derived from the Ancient Gneiss Complex and/or from depth as a result of a major potassium addition to the crust.

The linear zone of cassiterite-bearing pegmatites, extending northwestwards across Swaziland, is apparently related to albitization, although the available data is not yet adequate to fully substantiate this statement. Tantalum minerals are associated with the cassiterite in these pegmatites. Around Forbes Reef, where a more potassic phase of the Homogeneous Granite crops out on the northeastern side of the Tin Belt, columbium minerals have been recovered from placer deposits derived from the erosion of this granite. Although no columbite has been found *in situ* in this granite it seems reasonable to assume that the potash-rich granite and its associated pegmatites are the hosts of the columbite.

These features require explanation but at this stage the data is inadequate to formulate any firm conclusions. Spencer (1938) has suggested that at a late stage of crystallization a magma separates into two fractions of gradually increasing immiscibility : one very rich in soda and the other in potash with some soda. Soda-rich magma being smaller in quantity and possibly denser might follow channels taken by the potash-rich solutions and give rise to albitization and the complex mineralized pegmatites. Grieg (1927) has shown that the silicates of potash and soda are completely miscible but it is significant that the immiscible systems he describes are those which contain high silica concentrations and may therefore be more analogous to the end-stage pegmatites. The confinement of the albitization to a linear zone suggests that some deeper structure was responsible and it may be that the late albitization which apparently accompanied the migration of the tin is unrelated to any fractionation in the Homogeneous Granite.

The antipathetic relationship between columbite and tantalite may be a reflection of zonation with the latter belonging to a deeper thermal zone. Alternatively, the fact that the Homogeneous Granite in the Tin Belt carries more sphene, zircon and allanite may influence the distribution of columbite and tantalite. Columbium can diadochically replace Ti and Zr up to several per cent in the abovementioned accessory minerals which may result in an apparent empoverishment in columbium and an enrichment in tantalum in the Tin Belt.

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KEY TO FIGURES

Figure 1 : X-ray powder diffraction curves for potassium feldspars from Swaziland. The samples are from :

A. Ngwempisi pluton, Sample No. 1.
B. Ngwempisi pluton, Sample No. 35.
C. Older granite pluton, Sample No. 46.
D. Homogeneous granite, Sample No. 8.
E. Homogeneous granite, Sample No. 41.
F. Homogeneous granite, Sample No. 42.
G. Feldspar in leucocratic veinlets in Ancient Gneiss Complex, Sample No. 15.
H. Augen in Ancient Gneiss Complex, Sample No. 14.

Figure 2 : Oligoclase porphyroblast in biotite-hornblende gneiss being replaced by cross-hatched microcline. Transitional zone from gneisses to Homogeneous Granite near Nyonyane Hill, southeast of Mbabane. X50.

Figure 3 : Typical grain of microperthitic microcline with enclosed grains of amphibole and plagioclase in mesocratic Homogeneous Granite from near contact with Swaziland Sequence in Usushwana Valley. Near the bottom of the photograph there is a plagioclase grain with a distinct, clear, albite rim against the microcline. X50.

Figure 4 : Typical equigranular texture of medium-grained Homogeneous Granite, west of Mankaiana. Note the absence of microcline cross-hatched twinning and of replacement of plagioclase by potassium feldspar. X50.

Figure 5 : Bulbous heads of myrmekite embayed into microcline-microperthite. Homogeneous Granite. X50.

Figure 6 : A large plate of plagioclase feldspar in contact with grains of microcline. Note absence of myrmekite but microcline embays the plagioclase to the left of centre of photograph. Homogeneous Granite. X50.

Figure 7 : Flame-like veins of albite in the extinction position. Note the host microcline displays on it past the typical cross-hatched twinning. Homogeneous Granite from the so-called Tin Belt near Mbabane. X50.

Figure 8 : Locations of feldspar samples collected for triclinicity studies.

* *

APPENDIX

LIST OF LOCATIONS AND TRICLINICITY VALUES OF POTASSIUM FELDSPARS

Collection No.	Location	Triclinicity Value
	GRANITE PLUTON	
1.	Ngwempisi pluton 200 m from contact, 11 km north of Mankaiana	0,96
3.	Sinceni pluton at Tulwane Store	0,97
5.	Sinceni pluton, turn-off to Lukula Ranch on Sipofaneni road	0,91
6.	Sinceni pluton at Tulwane Store	0,97
30.	Mbabane pluton, porphyroblasts at head of Pine Valley	0,92
31.	Mbabane pluton porphyroblasts, near contact, 2,4 km north of Mbabane	0,96
32.	Ngwempisi pluton, at road bridge over Hlabashana stream	0,91
33.	Sicunusa pluton, 1,8 km east of Sicunusa	0,97
34.	Sicunusa pluton, near contact, 3 km north of Sicunusa	0,86
35.	Ngwempisi pluton, near contact, 8 km northeast of Mankaiana	0,88
38.	Ngwempisi pluton, porphyroblasts in gneiss inclusion, 11 km northeast of Mankaiana	0,92
44.	Mhlosheni pluton, 17 km southeast of Goedgegun	0,96
45.	Mhlosheni pluton, 24 km southeast of Goedgegun	0,96
18.	Older granite pluton, Kwetta Spruit	0,91
46.	Older granite pluton, 3 km southeast of Mhlosheni	0,96
47.	Older granite pluton, porphyroblasts, 3 km southeast of Mhlosheni	0,96

Collection No.	Location	Triclinicity Value
	HOMOGENEOUS GRANITE AND ASSOCIATED PEGMATITES	
8.	Granite, railway cutting, Usushwana River, 14 km south of Mbabane	0,98
9.	Granite, contact with Swaziland Sequence, from borehole core near Forbes Reef	0,98
17.	Graphic granite alongside main road 8 km south of Border Gate	0,98
25.	Granite (tin belt), Mhlambanyati road 3 km southwest of Mbabane	0,91
27.	Granite, Enkoyoyo quarry near main road to Oshoek	0,95
37.	Large insets in granite Swaziland Plantations	0,99
40.	Granite, 3 km south of Pigg's Peak	0,97
41.	Large insets in granite 6 km south of Goedgegun	0,99
42.	Granite, 10 km southeast of Mhlosheni	0,93
43.	Granite, 6 km south of Goedgegun	0,92
7.	Pegmatite in Swaziland Sequence adjacent to contact in borehole, Forbes Reef	0,98
19.	Pegmatite, Pentouyz, Sinceni	0,98
20.	Pegmatite, Ncgotshane River, southwest of Hluti	0,98
21.	Pegmatite, Mkhondo River, 3 km northeast of Mahamba	0,90
26.	Pegmatite 3 km southwest of Mbabane	0,98
	MISCELLANEOUS SAMPLES OF FELDSPAR	
13.	Pegmatite in hybrid quartz diorite Usushwana River road bridge carrying main Mbabane-Manzeni road	0,82
14.	Augen in quartz-biotite-garnet gneiss, 14 km northeast of Hlatikulu	0,97
15.	Feldspar in leucocratic veinlets in gneiss, Poponyana Falls, 7,6 km northeast of Pigg's Peak	0,98
28.	Feldspar in leucocratic veinlets in gneiss at contact with Swaziland Sequence, Motshane Valley, 11 km west-northwest of Mbabane	0,96
29.	Augen in migmatites at Swaziland Sequence contact, Motshane Valley, 15 km west of Mbabane	0,97
30.	Augen in migmatitic gneisses Poponyana Falls, 7,6 km northeast of Pigg's Peak	0,97

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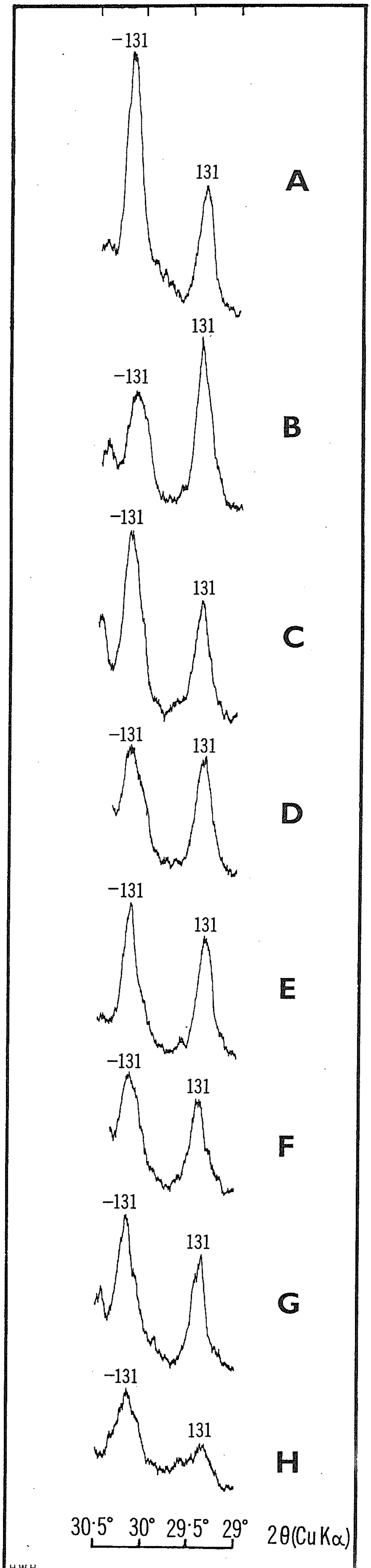

−131
131
A
131
−131
B
−131
131
C
−131
131
D
−131
131
E
−131
131
F
−131
131
G
−131
131
H
30·5°
30°
29·5°
29°
2θ(CuKα)
H.W.H.

Figure 1.

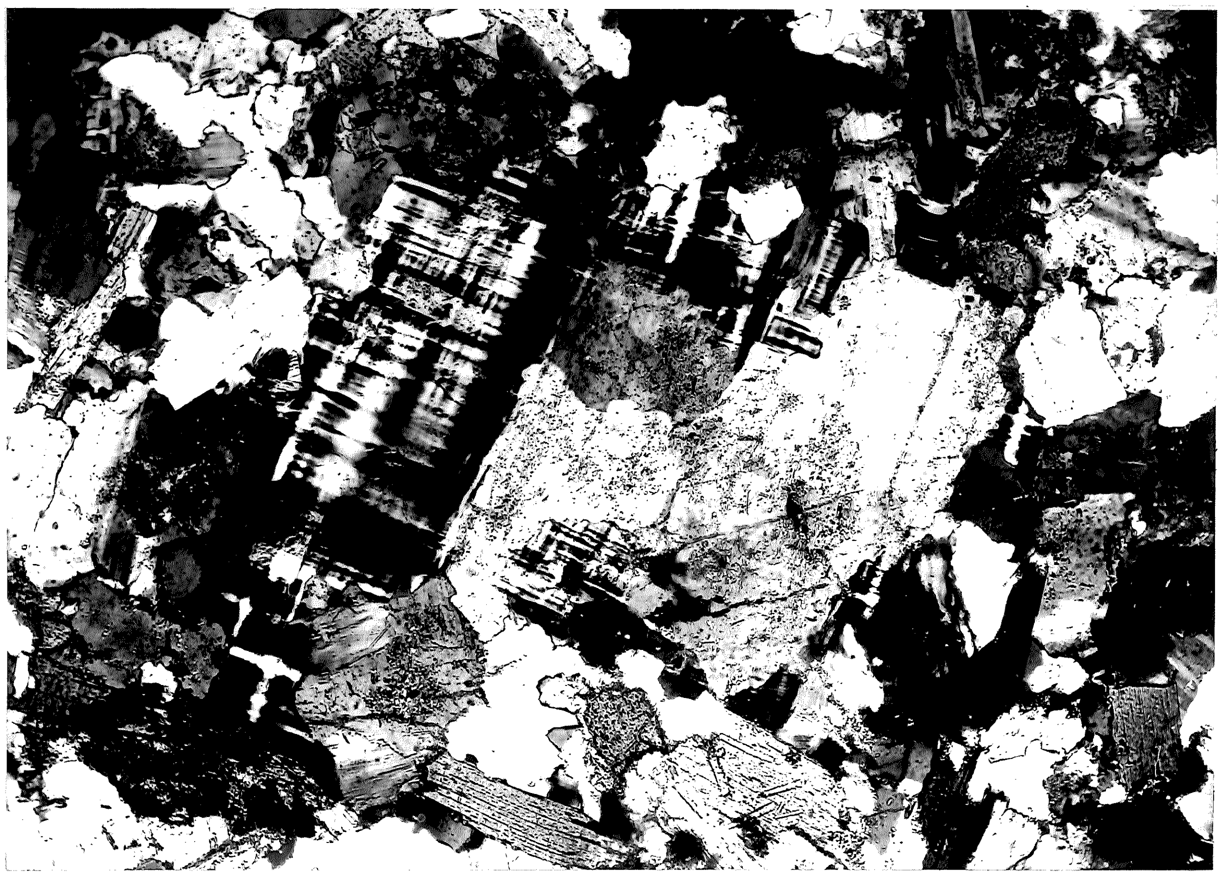

FIGURE 2

FIGURE 3

FIGURE 4

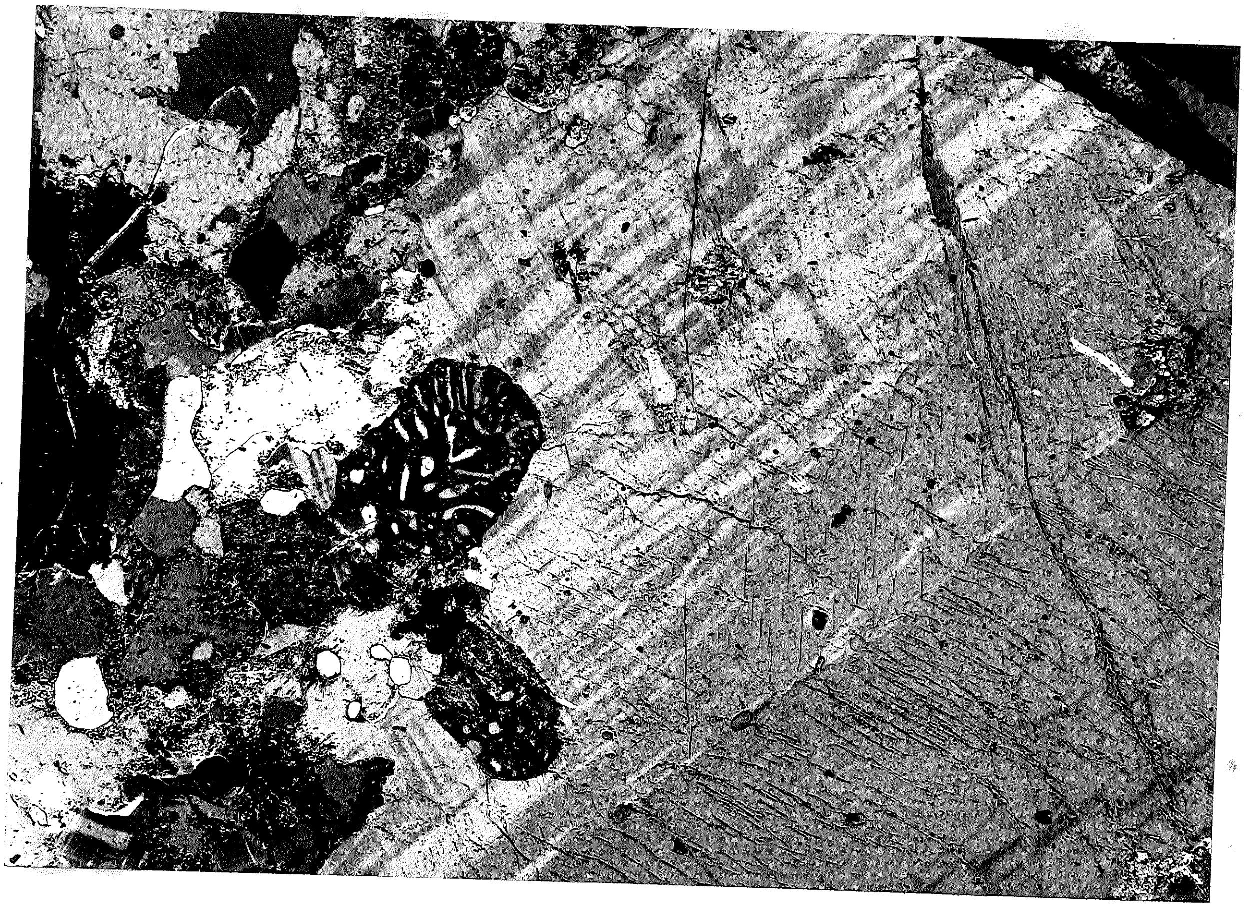

FIGURE 5

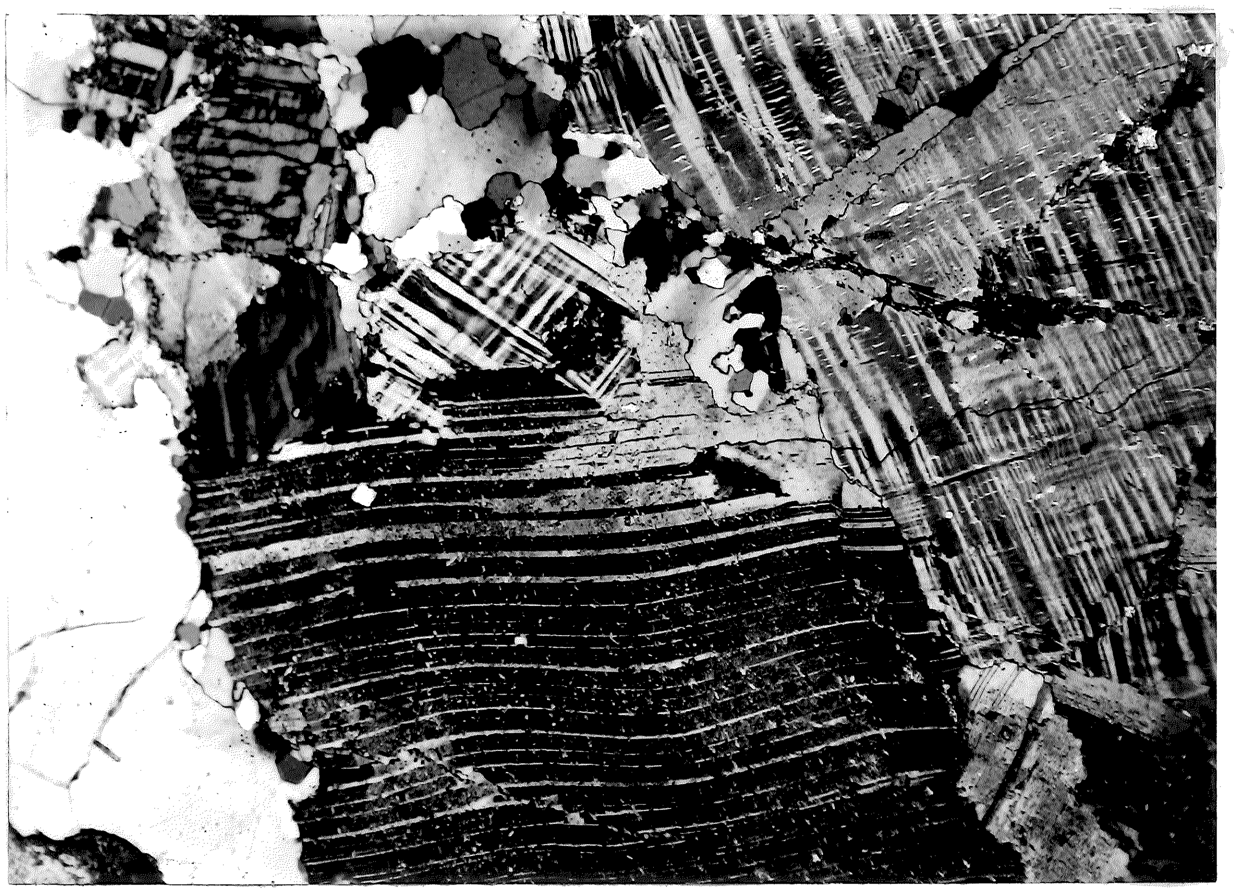

FIGURE 6

FIGURE 7

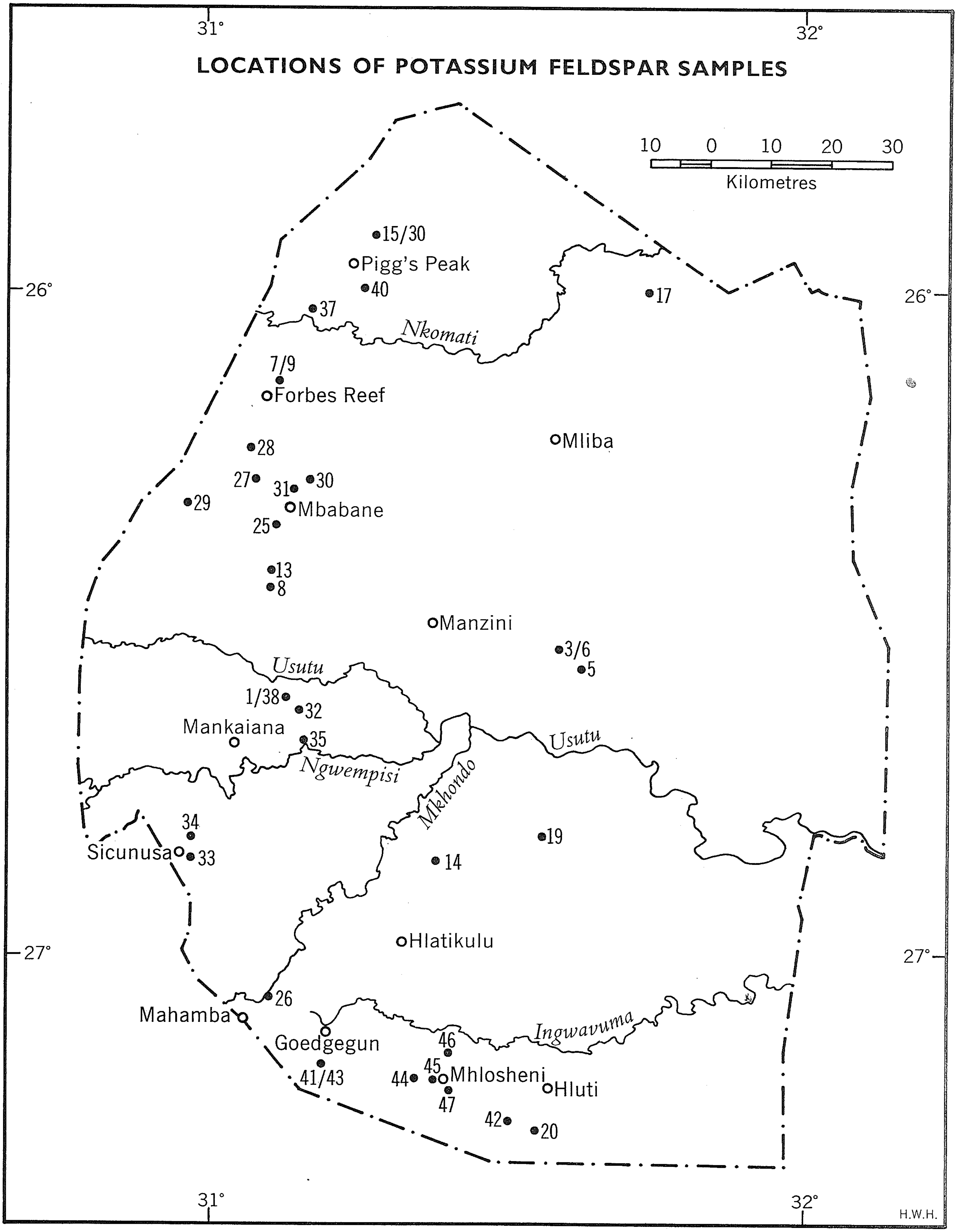
31°
32°
LOCATIONS OF POTASSIUM FELDSPAR SAMPLES
10 0 10 20 30
Kilometres
26°
26°
15/30
Pigg's Peak
40
37
17
Nkomati
7/9
Forbes Reef
Mliba
28
27
31
30
29
Mbabane
25
13
8
Manzini
3/6
5
Usutu
1/38
32
Mankaiana
35
Usutu
Ngwempisi
Mkhondo
34
Sicunusa
33
19
14
Hlatikulu
27°
27°
26
Mahamba
Goedgegun
Ingwavuma
46
45
41/43
44
Mhlosheni
Hluti
47
42
20
31°
32°
H.W.H.

Figure 8.