III. THE ROOF-ROCKS

The roof-rocks are restricted to the western half of the area and form the high-lying region generally referred to as the Sekhukhune Plateau. A great variety of acid volcanic and intrusive rocks is developed here, previously described in some detail by Boshoff (1942) and A. F. Lombaard (1949). The aim in remapping these rocks was to establish whether the relationships between the various roof-rocks at the southern extremity of the Sekhukhune Plateau could be correlated with the proposed origin of similar rocks from west of Bothasberg (Von Gruenewaldt, 1968). Consequently, the description of these rocks in the following pages is based mostly on the observed relationships in the field, as microscopic re-investigation would probably only confirm the work of Boshoff (1942) and Lombaard (1949).

1. The Rooiberg Felsite

a) Field-relationships

Rocks which are considered as belonging to this volcanic sequence, occupy a large basin in the western half of the area. They are intruded discordantly by a thick sill of granophyre which separates the highly metamorphosed rocks at the base from relatively little altered types at the top. Owing to the Steelpoort Fault, only the lower, metamorphosed rocks of this sequence are developed to the east, whereas the bulk of these acid volcanics which lie above the granophyre outcrop to the west of the fault. From dip measurements of the banding and from intercalated sediments, the thickness of the volcanic rocks was calculated as being close to 3000m of which more than 2500m are preserved above the granophyre.

Recently, the author (1968, p. 159) has subdivided the Rooiberg Felsite west of Bothasberg into three zones on the basis of different rock types developed in the sequence. The Lower Felsite Zone, (ibid., p.154-159) which consists of black felsitic rocks recrystallized to micrographic felsite and leptite, is separated from the Upper Felsite Zone of mostly red porphyritic rock types, by a thick middle zone of predominantly amygdaloidal felsite. This threefold division can also be applied to this area, although there are pronounced differences, especially between the upper two zones of these two areas.

i) The Lower Felsite Zone

The rocks of this zone have a sharp, undulating contact with the rocks of the Layered Sequence (Fig. 2) and are highly altered to a variety of recrystallized and partially remelted rock types collectively referred to as leptite. As a result, it is practically impossible to determine the original nature of these rocks, but because of the relatively homogeneous appearance of this leptite, and the presence of plagioclase phenocrysts, they were probably uniform, dark, glassy porphyritic felsites. Seeing that felsites of the higher zones are also involved in this high-grade metamorphism, the leptites are described collectively under a separate heading below.

In the extreme west of the area, on the farm Bankfontein 158 JS some of the rocks of this zone are present above the granophyre and are less altered than their counterparts from lower horizons. They consist, for the greater part, of alternating brown and black, very fine-grained, slightly recrystallized, porphyritic and non-porphyritic felsite.

Amygdaloidal felsite is extremely scarce in this zone and was observed between Doornpoort 171 JS and Drievoet 182 JS, on Kafferskraal 181 JS and on Buffelsvallei 170 JS. Recrystallized rocks which still display flow-banding and also some agglomeratic textures are found in association with the first-mentioned occurrence of amygdaloidal felsite.

On the north-eastern side of the hill on which the trigonometrical beacon 121 south of Tauteshoogte is situated, fine-grained dark grey to black amygdaloidal lavas are developed. A thin section (G17) of these rocks revealed the presence of large amounts of small plagioclase crystals (An_{41}) as well as a few grains of garnet. These rocks may represent uplifted Dullstroom Volcanics, the garnets probably having originated from material in the amygdales.

ii) The Middle Felsite Zone

This zone, some 1700m thick west of Bothasberg (ibid., p. 159), has its counterpart in this area in one thin layer of amygdaloidal felsite about 150m thick. It occurs above the granophyre on the farm Bankfontein 158 JS where it consists of a black amygdaloidal felsite, and also below this granophyre on the eastern side of the Steelpoort Fault. Here it could be followed from Zaaiplaats 157 JS in the north to Uitkyk 172 JS in the south, where it seems to peter out, although the amygdaloidal rocks on Duikerskrans 173 JS and The Wedge 175 JS may also belong to this zone.

iii) The Upper Felsite Zone

Rocks of this zone form the bulk of the Rooiberg Felsite in this area. They

Fig. 2. Sharp, undulating contact between diorite of the Upper Zone (light) and leptite (jointed, dark). Quarry north of the main road on Buffelsvallei 170 JS

consist mostly of homogeneous porphyritic and non-porphyritic black or red felsite. Black varieties are especially common in this zone and were not found by the author west of Bothasberg. Near the middle of the succession is a thin layer of quartzite which could be followed for 4,5km along strike. On Paardenfontein 159 JS, strange asterisk-shaped patterns are developed on the weathered surface of these rocks (Fig. 3), but were not investigated. Some agglomerate is developed below and above the quartzite on the western portion of this farm. The top of the zone shows some variation in this respect that flow-banding is well developed along the western boundary of Holnek 153 JS (Fig. 4) and that the highest exposed horizons consist of a prominent black agglomerate (Fig. 5) underlain locally by a red tuff which contains a few volcanic bombs. Apart from fragments of felsitic material, the agglomerate also contains fragments of quartzite (Fig. 6).

The noticeable differences between successions of Rooiberg Felsite from the Sekhukhune Plateau and Bothasberg do not make regional correlations of certain horizons feasible at this stage, as was done recently by the author (1968, Table 1, p. 159. See also Coetzee, 1970, p. 324).

It is generally believed (Hall, 1932, p. 242-250; B. V. Lombaard, 1932, p. 163 and Willemse, 1969a, p. 6) that the Rooiberg Felsite represents lavas, but owing to the homogeneous nature of the greater portion of the succession, no clarity exists as to the mode of emplacement of these rocks, and Willemse (1964, p. 115) even mentioned the possibility that the rocks could be a composite product of magmatic differentiation, anatexis and palingenesis.

An ignimbritic origin for the agglomerates west of Naboomspruit was postulated by Menge (1963, p. 7-12). A similar origin for the massive, homogeneous porphyritic and non-porphyritic felsite north of Nylstroom was rejected by Coetzee (1970, p. 322-323) on account of a lack of textural evidence in these rocks and he suggested that (p. 324) "the felsites themselves are fused and mobilized Pretoria Series sedimentary rocks". Such a theory is hardly acceptable because of the presence, although not abundant, of amygdaloidal rocks, flow-banding, agglomerates and tuffs. The author would favour a volcanic origin for these rocks, whether as separate lava-flows or as thick accumulations of ignimbrites. Very detailed mapping, microscopic investigation and chemical analyses may throw some light on the thicknesses and lateral extent of the individual flows and also on the mode of emplacement of these rocks.

Fig. 3. Asterisk-shaped patterns in quartzite interbedded in Rooiberg Felsite. Paardenfontein 159 JS.

Fig. 4. Flow-banded felsite in the Upper Felsite Zone on Holnek 153 JS.

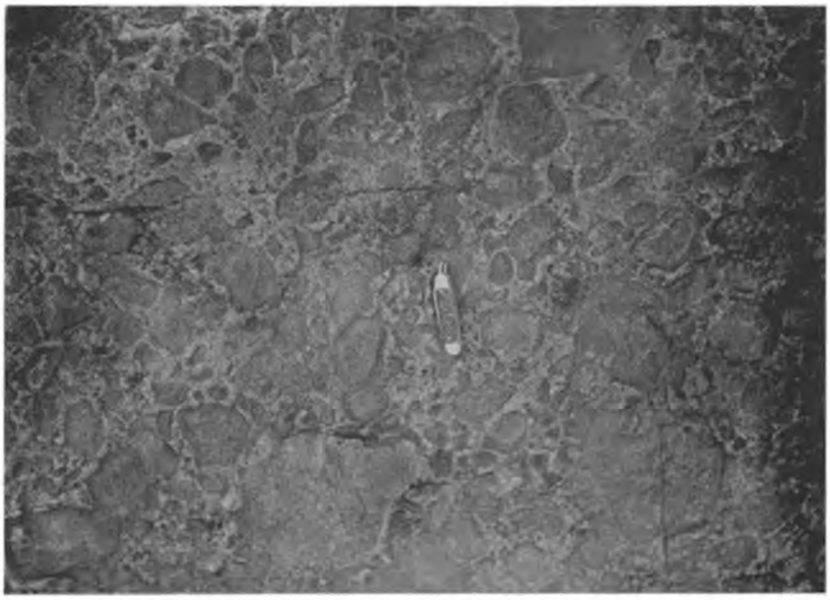

Fig. 5. Agglomerate of the Upper Felsite Zone on Holnek 153 JS.

Fig. 6. Black agglomerate containing fragments of quartzite. Upper Felsite Zone, Holnek 153 JS.

b) Leptite

As stated above, rocks of all the three zones are developed below the thick transgressive sheet of granophyre and are collectively referred to as leptite. The author (1968, p. 156) considers these fine-grained acid rocks to be recrystallized, metamorphosed Rooiberg Felsite. They were subdivided (p. 155-156) into leptite, (i. e. fine-grained, granular quartz-feldspar rocks) at the base and micrographic felsite (i. e. those rocks which display an intergrowth of quartz and K-feldspar (ibid., Plate I, Fig. 1)) above the leptite. Microgranites were described as occurring on the same stratigraphical horizon as the leptite and the micrographic felsite and are considered to have originated by partial melting of these rocks.

All three these rocks are present in the Tauteshoogte area and although an effort was made to distinguish between them in the field, it was found to be very difficult owing to the irregular relationships and gradual variations between them. The macroscopic characteristics and distribution of the various rocks are broadly as follows:

i) The micrographic varieties are usually dark in colour, i. e. dark grey to dark brown, but red where coarser grained. Leptite is usually brown to red in colour but where these rocks grade into micrograntites the colour is usually red to light red.

ii) In the fine-grained varieties, original plagioclase phenocrysts can clearly be seen on weathered surfaces as small, white angular spots. Original amygdales are sporadically found in these rocks and consist either of quartz or of spherical concentrations of hornblende. In the microgranites, these textures were not observed.

iii) Micrographic felsite is present only in the southern area i. e. on the farms Doornpoort 171 JS, Uitkyk 172 JS, Kafferskraal 181 JS and Paardekloof 176 JS where they usually overlie leptite or micro-granite. They were hardly ever observed to be in direct contact with the topmost differentiates of the Layered Sequence, the only place being locally along the new road in the valley south of Tauteshoogte.

iv) Microgranite is developed between the Layered Sequence and the overlying micrographic felsite on the southern half of Doornpoort 171 JS, for some distance along the southern edge of the Sekhukhune Plateau on Kafferskraal 181 JS and also on the south-eastern portion of Uitkyk 172 JS.

v) Leptite, on the other hand, is present over the whole area, but is the only rock type along the eastern and southern scarps of the plateau north of The Wedge 175 JS and eastwards from Buffelsvallei 170 JS, respectively.

Under the microscope, the textures of these rocks are very similar to those described by the author (1968, p. 155-157) from the Kruis River area and need not be repeated here. It is sufficient to say that variations in the grain size are common and that it is difficult to draw a line between leptite and micro-granite. Rocks of which the grain size is about 1mm or more were usually considered as microgranites and the finer-grained rocks as leptites.

The distribution of amygdaloidal rocks, agglomerates and those which display flow-banding has already been described and these rocks may therefore be termed "amygdaloidal leptite", "agglomeratic leptite" and "flow-banded leptite", respectively.

In a few localities grey, banded rocks were encountered in the leptite on the south-eastern part of the plateau. In hand-specimens, these rocks closely resemble hornfels, but in thin section they display the same fine granular texture as leptite. They differ, however, from the latter in that they contain larger amounts of hornblende and clinopyroxene and in some specimens also contain larger grains of quartz irregularly distributed throughout the ground-mass (G192, G225). Seeing that the composition and the texture of these rocks militate against a sedimentary or intrusive origin, they are provisionally considered to be interlayered tuffs, slightly more mafic than the associated leptite.

Throughout the whole area, the leptite is traversed in an irregular manner by three types of rocks, namely, veins of red, fine-grained granite, granodioritic rocks and larger patches of granophyre. The fine-grained granite closely resembles the coarser-grained varieties of the larger masses of micro-granite and is present in the leptite as thin veins to small irregularly shaped pockets, a few cm in diameter. Contacts are mostly gradational into the leptite (Figs. 7 and 8) although sharp contacts with thin rims of mafic minerals (basic fronts, Reynolds, 1947, p. 209) are also developed.

The granodiorite is generally found as larger veins and pockets, a few metres in diameter, but also as thin irregularly anastomosing veins in the leptite (Fig. 9). The larger occurrences usually have sharp, unchilled contacts

Fig. 7. Veins of fine-grained granite cutting irregularly across leptite (dark). Zaaiplaats 157 JS.

Fig. 8. Gradational contacts between leptite (dark) and fine-grained granite. Zaaiplaats 157 JS.

Fig. 9. Irregular veins of granodioritic composition produced by melting of the leptite. Duikerskrans 173 JS.

Fig.10. Close-up of Fig. 9 to illustrate gradational contacts between leptite (fine-grained) and granodiorite (coarser-grained). Duikerskrans 173 JS.

with the latter and often contain numerous inclusions of leptite whereas the contacts of the smaller veins are gradational into the leptite (Fig. 10). Of interest is the fact that, apart from appreciable amounts of quartz, K-feldspar, plagioclase and hornblende, these granodiorites also contain small amounts of fayalite. These rocks were described in detail by Boshoff (1942, p. 60-64) as sub-acid granodiorite and sub-acid granite, and by A. F. Lombaard (1949, p. 365-366) as granodiorite.

2. Granophyre and the basal granodiorite

The bulk of the granophyre is present as a thick, discordant sheet-like intrusion in the Rooiberg felsite. It has a thickness of about 2000-2500m on Buffelsvallei 170 JS and Bankfontein 158 JS but may be thicker in the vicinity of Paardekop in the north. The northern contact with the felsite on Goedgedacht 152 JS seems to be steep and cross-cutting so that dips of rocks in which it is intrusive cannot be used for calculation of its thickness, as was done in the south. The difference in elevation between the top of Paardekop and the lowest occurrence of granophyre on Groothoek 139 JS is about 1000m and this value is therefore an absolute minimum of its thickness in this area.

On the eastern side of the Steelpoort Fault, the granophyre seems to be essentially flat-lying and relatively thin, judging from the low dip of the contact with the underlying rocks in the deeply incised rivers. In the vicinity of Tauteshoogte the granophyre is also present as irregularly shaped pocket-like, sometimes granitic, intrusions in the leptite.

Throughout the greater part of the area, the granophyre varies only slightly in appearance. There are small differences in the colour, but it is homogeneous in composition in that it consists essentially of intergrown quartz and microcline perthite (see also descriptions by Boshoff, 1942, p. 39-40 and A. F. Lombaard, 1949, p. 367). Variations are microgranophyres, the most conspicuous of which is developed at Paardekop. B. V. Lombaard (1934, p. 11) referred to these rocks as felsite, and both he and Daly (1928, p. 718) consider them to be a chilled phase of the granophyre. These rocks are even more fine-grained than the microgranophyre described by the author (1968, p. 160) as cross-cutting sill-like intrusions in the Middle Felsite Zone west of Bothasberg. In thin section, the rock consists almost exclusively of an extremely fine intergrowth of quartz and K-feldspar which closely resembles spherulites in lavas. Lower down in the sequence, the granophyric intergrowth becomes gradually coarser, but on the larger part of the farm Dwars-in-de-Weg 137 JS the granophyre is finer-grained than its counterpart farther south. A. F. Lombaard (1949, p. 367) describes similar fine-grained spherulitic "felsites" which also display gradational contacts with the normal granophyre on the portion of the farm Haakdoorndraai 169 JS outside the area mapped. Finer-grained granophyres are also developed directly north of Baviaansnek on the farm Elandslaagte 155 JS.

A coarse-grained granitic variety of the granophyre is locally developed at the lowest exposed horizon on the farm Groothoek 139 JS (Folder I). In grain size it corresponds closely to the Bushveld Granite near by, but differs from the latter in this respect, that it contains some granophyric intergrowth, less hornblende and accessory minerals and no allanite. This granitic phase of the granophyre seems to be more common farther north, where sheets of granite intrusive into the granophyre and also various stages in the alteration of granophyre to Bushveld Granite were found by Molyneux (1970, p. 10). Granitic varieties were also found by the author (1968, p. 161) in similar rocks west of Bothasberg, where no Bushveld Granite is developed and it seems possible that some of the granite associated with granophyre in the area described by Molyneux may in fact be related to the granophyre.

On aerial photographs of the farms Goedgedacht 152 JS and Dwars-in-de-Weg 137 JS an interesting concentric pattern is observed in the granophyre (dotted lines Folder I). Seeing that the "spherulitic" microgranophyre occurs at the topographically highest point, i. e. at Paardekop close by, it seems as if the granophyre lies relatively flat or has a shallow dip to the west, to conform with the regional dip of the rocks of the Layered Sequence. If this is so, then the observed concentric patterns cannot be due to layering in the granophyre and may represent steeply dipping ring fractures. The fractures are however only developed in the granophyre and do not continue into the adjoining felsite.

The upper contact of the granophyre with the felsite was always found to be sharp, but at the lower contact it is separated from the leptite by a thin layer of granodiorite termed "porphyritic granophyre" by Boshoff (1942, p. 40). It differs from the granophyre in this respect that it contains appreciable amounts of hornblende and plagioclase, but it may also contain granophyrically intergrown quartz and K-feldspar and could therefore be termed "melanogranophyre". The contact with the overlying granophyre is gradational but sharp and unchilled against the underlying leptite. The melanogranophyre differs slightly in appearance from one locality to the next which is mainly due to small variations in the content of hornblende and plagioclase. In several localities it closely resembles the granodiorite which occurs as pockets and veins in the leptite, a feature also noted by A. F. Lombaard (1949, p. 367). Numerous small inclusions of leptite are present in these rocks, but are never observed in the overlying granophyre.

Of interest is the presence of veins of red granophyric granite which are intrusive in the diorites of the Upper Zone in the vicinity of Tauteshoogte. They were found in two deep valleys on the northern portion of Kafferskraal 181 JS, close to the main road, and also in the deep valley at the boundary between Uitkyk 172 JS and The Wedge 175 JS (Fig. 11). Although these rocks were not investigated under the microscope, they closely resemble the pocket-like intrusions of granophyre in the leptite. Their probable mode of origin is given below.

In his treatise on the geology of the Bushveld Complex in the Blood River area, A. F. Lombaard (1949, p. 358-361) describes a gradual transition from the olivine diorite of the Upper Zone to the overlying granophyre. These unusual transitional relationships are to be found along the slopes of two prominent hills which stand apart from the Sekhukhune Plateau and on which the western and southern beacons of the farm Drievoet 182 JS are situated (Folder I). As described by Lombaard, the rocks grade upwards from olivine diorite to fayalite-bearing diorite to fayalite-bearing melanogranophyre to granophyre. He (ibid., p. 369) considers this transition to be due to magmatic differentiation, but a different hypothesis by which such relationships may originate is postulated below.

3. The origin of the various roof-rocks

Any hypothesis on the origin of the various roof-rocks must account for the complicated relationships which have been described above, and are briefly summarized below.

a) The presence of various rock types which traverse the leptite and display gradational contacts with it, i. e. fine-grained granite and granodiorite, as well as the larger pockets of granophyre and granophyric granite.

b) The presence of granodioritic rocks, which contain small inclusions

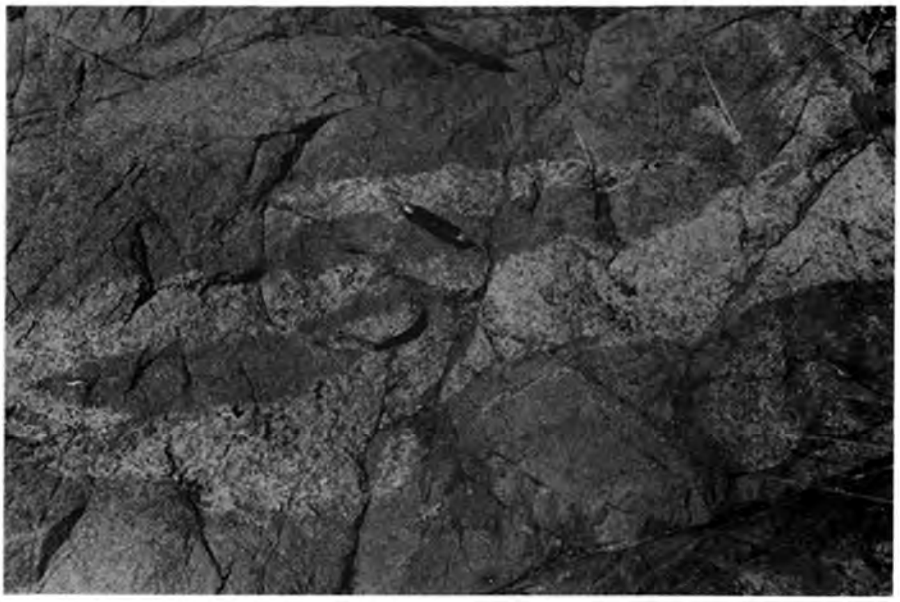

Fig. 11. Veins of granitic material cutting across diorite of the Upper Zone. Uitkyk 172 JS.

Fig. 12. Breccia of the Steelpoort Fault on Groothoek 139 JS.

of leptite, at the base of the thick sheet of granophyre and its gradation into this granophyre at the top.

c) The relatively thin sheet of leptite wedged between granophyre above and the Layered Sequence below. This leptite can be followed at the scarp of the Sekhukhune Plateau as far north as Signal Hill (Molyneux, 1970, Plate I).

d) The gradual transition from diorite of the Upper Zone to granophyre on Drievoet 182 JS and vicinity.

e) The presence of "spherulitic" micrographophyre in the normal granophyre.

f) Veins of granophyre which cut across the diorites of the Upper Zone in the Tauteshoogte area.

Boshoff (1942, p. 50-51) considers the various acid roof-rocks (granophyre, microgranite and leptite) to represent the most differentiated of successive surges of magma, from a deep-seated chamber, which gave rise to the Layered Sequence of the Complex. The discontinuity in composition between the topmost diorites of the Layered Sequence and the acid rocks is explained as being due to a considerable interval between the successive intrusions and that the composition of the magma which was generated at depth had changed in composition towards the final residual liquid during this interval, and (p. 51) "the Bushveld granophyre was emplaced after the differentiation in depth had finally attained the composition of the favoured residual magma". The inclusions of leptite in the melano-granophyre (porphyritic granophyre, p. 42) are considered by him to represent "schlieren developed locally in the lowest horizon of the porphyritic marginal phase of the granophyre" (ibid., p. 44). He also noted (p. 65) that the granodiorite and granite which occur as veins and pockets in the leptite have a composition intermediate between that of the topmost differentiates of the Layered Sequence and the Bushveld granophyre. He is of the opinion (p. 67) that owing to differentiation in situ of the pulse of magma which gave rise to the olivine diorites residual liquids of granodioritic composition were formed and injected into the overlying fine-grained rocks of the succeeding heave.

A. F. Lombaard (1949, p. 364) recognised the felsitic character of the fine-grained acid rocks (leptites) and did not include them in the Upper Zone of the Layered Sequence because of lack of evidence as to their position in time and because of the sharp contacts between these rocks and the over and underlying granophyre and olivine diorite respectively. Owing to the observed transition from olivine diorite to granodiorite and to granophyre and because both the granodiorite and the granophyre occur as pockets in the leptite, he considers (p. 366) these rocks to be part of the Layered Sequence. The sheet of granophyre which is separated from the Layered Sequence by the leptite is considered by him (p. 369) to have originated by magmatic differentiation below the roof and subsequent injection of the residual liquid into these fine-grained acid rocks.

Recently the author (1968, p. 156 and 162) summarized various other hypotheses concerning the origin of leptite and granophyre. He came to the conclusion (p. 156) that the leptite west of Bothasberg represents highly metamorphosed, recrystallized felsite, whereas the micrograNophyre and granophyre are palingenetic products of the felsite.

If the concept of Jackson (1961) of bottom crystallization and convective overturn is accepted for the origin of the Layered Sequence, then the largest amount of heat lost by the gabbroic magma was through the roof. He (ibid., p. 97) states that "convective overturn thus would have raised the temperature of the magma near the upper contact and maintained it at high values. High temperatures resulted in (1) a high rate of conductive heat loss at the top and (2) virtual cessation of crystallization there, because the adiabatic magma temperature exceeded the melting point temperature for pressures at that depth".

Recently Irvine (1970) calculated the heat transfer during solidification of layered intrusions. He is of the opinion (p. 1046-1049) that a high-temperature magma, such as a basalt, could melt a considerable amount of granitic material which has a melting temperature of 200-300°C lower than that of the magma. He calculated (p. 1059) that the time of accumulation of the Layered Sequence of the Bushveld Complex was about 200 000 years, and if the temperature of the magma was 1050°C it could melt about 1000m of the roof-rocks if melting of these rocks took place at 800°C.

Tilley et al. (1963, p. 81 and 1968, p. 458) investigated melting relations of samples from the chilled border-phases of layered intrusions and found that crystallization of liquids which gave rise to these rocks commenced at temperatures above 1200°C. These temperatures are based on dry measurements at one atmosphere and would therefore be slightly lower at higher water pressures under natural conditions. Tuttle and Bowen (1958) and Von Platen (1965, p. 342-

380) on the other hand have done a considerable number of experiments to determine the temperatures necessary to produce melts of granitic composition. From their data it is evident that at a depth of about 4km a felsite will begin to melt at about 700°C if the concentration of volatiles is high, whereas complete melting with 2 per cent of water will take place at temperatures slightly above 800°C. The available evidence therefore points to even larger differences in the melting temperature of the roof-rocks and the magma temperature of the intrusion. Consequently Irvine's conclusion that 1000m of roof-rocks could have been melted by the intrusion may even be considered as a minimum value.

Furthermore, it is of interest to note that the melting of a felsite would produce an initial liquid of a composition on the cotectic line close to the isobaric minimum in the system Ab-Or-Q-H_2O (Tuttle and Bowen, 1958, p. 75) and that subsequent cooling of this liquid necessitates simultaneous crystallization of quartz and microcline perthite, thus favouring granophyric intergrowths.

With the above experimental evidence in mind there can be little doubt that a considerable amount of melting of roof-rocks did take place and the following sequence of events, diagrammatically shown in Fig. 13, is therefore proposed to explain the observed relationships between the various rocks developed in the roof.

Emplacement of the gabbroic magma of the Bushveld Complex caused a gradual increase in the temperature of the overlying felsite which resulted in the recrystallization of these glassy rocks to micrographic felsite and leptite (Fig. 13A). As crystallization of the Layered Sequence commenced, the temperature of the metamorphic aureole gradually rose until melting started at an appropriate temperature. It is envisaged that these liquids concentrated as pockets in the leptite and gradually moved to higher levels where they spread out laterally to form, initially, thin, sheet-like intrusions in the felsite (Fig. 13B). As a large amount of the water in the felsite is probably contained in biotite and hornblende, the temperature of melting depends to some extent on the temperature at which these hydrated phases react to form pyroxene and magnetite thus releasing water for melting (Brown and Fyfe, 1970, p. 313-314). These early granophyric liquids were probably emplaced in a still fairly cool environment, resulting in rapid crystallization, thus forming sheets of microgranophyre in the Bothasberg area and the microgranophyre and "spherulitic felsite" in the Tauteshoogte-Paardekop area. As the metamorphic aureole became wider, and

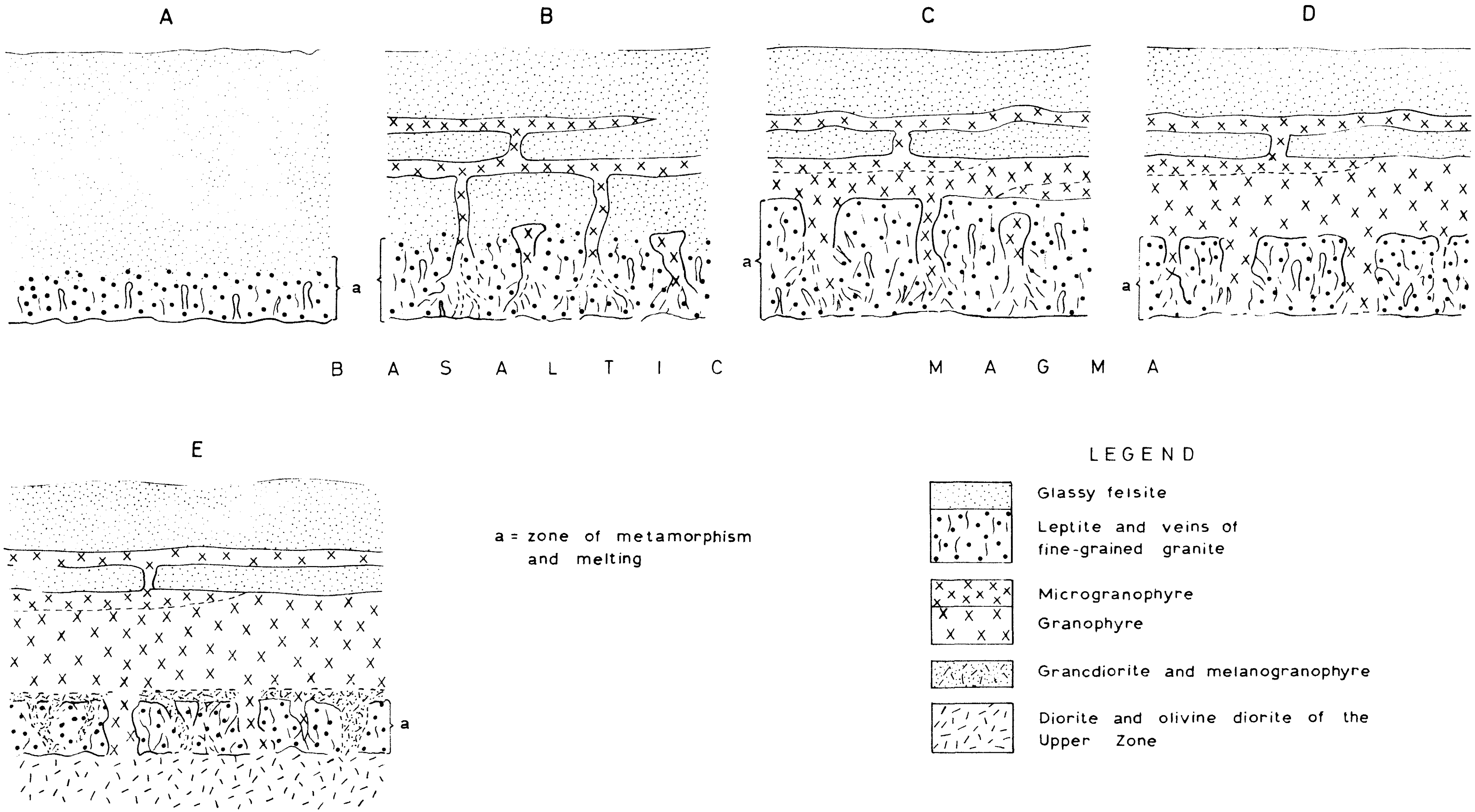

FIG. 13. STAGES IN THE DEVELOPMENT OF THE VARIOUS ROOF-ROCKS (For explanation see text)

the temperature in the roof-rocks gradually increased (Irvine, 1970, Fig. 12, p. 1047) these granophyric liquids remained fluid and were replenished by continued melting of leptite close to the contact with the basaltic magma (Fig. 13C). As stated above, some of the water for melting was probably derived from biotite and hornblende due to the reaction to form pyroxene and magnetite at high temperatures. The scarcity of biotite and hornblende in the granophyre indicates that after reaction the refractory residues remained in the leptite and were probably pushed outwards from the points of melting as basic fronts which are sometimes observed in these rocks. When the melt migrated to higher levels, the mafic constituents remained behind and were eventually assimilated by the gabbroic magma. Continuous addition of more liquid to the granophyric magma resulted in a thickening of the sheet. This thickening was in a downward direction, thus causing gradually higher horizons of the leptite to be melted (Fig. 13C and D).

This process continued until the greater part of the Layered Sequence had accumulated. At this stage, the sequence consisted therefore of a thick sheet of fluid granophyre, separated from the remaining magma of the Layered Sequence by a few hundred metres of leptite which displayed all stages of melting. This is seen as veins of granitic material cutting irregularly across the leptite and coalescing in places to form conduits which were connected to and "fed" the granophyre sheet. These conduits are preserved as the large number of pockets of granophyre and granophyric granite in the vicinity of Tauteshoogte.

The melting process so far must be considered as relatively "dry", the only water or volatiles being derived from the original felsite itself. Basaltic magmas which give rise to layered intrusions and show enrichment in iron in the later differentiates, are considered to be dry, (Hamilton and Anderson, 1967, p. 474-475) and as a result no, or very little water was added to enhance the melting of the roof-rocks. As fractional crystallization of this magma proceeded, the remaining magma became gradually enriched in volatiles, so much so that first biotite, then apatite and lastly hornblende appear as constituents in ensuing rock types.

The residual liquids of the Bushveld magma were probably enriched in water and it is considered (as also proposed by Boshoff, 1942, p. 67) that they invaded the leptite in the final stages of crystallization of the Layered Sequence.

These water-rich liquids, in composition probably similar to the topmost differentiates (diorites), caused additional melting of the leptite and were consequently hybridized to granodioritic liquids. These are now found to traverse the leptite as veins and pockets with gradational as well as sharp contacts and to contain numerous inclusions of leptite. The hybrid granodioritic liquids moved upwards through the leptite until they encountered the sheet of granophyre magma, at the base of which they were concentrated as a thin sheet (Fig. 13E). Although mixing of these two liquids took place, this was limited and the rocks display now, in the solid state, a transition from melanogranophyre or granodiorite to granophyre. This late-stage addition of granodioritic liquid to the granophyre magma may be considered as basal contamination of the latter by the former.

As gradual cooling set in after solidification of the topmost diorites, the sheet and pockets of granophyric material still remained liquid for some time and thin, dyke-like downward injections of this liquid may therefore be present in the topmost differentiates of the Layered Sequence as encountered at a few places near Tauteshoogte.

It seems very likely that large pockets or conduits of granophyre came into contact with the last differentiates of the intrusion. Limited mixing of these two liquids at the contact would result in the gradual transition from olivine diorite to granophyre as observed in the vicinity of Drievoet 182 JS.

The above hypothesis would seem to account for all the various relationships observed in the roof, as briefly summarized at the beginning of this chapter.

In Table II a few chemical analyses of rocks from the Tauteshoogte-Paardekop area are listed. Of these, the first four analyses are new, whereas the last four analyses have been published previously. These analyses show that the granophyres of this area all have essentially the same composition (G511, 3622, 3627) and that the microgranophyre from Paardekop (3627) does not differ appreciably in composition from the other granophyres. Analyses of leptite vary somewhat from one locality to the next (G328, Lieb-13 and 2(b)) and if these rocks are recrystallized felsite then such variations are to be expected (Von Gruenewaldt, 1968, p. 165). Although the composition of granodiorite G329 is very similar to that of leptite 2(b), the former sample is from a vein of granodiorite which has a gradational contact with the leptite G328. The difference in composition between G328 (leptite) and G329 (granodiorite) seems to indicate

TABLE I FOUR NEW AND FOUR PUBLISHED CHEMICAL ANALYSES OF ACID ROCKS FROM THE VICINITY OF TAUTESHOOGTE AND PAARDEKOP

Sample No.	G328	G329	G374B	G511	LIEB-13	2(b)	3622	3627
SiO_2	70,49	68,22	66,43	74,09	69,00	68,25	74,15	74,00
TiO_2	0,55	0,66	0,90	0,39	0,40	0,50	0,37	0,48
Al_2O_3	11,76	12,50	13,17	11,64	12,17	11,15	12,61	12,45
Fe_2O_3	1,91	1,41	1,70	1,65	3,35	1,95	0,90	0,47
FeO	4,54	5,98	5,74	2,02	3,80	6,50	2,39	1,88
MnO	0,13	0,17	0,22	0,14	0,11	n.d.	0,32	0,17
MgO	0,10	0,13	0,15	0,06	0,68	0,50	0,03	0,37
CaO	2,24	2,90	2,45	0,80	2,11	3,40	0,82	0,99
Na_2O	3,20	3,84	4,04	3,05	3,53	3,00	2,87	3,09
K_2O	4,14	3,74	3,92	5,07	4,30	4,05	4,86	4,93
H_2O^+	0,20	0,33	0,92	0,62	0,83	0,05	0,40	0,39
H_2O^-	0,31	0,23	0,23	0.19		0,05	0,17	0,13
P_2O_5	n.d.	n.d.	n.d.	n.d.	1,39	0,35	0,14	0,09
	99,57	100,11	99,87	99,72	101,67	99,75	100,03	99,44

G328 Leptite, Steynsdrift 145 JS

G329 Granodiorite, same locality as G328

G374B Granodiorite north of Baviaansnek, Elandslaagte 155 JS

G511 Normal granophyre, Elandslaagte 155 JS

Analyses by the National Institute for Metallurgy, Johannesburg.

Lieb-13 Leptite, Tauteshoogte, C. J. Liebenberg, 1961, p. 72-73.

2(b) Dark, greyish felsite, Tauteshoogte. B. V. Lombaard, 1934, Table 2(b), p. 12.

3622 Granophyre, ½ mile west of Paardekop, R. A. Daly, 1928, Table II, p. 717.

3627 Felsite (micrographophyre) from Paardekop. R. A. Daly, 1928, Table II, p. 717.

that melting of G328 was accompanied by the introduction of some mafic constituents, and as postulated above, they were probably derived from the residual liquids of the magma which gave rise to the Layered Sequence. It is considered that granodiorite G374B has originated in a similar way. This specimen was collected close to the contact of the leptite and the overlying granophyre in the northern road cutting at Baviaansnek, and contains, among others, a few crystals of fayalite.

4. The Bushveld Granite

Bushveld Granite is only developed in the northern part of the area where it is present as a few isolated outcrops on the farms Steynsdrift 145 JS and Tigerhoek 140 JS and as a tongue which projects outwards on Groothoek 139 JS from the large pluton north of Paardekop (Molyneux, 1970, Plate I). The isolated occurrences consist of granite porphyry which would seem to suggest that they are small stock-like intrusions of Bushveld Granite. In comparison, the larger masses on Groothoek 139 JS and on Steelpoort Park 366 KT (Hammerbeck, 1970, p. 301) to the southeast, are homogeneous coarse-grained granites.

The composition of the Bushveld Granite (G333) and the granite porphyry (G321, G332) is very similar: quartz, microcline perthite and hornblende are the major constituents, whereas apatite, zoned zircon and allanite are the most abundant accessory minerals.

A few dykes of fine-grained acid rocks are present on the farm Luipershoek 149 JS. Their strike is similar to that of the close by Steelpoort Park Granite and they are probably related to this intrusion.