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The Somerset Dam Igneous Complex A Preliminary Account

BY

By I. R. McLeod, M.Sc.

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ABSTRACT

In the hills west of Somerset Dam, a gabbro-red rock complex is emplaced in the Lower Triassic Neara Volcanics. The gabbroic portion is plug-like, and is mainly olivine gabbro with a horizon of banded troctolite. The upper part is quartz gabbro, with micropegmatite in the topmost portion.

The red rock is not a direct differentiate of the gabbro exposed. The main part at least, is magmatic in origin and was emplaced slightly later than the gabbro. It consists of quartz and perthite, often intergrown, with iron ore a common accessory.

The metamorphic effects due to these two rock types are compared and contrasted.

Quartz diorite and felsite dykes around the gabbro and red rock are thought to be part of the complex.

INTRODUCTION AND ACKNOWLEDGMENTS

The Somerset Dam Igneous Complex covers about six square miles of high ground to the west and north-west of the Somerset Dam, at the southern end of the Toogoolawah Mountains. Here the Stanley Gorge, in which the dam has been constructed, provides an interesting example of superimposed drainage, for the Stanley River has turned towards and cut down more than 800 feet into the hardened rocks surrounding the complex when it could have remained in the less resistant Neara Volcanics by maintaining a straight course.

Medium and large scale aerial photographs were available, and the former were used in the field.

The writer is indebted to the staff of the Department of Geology for their assistance during the investigation, in particular, Professor W. H. Bryan and Dr. R. Gradwell for petrological advice, and the latter also for making available his field notes and specimens from the area; Dr. Dorothy Hill took a keen interest in the course of the work; Dr. J. F. G. Wilkinson of the University of New England gave helpful advice on petrological matters.

The writer also expresses his appreciation of the help given by Miss P. Day, B.Arch., who helped draft the map; Mr. A. G. Smith, who helped with the photomicrography, Mr. G. B. Goadby who gave invaluable assistance during examination of some of the cliffs, and Mr. G. Grandy, who piloted the writer during an aerial inspection of the area and surrounding country.

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PREVIOUS WORK

Examinations of the rocks around the site of the dam wall were made by L. C. Ball (1933) and Reid (1933). The former thought Mt. Brisbane represented an ancient eruptive focus. C. W. Ball (1940) deduced the order of emplacement of the rocks at the dam site as:

Augite diorite (major intrusion)
Augite diorite (minor intrusion)
Quartz felsite dykes and alaskite
Quartz feldspar and tourmaline veins.

Hill (1931), describing the Brisbane Valley Porphyrite Series, remarks that "the Mt. Brisbane granodiorite and related intrusions are in all probability part of it."

A general account of the surrounding geology is given by Robinson and Hill (1939) and of the tectonic setting of the complex by Hill (1948).

GENERAL GEOLOGY

The complex is emplaced in the Lower Triassic Neara Volcanics, a thick sequence of andesite lavas and pyroclasts and tuffaceous sediments, with minor amounts of trachytic flows and tuffs. A few representatives of the acid rocks occur near the complex, but no sediments were recognised.

Texturally, the andesitic rocks can be divided into several types (Hill 1931 pp. 40, 41) but mineralogically they are fairly uniform, consisting of augite andesite flows and pyroclasts. Plagioclase (mostly andesine) occurs as phenocrysts and in the ground mass which may be partly glassy; subordinate hornblende and augite also form phenocrysts, and, in places, finer grains. Silica minerals occur as cavity fillings; alteration products include chlorite, sericite, iron oxides and clayey material.

There is some doubt as to the attitude of the rocks adjoining the complex. Ball (1940) thought that agglomerate east of the dam dipped W.S.W. at 10–15°, but the writer found no evidence for this although at 654327* flutings on the surfaces of boulders dip south-west at 10–15°. The rock has been almost completely reconstituted, hence it is not known whether the planar structure producing these flutings represents bedding in a tuff or flow layering of a flow or minor intrusion.

On the other hand, aerial photographs show trend lines west of the complex which suggest the rocks are almost vertical, with a north-westerly strike, and Hill (1931, p. 37) notes north-easterly dips of 80° some miles to the north of the complex; the writer found very poorly and irregularly stratified agglomerate, vertical, and striking north-west, at 643325.

The main mass of the complex consists of closely associated acid and basic rocks, irregular in shape, extending three miles from north to south and two from east to west.

The basic rocks are mainly olivine gabbro with a horizon of troctolite interposed. The olivine gabbro above and below this troctolite will be referred to as the upper and lower gabbro respectively. Above the upper gabbro, and grading into it, is a granophyric quartz gabbro. Together these basic rocks form a single steep-sided body, which collectively will be referred to as the gabbro.

The acid rocks are quartz-feldspar aggregates with considerable textural variation. They occur in one large irregularly shaped mass, partly overlying the gabbro, and four smaller satellite bodies, and will be referred to as red rock. The mutual relationship of red rock and gabbro is discussed later.

Thin acid veins are common around the margins of the complex, and a number of felsite dykes occur on the eastern side. In the andesites near the

* Grid references refer to the Caboolture 1 mile military sheet.

gabbro are irregular veins and patches of gabbroic material, some quite coarse grained.

By the roadside at 689336 near the bridge across the Stanley River are boulders of quartz gabbro not unlike the quartz gabbros of the main mass.

A brecciated hornfels at 660323 was the only evidence found of later faulting.

The upper surface of the troctolite on the slopes behind the township falls 150 feet from south to north in a distance of half a mile. This dip could be a reflection of that shown by lamination of the feldspars or may represent a slight regional tilting since the emplacement of the complex.

THE GABBRO

General Features

The outcrop of the gabbro is elliptical, roughly two miles long and a mile and a half wide. No contacts were seen in the field, but the gabbro is thought to be a steep sided body because:

(a) On the southern side of a steep gully at 663323 are cliffs of hornfels, 20 feet high; on the northern side, 15 feet from these, is a bank of very weathered gabbro, with fresh gabbro a further 20 feet away.

(b) At 666321 weathered gabbro outcrops 30 feet lower than, and to the north-west of a knoll of hornfels; hornfels but no gabbro fragments occur all down the side of the knoll to a level below that of the gabbro.

(c) The altitude of the edge of the gabbro varies between 1,050 and 300 feet. West of Brennan's Gully the margin cuts sharply across the contours. These differences are not due to tilting of a sill-like body; any later tilting was to the north.
The north-western margin of the gabbro follows the contours to some extent; possibly the contact here has an easterly dip.

The gabbro commonly possesses a lamination, the result of the feldspars having their long axes coplanar. This lamination dips inwards, the angle decreasing towards the centre, where it is horizontal. In places, the feldspar laths are lineated parallel to the dip of the lamination.

The troctolite is commonly banded due to variation in the proportion of olivine. There are all gradations from ill-defined bands with only slightly more olivine than the adjoining rock to dark grey bands sharply separated from the speckled intervening rock. The proportion of olivine, even in the darkest bands, probably never exceeds 50 per cent. The width of the bands varies from a half to three inches, and the distance between them from less than an inch to a foot. They tend to be discontinuous, and in places are better called lenses. The longer bands may bifurcate and reunite, enclosing lenses of olivine poor rock.

The bands tend to occur in groups. There may be several feet of unbanded rock, then several feet with banding developed to varying degrees of perfection. Bands are more common towards the top of the troctolite.

Parts of the upper and lower gabbro show a poor banding of the pyroxene; this is usually ophitic, and irregularly distributed along certain horizons of laminated gabbro. The bands for the most part are only one or two grains wide.

The gabbro is jointed on cubic lines, with one surface parallel to any lamination present, and another striking parallel to the margin.

The Olivine Gabbros and Troctolite

These are best examined in Brennan's Gully, where a thickness of about 1,000 feet is exposed, with the troctolite forming a horizon some 200 feet thick midway through this section. The mineralogy of the two types is similar, and they will be described together.

Feldspar. This is entirely plagioclase, staining failing to reveal any potash feldspar. The composition of the plagioclase in a number of slides was measured with the universal stage, using the zone method. The anorthite percentage of plagioclase in the olivine gabbro is between 65 per cent. and 69 per cent. Many of the grains have a homongeneous core passing with no compositional break into progressively zoned material. In most, the composition of zone and margin differs by only a few per cent.

In some cases, particularly in the troctolites, the extinction of the feldspars is patchy. This feature resembles zoning, but the patches are irregular, with no geometric relationship to the grain boundaries. The composition appears to vary irregularly through the crystal, in cases by as much as 10 per cent. These feldspars seem more basic than those in the olivine gabbro; an average of seventeen determinations gave an anorthite content of 75 per cent.

The plagioclase forms anhedral to subhedral grains, mostly elongated, with *b* the shortest crystallographic axis. The size of the grain varies, even in the same slide, with most between 4 mm. and .5 mm. long. This range is more or less constant throughout the mass, with perhaps a slight size decrease towards the top of the olivine gabbro. Twinning on the albite, carlsbad and pericline laws and combinations of these was found. The lamellae are commonly bent, and in some cases the crystals have been cracked and twisted, so that the lamellae meet at a distinct angle.

Clinopyroxene. The clinopyroxene in thin section has a marked purple tint, indicating a relatively high titanium content, so the standard curves could not be used to determine the composition of the clinopyroxene from its optical properties. $2V = 50°–55°$; $Z \wedge C = 44°$. A few grains in the upper gabbro exhibit twinning; on the whole, it is rare.

In the lower gabbro, the clinopyroxene is almost invariably ophitic, with some individuals over 2 cm. in extent. These grains commonly enclose rounded olivines, producing a coronophitic texture (Fig. 1). Above the troctolite, ophitic texture is rare; the grains form individuals which send short angular tongues into the angles between feldspar laths. Where the grains have a long axis, it is parallel to that of the feldspars.

Schiller structure is a common feature especially in the ophitic grains. The inclusions are black and opaque, probably iron ore, and occur both as long thin needles and short stumpy rods. Many of the clinopyroxenes contain minute irregular grains of iron ore, which may be distributed throughout the host, or be confined to broad curved trails across it. Their common occurrence along cleavages or cracks near the edge of the crystal suggest they are secondary and not included primary material.

The clinopyroxene is replaced to a greater or less extent by amphibole of two types: a brown hornblende, which forms coronas around the pyroxene or irregular flecks through it, and clear fibrous uralitic material.

Olivine was found in all slides except one made from the lowest exposed gabbro in Brennan's Gully. Universal stage measurements for several slides showed a constant $2V = 84°$ (–ve) hence no further determinative work was done. This angle gives a molecular forsterite content of 75 per cent.

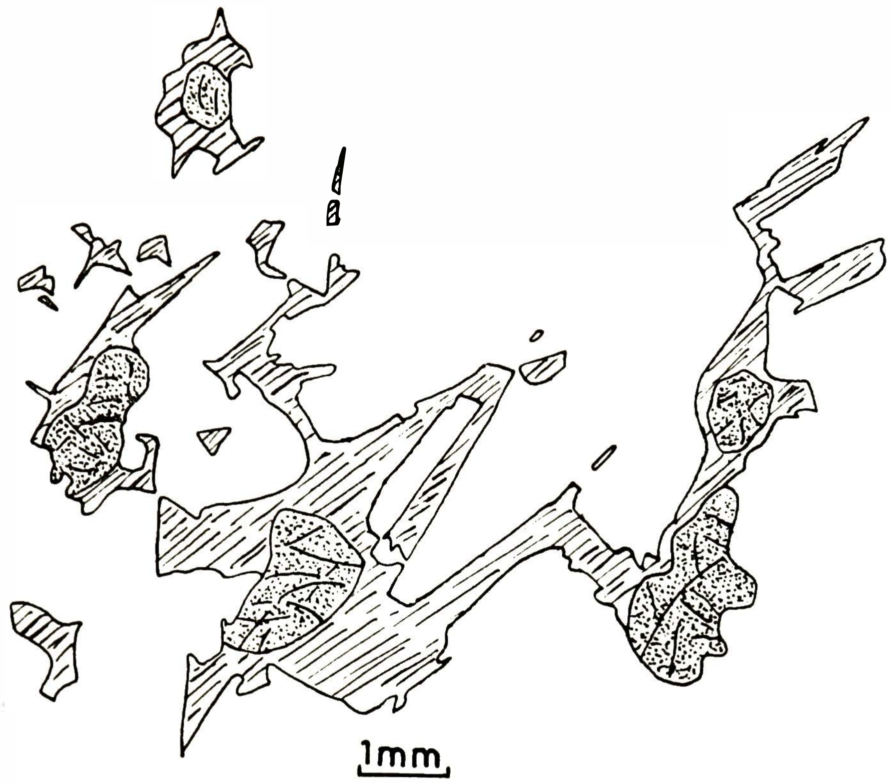

Fig. 1—Clinopyroxene enclosing olivine and ophitic to plagioclase. Ordinary light.

The olivine in the lower gabbro is commonly enclosed by ophitic clinopyroxene; in a few cases the place of the clinopyroxene is taken by a thin mantle of colourless orthopyroxene, and in one case, of biotite. An occasional small grain occurs interstitial to the feldspars. In the upper gabbro, the olivine is mostly in direct contact with the feldspar, and sends short tongues into the angles between the laths.

Fig. 2—Grain of granophyric-like iron ore in olivine.

The olivine is almost invariably altered. The effects vary from a few ore granules along cracks to complete pseudomorphing by serpentine (antigorite with some serpophite), bowlingite and ore granules.

In some, the olivine commonily contains small droplets and blebs of ore. The general appearance is very similar to micropegmatite (Fig. 2) and quite dissimilar to the dusty material produced by alteration.

Hornblende. This is mostly shades of brown X = fawn, Y = pale brown, Z = mid-brown. In a number of slides, the colour varies irregularly, the different shades having slightly different extinction positions. 2V is high but variable; $Z \wedge C = 30°$

This hornblende mostly mantles clinopyroxene, olivine or iron ore. Around the last, it forms only a thin skin, but may extend some distance from the pyroxene and olivine, and then has a coronophitic texture very like that of the pyroxenes of the lower gabbro. Some of the hornblendes have been partly altered to clear fibrous amphibole.

The occurrence of this hornblende as large grains, ophitic towards the plagioclase, points strongly to a primary origin. Sederholm (1916, p. 5) writes, "there occurs a brown hornblende which possesses the same orientation over extensive areas and includes sharply defined crystals of augite, as well as plagioclase, etc. This hornblende is very probably of primary origin." On the other hand, although writers do not emphasise the fact, figures of coronas formed by reaction in the solid state between adjoining mineral grains invariably show a fibrous or granular product.

If, in the late stages of crystallisation, clinopyroxene begins to react with the residium to form hornblende, this would then crystallise, and, like the clinopyroxene which formed earlier, could penetrate the interstices in the feldspar mesh, producing an ophitic texture. For some reason, conditions were such that any source of iron provided a locus of crystallisation. Deposition around the iron ore ceased as soon as the source of iron was completely sealed off by a thin film of hornblende, the residium apparently being unable to supply all the necessary constituents. There are two explanations for the thicker mantles on the olivine; either its composition was such that it could supply material for the formation of the hornblende, or more likely, it was originally enclosed by pyroxene which has now been completely replaced by hornblende, leaving the as yet unaffected olivine as a core.

Secondary Amphibole. This forms sheaves or felted aggregates of fibrous material wholly or partly pseudomorphing pyroxenes. The fibres are pleochroic from pale green (in some cases with a bluish tinge) to an almost colourless brownish green. This pale colour and the small extinction angle (10°–20°) suggest an actinolitic amphibole.

In some cases this uralite has itself been altered to chlorite.

Iron Ore. Grains of this occur throughout the gabbro. The primary ore forms anhedra up to 1 mm. across, interstitial to (and in some cases actually ophitic towards) the feldspar. A few grains are rimmed by biotite.

Biotite. This is not common; it forms irregular flakes pleochroic from reddish brown to almost colourless. Except for one slide, where they are up to 5 mm. across, the flakes are quite small and closely associated with dark minerals and appear to be another alteration product of these.

Orthopyroxene. In a few slides, this forms thin rims around olivine, but occurs as small ophitic grains in one case. It is either colourless or pleochroic from faint pink to very pale green.

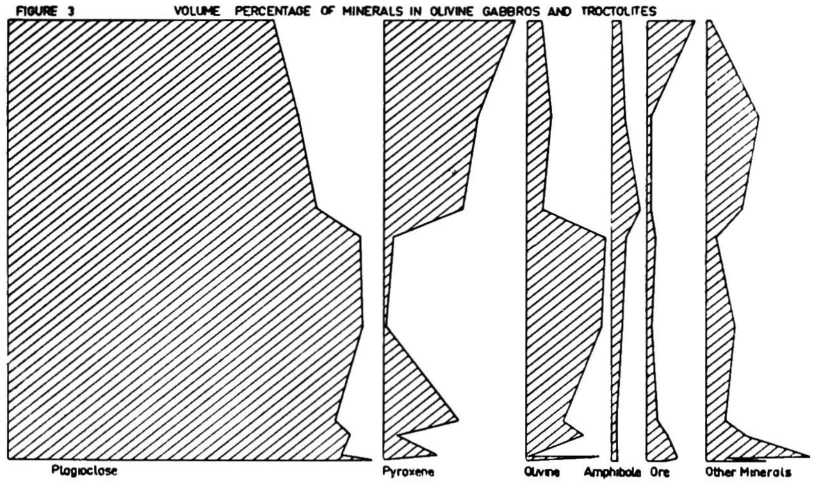

Fig. 3—Volume percentages of minerals in the olivine gabbros and troctolite.

In a few of the slides are shapeless grains up to .5 mm. across, of apatite. A few grains showing the usual prismatic habit occur very rarely in the olivine gabbro.

Petrography. The gabbros are medium grained grey rocks. Plagioclase forms clear lathlike or tabular crystals, commonly laminated and in places, lineated. Pyroxene is recognisable by its cleavage and occurrence as ophitic grains. Olivine is very dark, almost black, but can be distinguished by its sub-conchoidal fracture and lack of cleavage. Iron ore forms small grains with metallic lustre. Above the quarry, the gabbro near the margin contains a number of aggregates half an inch across, of fine black radiating amphibole needles.

Brennan's Gully was the only vertical section with outcrops common enough to give some idea of any systematic variation in the proportions of minerals. The results of modal analyses of rocks from this section are shown in Table I, and diagramatically in Fig. 3. To minimise the effects of the banding in the troctolite, modal analyses were made of troctolites from two other parts of the complex, viz., from 663339 and 675330. These also are shown in Table I. Percentages are given to the nearest whole number; *tr* indicates that the mineral is present in an amount less than .5 per cent. of the total. "Other minerals" consists almost entirely of secondary amphibole, with some serpentine, biotite and apatite.

In thin section a typical olivine gabbro has plagioclase laths of varying size, but commonly about 1.5 mm. long and .5 mm. wide. Where the pyroxenes are ophitic, this mineral fills the interstices between the feldspars. Olivine occurs as rounded grains, commonly enclosed by clinopyroxene; where it is not, it sends short extensions into the angles between the feldspars. In the non-ophitic olivine gabbro the olivine grains are larger, mostly 1–2 mm. across with some up to 3 mm. Clinopyroxene is slightly larger than the olivine, and the two commonly occur in close association, but the olivine is never enclosed by the pyroxene. Both extend as short tongues into the angles between adjacent feldspar laths. The iron ore grains are irregular; they, too, send thin tapering extensions into the feldspar mesh. Hornblende, where it occurs, is ophitic like the augite. Biotite is not common, except in places near the edge of the gabbro, where it forms reddish brown flakes, invariably moulded on pyroxene or ore.

In the troctolites, the feldspar is generally slightly smaller than that of the olivine gabbros. The laths invariably show a strong alignment, a reflection of the macroscopic layering. Olivine forms rounded grains 2–3 mm. across, mostly

TABLE I

Volume percentage of minerals in olivine gabbros and troctolites

	Altitude (feet)	Plagioclase	Clinopyroxene	Orthopyroxene	Olivine	Hornblende	Ore	Other Minerals
Lower gabbro	550	78	Tr.	Nil	?	1	3	17*†‡
	555	72	Tr.	Tr.	16	1	6	6*
	560	71	12	Nil	Tr.	1	6	11*†
	600	73	3	Tr.	12	1	4	8*
	630	70	16	Nil	8	1	2	4*
Troctolites	830	76	Tr.	Nil	16	2	Tr.	6
	1020	75	2	Nil	17	3	1	2*
	1450 (*a*)	84	1	Tr.	11	Tr.	1	3*
	1450 (*b*)	85	1	Tr.	12	Tr.	1	4*†
	?	81	3	Nil	12	Tr.	1	4*†
	Average	80	1	Tr.	14	1	1	4*†
Upper Gabbro	1080	66	17	Tr.	3	6	Tr.	7
	1280	61	20	Nil	5	3	Tr.	11*
	1480	56	28	Nil	3	2	10	1

* Including biotite. † Including apatite. ‡ Including serpentine and epidote.

TABLE II

Volume percentage of minerals in quartz gabbros.

Altitude (feet)	Plagioclase	Pyroxene	Amphibole	Ore	Biotite	Quartz	Perthite	Micro-pegmatite	Other Minerals
1100	55	3	25	6	2	Nil	Nil	Nil	6*
1350	74	Nil	19	3	Tr.	Tr.	Nil	Nil	3†
1520	79	Nil	4	2	1	3	8	23	Nil

*Including 1 per cent. apatite. †Including calcite and 2 per cent. apatite.

altered to some extent, and commonly enclosing a few small plagioclase euhedra. Some are rimmed by orthopyroxene, others by coronophitic brown hornblende. Clinopyroxene, when present in important amount, is also ophitic. The smaller olivine grains commonly aggregate to form a clot 4–5 mm. in extent.

At the lowest exposed gabbro in Brennan's Gully there is a rapid variation in rock types, a feature not found elsewhere. The lowest exposed rock is an olivine gabbro, rather coarser than usual, and containing small amounts of hornblende, biotite and epidote. A few feet above the pool here is a parallel-sided band of fine dark rock, $\frac{3}{4}$ inch thick and dipping north at 15°. This contains the same minerals as the normal olivine gabbro, with the addition of apatite in important amount. The texture, however, is quite different. Feldspar forms elongate anhedra, with a marked parallelism, except where they are swathed about a pyroxene grain much larger than the rest. Some are slightly zoned. Clinopyroxene and olivine form granules up to .5 mm. across; they are never ophitic, although some penetrate the feldspar mesh to a slight extent. Pyroxene is much more common than olivine. Hornblende forms thin rims about pyroxene and ore, and is commonly ophitic. Iron ore is very common, forming at least 10 per cent. of the band, occurring as small elongate grains, aligned parallel to the feldspars, or as small inclusions in the pyroxene.

The junction of this rock with the underlying gabbro is quite sharp. The interstices of the medium grained feldspars of the gabbro along the contact may be occupied by projections from grains of the fine material, but there is not the slightest evidence of a gradation from one to the other. The band itself is texturally uniform from its base to its upper surface, which again is quite sharp.

Above this band the rock is finer grained and much darker than the normal gabbro. Its most noticeable feature is the occurrence of reddish-brown plates of biotite up to 1 cm. across. The feldspars are lineated, plunging north at 15°. Microscopic examination shows it to be a biotite troctolite, containing plagioclase, olivine, iron ore and brown hornblende.

This biotite troctolite is 5 feet thick. Above it, and separated sharply from it, is a rock very like that below the thin fine grained band, except that olivine is absent.

At the margin of the gabbro at 656331 are several boulders of a white rock, poorly laminated and much finer grained than usual. The plagioclase is very sericitised and pennine occupies the centre of many grains. Small amounts of interstitial clinopyroxene (with marked undulose extinction) and iron ore, as well as epidote and apatite also occur. The relation of this rock to the gabbro could not be determined. Well laminated olivine gabbro outcrops 20 feet to the south and dark granulitic hornfels 20 yards to the north.

At 665344 a few yards from the red rock is a dark medium grained olivine gabbro with ophitic pyroxene. This differs from the normal olivine gabbros in that biotite is slightly more common, and the plagioclase is faintly clouded by very fine grains of opaque material. The presence of such a rock so close to the red rock is unusual; elsewhere, wherever the gabbro is close to the red rock it is the granophyric quartz gabbro.

Xenoliths are absent from the olivine gabbros and only one was found in the troctolite, Plate 1, Fig. 5. This is mainly feldspar, with scattered clots of olivine and small amounts of clinopyroxene hornblende and iron ore, these decreasing in amount towards the lower right hand part, which is laminated like the surrounding rock, but in a slightly different direction. The upper edge is marked by a rim of fine grained feldspar, the inner margin of which is gradational on the left hand side of the xenolith and sharp on the laminated mafic-poor right hand side. All parts of the outer margin are quite sharp against the enclosing troctolite. This xenolith is probably cognate because of its mineralogical similarity to the surrounding troctolite.

The Quartz Gabbros

These rocks outcrop beneath part of the main red rock mass, grading down into the olivine gabbros. Not all can be strictly called quartz gabbros. Quartz may be absent, or present in only small amount. A more common feature is the disappearance of clinopyroxene, its place being taken by hornblende. Near the red rock, the plagioclase is more sodic, making the rock a quartz diorite; in a few cases, the potash feldspar content is sufficient to make the rock a granodiorite. Despite these variations the rocks show many mineralogical and textural similarities, and the term quartz gabbro will be used when general reference is made to rocks of this type.

In the hand specimen, members of this group furthest from the red rock are quite like the olivine gabbros which occur deeper in the complex. In other places, the rock may be a pinkish grey, due to a micropegmatitic mesostasis; biotite is common in this type. Near the red rock, the mesostasis becomes common and the place of the biotite is taken by black amphibole crystals up to .5 cm. across. The general grain size of the feldspar increases, and the plagioclase is greyish and opaque. Pink grains of perthite occur sporadically.

Mineralogy and Petrography. Modal analyses were made of three representative types from the gully falling east from 680348. One of these is the highest gabbro exposed *in situ,* a couple of feet from the red rock; the second occurred 200 feet lower and the third 200 feet lower still, from the lowest exposed gabbro, and has many similarities to the olivine gabbros. These analyses are shown in Table 2. Because of the variation from place to place and small number of analyses, the diagrammatic representation in Fig. 4 can be regarded only as a generalised illustration of the changes.

The rock most like those deeper in the complex is texturally very like the ophitic type of olivine gabbro, but the place of the pyroxene is taken by a characteristically coloured hornblende X = pale tan, Y = light tan, Z = mid tan. Grains of this may be more than 1 cm. in extent, and enclose feldspar, ore, apatite and biotite. Original pyroxene has been almost entirely replaced by pale uralitic amphibole, pleochroic from pale green to a very pale, almost colourless, greenish brown. $Z \wedge C = 15^\circ$. Plagioclase forms subhedral laths up to 2 mm. long; many are zoned or extinguish irregularly, and most are sericitised; the average composition is sodic labradorite. Opaque ore is common as shapeless granules up to $\frac{1}{2}$ mm. across, and as small grains associated with the uralite. Biotite forms irregular flakes, pleochroic from a pale brassy colour to dark brown. Along the cleavages of many are lenses of material resembling the uralite. Apatite occurs as needles and stumpy prisms.

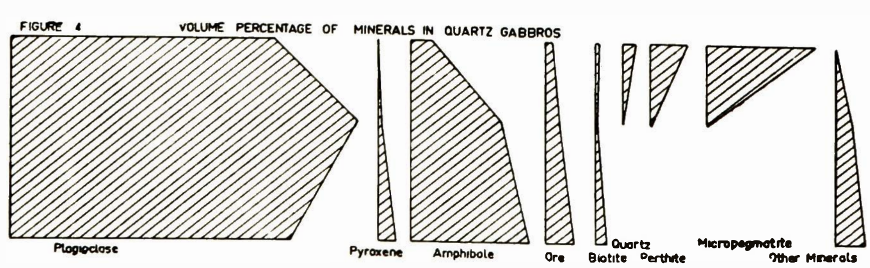

Fig. 4—Volume percentages of minerals in the quartz gabbro.

Quartz occurs in some slides as small shapeless grains intergrown with perthite, forming small angular patches of micropegmatite in the feldspar interstices, or forms small shapeless grains with no associated feldspar. In these rocks, the hornblende is much less ophitic, and remnants of clinopyroxene enclosed in it have not been uralitised, although this process has affected those pyroxenes not enclosed by hornblende.

In one case, hornblende is rare, and pyroxene absent. Instead, there occur roughly elliptical grains .5 mm. in length of amphibole, X = very pale green, Y = pale green, Z = pale bluish green. $Z \wedge C = 22^\circ$. A few display twin lamellae. Except for their form, they are very like the fine grained uralite occurring in the same slide. Both biotite and apatite are more common than usual in this rock.

Some slides show partial replacement of the ophitic hornblende by biotite and amphibole. Most of the hornblende is the usual tan colour, but parts of some of the grains are a very pale fawn, with only slight pleochroism. The change from one colour to the other is sharp, but the differently coloured parts are optically continuous. The entire hornblende may be pseudomorphed by a decussate aggregate of biotite and/or amphibole, with a grain size less than .05 mm. Where replacement is only partial, the hornblende is crossed by trails of similar but rather finer material.

Although this new amphibole and biotite do occur together, they tend to be mutually exclusive. Aggregates dominantly biotite are much the less common, and form the trails through the hornblende. The biotite is pleochroic from pale to deep brown. The amphibole is very pale, and hardly pleochroic. In appearance it is very like the pale coloured parts of the hornblende, and it may well be that this bleaching of the hornblende is a sign that recrystallisation is imminent.

In the upper part of the quartz gabbro some of the feldspars have a thin rim of clear oligoclase, grading rapidly into the enclosed strongly zoned feldspar. This rock is coarse grained, with coarse irregular quartz-feldspar intergrowths. A feature unusual in the gabbros is the presence of several grains of zircon.

As the red rock is approached, the plagioclases acquire a fringe of perthite. The plagioclase component of this is optically continuous with the enclosed feldspar, and any zoning is continued into the perthite. Within 20 feet of the base of the red rock, interstital micropegmatite is very common, forming fringes around the plagioclase, but separated from it by a thin band of perthite. The central plagioclase is commonly quite euhedral, and the perthite forms a rectangular frame from which the micropegmatite extends, so that the spaces between the plagioclase euhedra are filled with beautifully delicate micrographic intergrowths. The plagioclase is almost invariably strongly zoned or has very blotchy extinction. An unusual feature is the development of marked oscillatory zoning. The average composition is more sodic than lower in the gabbro; it is andesine at least and may even be oligoclase.

The most common femic mineral is a very pale amphibole, occurring as a fine grained decussate aggregate or as isolated rounded grains up to .5 mm. across, some of which contain remnants of pyroxene. Needles of apatite are very numerous in and near this amphibole. More or less equant grains of brassy coloured biotite are a common feature. Iron ore is not common; it forms small scattered grains, usually associated with amphibole.

The actual contact of gabbro and red rock was not found *in situ*, but was found in a large boulder on the north bank of a gully at 680349 (Plate I, Fig. 1). The red rock could be a vein, but its texture is quite unlike any of the veins in the area, it is at least 18 inches wide (most veins are only a few inches) and the boulder occurs between outcrops of red rock on one side and gabbro on the other.

The gabbro 6 inches from the contact in this boulder is very like that occurring *in situ* a few feet away. Within an inch of the contact the grain size becomes finer (up to 3 mm. instead of almost 1 cm.), and although the feldspars have perthitic fringes, the delicate interstitial micropegmatite is absent. The plagioclases exhibit slight zoning but not the oscillatory zoning of those further from the red rock. Quartz forms small shapeless grains between or in the feldspars.

The red rock is a medium to coarse grained rock made up of quartz and perthite with a very small amount of iron ore and sericite. The junction between it and the gabbro is quite sharp.

Metamorphism by the Gabbro

Although the andesites near the gabbro have been markedly altered by it, the effects of the intrusion do not extend very far, and 400 yards or so from its margin, the rocks are typical of the Neara Volcanics, viz., fine grained or porphyritic andesites and agglomerates.

The first sign of alteration is the greenish black glossy tinge produced in the finer grained rocks by the formation of biotite. With increasing metamorphism, the grain size increases slightly, until in the highest grades the rock is a light to dark grey uniformly fine grained granular aggregate of feldspar and ferromagnesian minerals, which in extreme cases acquires a beerbachitic texture. Even where the rock has been quite strongly metamorphosed its original agglomeratic nature is in places reflected by differential weathering of exposed surfaces.

In many outcrops these high grade hornfelses are cut by veins of white or pink felsic material a few millimetres wide. These may be short and irregular in direction, or extend for several feet (Plate I, Figs. 2, 6). Thin straight parallel veins of chloritic material found in several places represent joint infillings.

In thin section the first noticeable effect of metamorphism is the production of idioblastic grains of pale green slightly pleochroic amphibole ranging in size from less than .01 to .05 mm. $Z \wedge C$ is about 20°. Biotite, pleochroic from light to dark brown, first forms small ragged flakes, which give way to small granules. It may occur as poikiloblasts enclosing euhedra of plagioclase and hornblende. Traces of original pyroxene phenocrysts still remain, but most are replaced by decussate aggregates of biotite, actinolitic amphibole and iron ore.

Both phenocrystic and ground mass plagioclase appear to be unaffected at this stage, except in one case where there is clouding of the plagioclase and remaining pyroxene by minute inclusions of rounded or slightly elongate grains with a marked relief, and not unlike the smaller grains of amphibole occurring in the body of the rock. They are distributed throughout the clinopyroxene, the inequidimensional grains having their long axis parallel to one of the two cleavage directions of the host. In some crystals, the concentration of inclusions is so high that the pyroxene is almost opaque under low powers. In the feldspar, the concentration of inclusions differs slightly from part to part. They form closely spaced rows, a single grain wide, parallel to the trace of the albite twin lamellae, with the inequidimensional individuals elongated in the same direction.

In a number of feldspar phenocrysts are pale brown semi-opaque trails, straight or gently curved, with a uniform width of .03 mm., which either run straight across the phenocryst or fade away inside the feldspar. Down the centre of the trail is a narrow clear zone containing grains rather larger than those causing the clouding, in fact, very like the fine amphiboles elsewhere in the rock. The colour of the trail becomes slightly paler towards this zone, but the change from turbid to clear material is quite abrupt. There is a slight increase in the number of clouding inclusions in the feldspar bordering the trails.

Poldervaart and Gilkey (1954, pp. 79, 80) mention and figure similar clear trails studded with enclosures, but make no reference to turbid material on either side. This turbidity may be due to dusty inclusions much finer than elsewhere in the host crystal, and the trails may represent cracks which healed after formation of the grains in them.

With further metamorphism, the place of the pale green amphibole of earlier stages is largely taken by granoblasts up to .1 mm. across of ortho- and clino-pyroxene. The latter may form also ragged schillered poikiloblasts enclosing small plagioclase euhedra and flakes of biotite. In other cases, biotite may form poikiloblasts wrapped around pyroxene remnants, and enclosing apatite and iron ore.

At this stage, too, the feldspar shows the first signs of recrystallisation. Here and there in the ground mass are areas of fine grained recrystallised plagioclase, producing, with the new pyroxene, small patches with a typical granoblastic or beerbachitic texture. The patchy extinction of many of the phenocrysts indicates incipient recrystallisation, and a few contain small irregular clear patches with a lower refractive index, *i.e.*, more sodic in composition.

The hornfels at the edge of the gabbro at 659325 is very similar to these rocks, except that the grain size is, as a whole, slightly larger, and recrystallisation of the feldspar is more advanced.

Two cases of hornfelses which do not fit into the general sequence of alteration may be mentioned. At 657322, several hundred yards from the edge of the gabbro the rock has been almost completely recrystallised and now consists of a granoblastic aggregate of oligoclase-andesine, clinopyroxene, iron ore and numerous small apatite laths, through which are scattered very irregular poikiloblasts of brown hornblende and colourless olivine. The few original augites which remain have rounded margins and are heavily dusted by ore granules of varying size.

There is no obvious reason for the almost complete reconstitution of this rock, while those at the very margin of the gabbro still retain their original textures. A possible explanation is that it was originally a tuff. It is an accepted fact that smaller grains in a rock are more prone to chemical reaction and recrystallisation than larger grains of the same mineral, *e.g.*, Harker (1939, p. 106). The fine grain size of a tuff could enable complete reconstitution to be brought about while coarser rocks were only partly altered.

At 686345 is a light coloured rock with irregular darker patches distributed through it. In thin section the dark patches are found to consist of a fine granoblastic aggregate of andesine with scattered brown biotite and pale green amphibole, while the light coloured material is almost entirely quartz and feldspar in beautifully delicate granophyric intergrowth. Sporadic iron ore and rarely epidote, occur throughout the slide. The change from granophyric to granulitic texture is quite sharp.

The marked textural difference between this rock and the other hornfelses can only be ascribed to a compositional difference, but it is impossible to be sure what the original rock was. Quartzites such as give rise to granophyre around South African basic intrusives are not known in the area around the complex. Harker (1939, p. 112) considers that thermal metamorphism of quartzo-feldspathic rocks will produce "some tendency" to intergrowth. Such rocks do occur in the Neara Volcanics and an acid pyroclast may be the parent of the hornfels in question.

At a number of places in the area are small patches of coarse grained basic material, taking the form of short irregular veins and lenses which vary rapidly in width, direction and amount. In two places (*i.e.*, 687348 and 662346) such veins were found emplaced in gabbro near its margin, but they are best developed in granulitic hornfelses at 651330 near the head of O'Shea Creek, where the stages of their formation can be traced.

The first step is the appearance of lustrous black grains of hornblende scattered at random through the hornfels. They may be accompanied by a few flakes of biotite. The next stage is the formation of small patches of white plagioclase, always closely associated with the hornblende. These patches increase in size and take the form of thin veins of white feldspar speckled with black hornblende and biotite, which branch irregularly, intersect and pinch out rapidly. As the size of the patches increases, so does the grain size of the constituents, until they are up to .5 cm. across. The feldspathic material is sharply demarcated from the hornfels, but the large hornblende and biotite grains occur in both. In a number of cases a feldspathic vein lenses out, but is continued as a trail of hornblende grains.

Under the microscope, the hornfels is the usual granulitic type made up of strongly clouded slightly zoned basic andesine, ortho- and clinopyroxene, iron ore, and large brown biotite poikiloblasts. The hornblendes appear as poikiloblasts several millimetres in extent, enclosing the other minerals; X = pale brassy brown, Y = brassy brown, Z = khaki brown. $Z \wedge C = 23°$. As the feldspar becomes important the granoblastic texture of the hornfels is largely lost. The feldspar, although inclusions are not uncommon, is not clouded, and is slightly more calcic. The hornblende (some of which is now green instead of brown) is accompanied by similar but smaller poikiloblasts of orthopyroxene. Clinopyroxene is present in lesser amount, mostly as small granules still, with a few larger anhedra, not poikilitic. Some of the pyroxene is uralitised.

In the final stage of development the vein is medium grained, with plagioclase, amphibole and quartz the dominant minerals, and small amounts of potash feldspar, iron ore and apatite. The amphiboles, although they contain a few inclusions, are not the large poikilitic type of earlier stages. The brown variety is still the most common; the shade may vary from one part of the crystal to another, and in other cases the extinction is variable. These latter are usually partly altered to biotite, iron ore and small flakes of a very pale green amphibole, with $Z \wedge C = 24°$. This new actinolitic amphibole appears to be the stable variety in the veins.

At 688349 was found a block (not *in situ*) of coarse grained material containing elongate crystals of hornblende up to 2 inches long. In thin section these are pale brown, and partly altered to biotite, iron ore and actinolite, with a small amount of epidote. The feldspar is andesine, with slight progressive zoning. Quartz forms isolated anhedral grains, some of which are optically continuous. Apatite and zircon are common.

These patches of coarse grained material, although they do not contain any quartz-feldspar intergrowths, are mineralogically very like some of the quartz gabbros. This similarity between veins and the main mass has also been noted in Ardnamurchan by Richey and Thomas (1930, p. 307) where, however, the veins are straight (*op. cit.*, p. 296) rather than the irregular lens-like patches at Somerset Dam.

The rapid textural variation of the patches, their irregular form, and the stages of formation in otherwise normal hornfels all point to permeation rather than injection. If this is the case, the patches should become more common as the gabbro is approached, but this view cannot be checked because there are no exposures between the outcrops described and the margin of the gabbro.

Xenoliths in the Gabbro

Xenoliths were found in several places, with one exception (which has been described), always in the quartz gabbro. They are very numerous in the cliffs at 675338 (Plate I, Fig. 3).

Most are only a few inches across and more or less equidimensional; where they are elongate, the long axis is about horizontal. The edges for the most part are crenulated but well defined, although they may be hard to discern where the texture of the xenolith is like that of the surrounding gabbro. All appear to be igneous in origin, mostly porphyritic, with a few uniformly fine grained.

The degree of metamorphism varies considerably from xenolith to xenolith, but in general the changes are the same as those in the hornfelses around the gabbro.

At 674340, less than 100 feet below the edge of the red rock the gabbro encloses a number of angular blocks up to 18 inches across, of light grey felsitic material with pink euhedral glomeroporphyritic feldspar phenocrysts. Many of the joint planes are marked by films of silica and nests of biotite. Even in thin section there is no sign of alteration, which is remarkable in a rock so different from the gabbro. The phenocrysts are albite-oligoclase, and the ground mass an aggregate of untwinned but zoned feldspar and smaller iron ore granules. This texture is maintained right up to the gabbro and the junction is quite sharp.

Nothing comparable to this trachyte was found in the area around the complex. The felsites are not porphyritic and quartz phenocrysts such as occur in the porphyritic red rock, are absent, so the xenoliths could not have been derived from either of these.

Basic Dykes and Veins

A common feature in the hornfels around the gabbro are masses of diorite, occurring as irregular patches up to several yards in extent, or dyke-like bodies either parallel sided or very irregular in width. The finer grained representatives mostly form irregular schlieren or thin veins which may be common enough to form a network through the hornfels (Plate I, Fig. 4).

In most cases, the margin is well defined but a few of the coarser types grade into the hornfels over a distance of several millimetres. At 658322 the junction is marked by a rim a couple of millimetres wide of biotite rich material, which runs away from the diorite as a vein into the enclosing hornfels.

The most common rock type forming these veins is a grey, medium grained biotite quartz diorite. The feldspar laths commonly show lamination analogous to that of the main gabbro mass. Microscopic examination shows the rock to have an irregular grain size. Feldspar is calcic andesine, commonly zoned, with some slight reversals, or with patchy extinction. Quartz forms interstitial anhedra; micropegmatitic material is absent, but a few grains of perthite occur interstitially. Biotite is the most common dark mineral; much of it occurs partly wrapped around amphibole or pyroxene grains; the larger flakes particularly are crowded with apatite. Amphibole is the pale coloured variety, occurring as subhedral laths or uralitic aggregates enclosing remnants of clinopyroxene, which occurs also as sporadic almost unaltered grains. Shapeless granules of ore are common, mostly associated with the biotite or amphibole. Apatite is remarkably common; sphene and zircon occur in very minor amount.

Microscopically, there is an abrupt transition from the medium grained biotite-quartz diorite to fine grained hornfels. A notable feature is an increased amount of biotite in both rocks near the junction, a feature which may represent a "basic front".

In places schlieren of coarsely crystalline feldspathic rock occur in the hornfels near the biotite-quartz diorites, or in the latter themselves. The dark mineral is either hornblende or biotite, and its concentration varies from almost nothing up to a third of the rock. The feldspar is labradorite, with colourless amphibole ($Z \wedge C = 20$) and micropegmatite interstitial to it. Lenses of the same amphibole occur along the cleavage planes of the biotite. Iron ore, sphene, apatite and epidote occur as accessories. These coarse rocks are probably analogous to the coarse basic veins at the head of O'Shea Creek.

In Brennan's Gully, 100 yards from the edge of the gabbro, is an extensive outcrop of medium grained laminated troctolite. Texturally, it is very like the olivine gabbros of the main mass, and, except that clinopyroxene is rare, its mineralogy is closely akin to these also.

Due to lack of exposures, it could not be decided whether this rock was an offshoot from the main mass, or part of it, with the intervening hornfels forming a large xenolith.

Near the western end of the bridge across the Stanley River just below the dam are a number of boulders of a rock very like parts of the quartz gabbro. This resemblance still holds when the rock is examined microscopically. The rock contains zoned or blotchy andesine-labradorite with perthitic outgrowths, interstitial micropegmatite, brown and pale green amphibole, uralite, brassy biotite, and minor iron ore and sphene. Apatite, as in the quartz gabbro, is common.

This mass appears to be the same as the "minor augite diorite" mapped by Ball (1940).

THE RED ROCK

Red rock forms a large irregular mass in the northern part of the complex, and several small satellite bodies.

For descriptive purposes, it is convenient to arbitrarily divide the main mass into two parts, separated by a line approximately along the 352 grid northing. The southern part will be referred to as the Trig. Point portion, the northern as the Waterfall Gully portion. The former appears to overlie the gabbro; the latter is bordered by andesites and is probably a discordant plug like body.

In the hand specimen, the red rock is pink or buff coloured, with mariolitic cavities containing quartz and, less commonly, epidote and white clayey material. The principal constituents are feldspar and quartz and accessory iron ore, only very slightly magnetic, and rare biotite. It shows marked textural variation. For convenience, it can be divided into equigranular and porphyritic types, between which there are all gradations. The texture generally trends to one extreme or the other, so they can be distinguished in the field. There does not appear to be any rapid alternation of the two types, except in the section up Waterfall Gully, where there may be a change as often as every two or three hundred yards. The porphyritic type is less resistant to erosion, and forms a broad flat depression at the head of Waterfall Gully with ridges of the equigranular type on either side.

The typical equigranular red rock is medium grained, with fine scattered grains of quartz. Less commonly, it is coarse grained, with a typical granitic appearance. Many of the feldspars can be seen to be perthitic. There is usually little sign of micropegmatitic texture, but at 679349 a boulder is entirely made up of beautiful granophyric intergrowths of feldspar and quartz.

The typical porphyritic red rock has rounded phenocrysts of quartz about 1 mm. in diameter, and of feldspar, commonly present in two generations, one consisting of euhedral crystals about the same size as the quartz, and the other forming larger shapeless grains of perthite, mostly forming glomeroporphyritic aggregates, and commonly altered to white opaque clayey material. The phenocrysts are more or less constant in size, irrespective of the grain size of the matrix which, in the extreme porphyritic type, is composed of very fine equigranular quartz and feldspar. As the phenocrysts become more numerous and the grain size of the matrix increases and becomes uneven, the porphyritic appearance is less obvious, and with further change all variations between the two extreme textural types can be found. Where the matrix has an intermediate grain size, granophyric growths are common in it.

Junctions between textural types were found at 665344, 679355 (between porphyritic and equigranular rocks) and 670366 (between coarse and fine equigranular types). In the first and third, the change is sharp, and marked by a decrease in grain size of the finer rock within .5 cm. of the coarser, a feature very like a chilled margin. At 679355 the two types are separated by a fine aplite, which varies in width from four feet to practically nothing, and has a sharp junction against the porphyritic type.

In thin section the mineralogy of the red rock is simple. It consists essentially of perthite and quartz (the latter in slightly smaller amount) with accessory ore, muscovite, and rare biotite, plagioclase and dark minerals.

String perthite* is by far the most common type, with strings a millimetre or more in length and up to .02 mm. wide. In cases, individual strings may bifurcate and reunite, or there may be anastomosis of adjacent strings producing a braid perthite.

Some slides contain a small amount of patch perthite. The plagioclase component of this last, at least, is oligoclase albite.

Quartz is remarkably uniform in appearance throughout the mass. It forms clear grains, most of which show slight undulose extinction. Some show marked strain extinction; in one case, such a grain is crowded with small granules of ore. On the whole, inclusions are not common in the quartz, but cavities are; most of the larger grains, particularly, are crowded with them.

The quartz-feldspar intergrowths are for the most part relatively coarse. In many cases, there is no pattern evident, the quartz occurring as shapeless grains, apparently discrete, but with the same extinction position. With development of the texture, the grains become angular, then elongate and parallel, forming rods up to 1 mm. long, with an irregular, commonly hieroglyphic shape, and up to .1 mm. across. Where the perthite is completely occupied by micrographic texture the intergrowth in the central part of the crystal is very delicate, and rapidly becomes coarser towards the margin. In a number of cases, picture frame intergrowths are developed.

The proportion of iron ore varies irregularly through the red rock. It forms very irregular, sometimes skeletal grains, and in cases, has pseudomorphed mica flakes. These last have small zircon grains closely associated.

A few small flakes of muscovite may be primary. It is common as an alteration product of feldspar. Sporadic small subhedral grains of homogeneous albite-oligoclase were noted. A few grains of tourmaline occur, with opaque ore grains closely associated. The tourmaline is pleochroic: E = greyish brown, O = dark bluish green.

The microscopic texture, like that of the hand specimen, is variable. In some cases the quartz forms rounded, more or less equidimensional grains, not unlike

*The blebs are similar, if rather more elongate, to those described by Alling (1938 pp. 143, 144) as strings, and in spite of their much greater size, this term is used here.

those in a coarse aplite. In other slides, it is irregular, forming amoeboid-like grains which develop into micropegmatitic intergrowths. From this stage, the proportion of micropegmatitic material increases and the apparent (but not the real) grain size decreases until the texture is almost entirely symplectic.

In the porphyritic red rock the phenocrysts are perthite, 3–4 mm. in extent, and slightly smaller quartz grains. Most of the former have a marginal fringe of micropegmatite, in which the quartz individuals resemble those of the matrix and the feldspar is optically continuous with the bulk of the grain. The grain boundaries of glomeroporphyritic groups are marked by droplets of quartz. The quartz phenocrysts are amoeboid, wholly or partly enclosing feldspars of the matrix (Fig. 5). The texture of the matrix is variable. It may consist of an equigranular mosaic of quartz and perthite with little or no intergrowth. In other cases the feldspar is larger, of varying size, and partly intergrown with quartz; when this effect is carried further there is no clear division between porphyritic and "ground mass" feldspar.

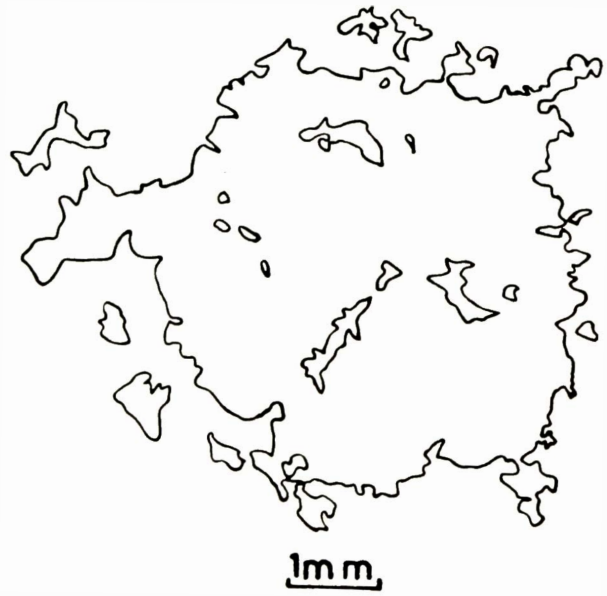

Fig. 5—Grain of amoeboid quartz in porphyritic red rock, enclosing feldspar grains of the matrix.

At 680355, although exposures are not continuous, there is a suggestion that the porphyritic rock grades into the coarse equigranular type. At the top of the slope into Waterfall Gully, the rock is the usual porphyritic type with no intergrowth in the matrix; 10 feet lower, the matrix is slightly coarser, and more variable in grain size; a further 10 feet down, it is difficult to distinguish phenocrysts from matrix, and penetration of feldspar by quartz is marked; another 10 feet away, the rock is the coarse, more-or-less equigranular type.

At the junction between gabbro and red rock described earlier, the lowest red rock exposed *in situ* is an equigranular type with well-developed radiating quartz-perthite intergrowths. An unusual feature is the coring of many of these by a euhedral crystal of perthite without intergrowths. 20 feet above this, the rock is medium grained and equigranular, with very few intergrowths, and these only poorly developed.

The red rock in the boulder containing the red rock-gabbro contact is equigranular, with very few intergrowths; it consists of perthite, quartz and accessory iron ore and muscovite. Four inches from the contact it is medium to coarse grained; within an inch of the gabbro it is slightly finer, and intergrowths are slightly more common, but still very irregular.

There is some doubt as to the shape of the main red rock body. The distribution of red rock in relation to topography suggests the Waterfall Gully portion is steep sided. Evidence for the form of the Trig. Point portion is inconclusive. The steep spurs on the western side are red rock on top and gabbro in their lower parts, so that red rock appears to overlie the gabbro, but no absolutely vertical section was found, so a steep sided body could produce the same relationship.

The areas of hornfels on either side of Waterfall Gully are probably roof pendants, rather than a huge inclusion. The rarity of inclusions in the red rock (only one was found) make the latter possibility unlikely.

Metamorphism by the Red Rock

The hornfelses adjacent to the red rock are not dark granulitic hornfelses like those near the gabbro, but grey and fine grained, with a texture not unlike the porphyritic parts of the red rock itself, *i.e.*, with subhedral to euhedral pink or creamy feldspar, forming isolated crystals or glomerophyritic aggregates, and scattered rounded grains of quartz. Veins and stringers of pink quartzo-feldspathic material occur in places. Further from the red rock the general appearance is dark and fine grained, with the original phenocrysts marked by blastoporphyritic biotite and amphibole. The high biotite content gives fresh surfaces a dark sheen. These rocks pass outwards into normal andesites. In fresh exposures near the red rock, pyrite is common along joints.

As is the case with andesites around the gabbro, the first sign of alteration is the production in the ground mass, of pale green fibrous amphibole, pleochroic from bluish green to greenish brown; $Z \wedge C = 24^{\circ}$. Flakes of biotite are fairly common. Biotite and amphibole tend to be mutually exclusive in any one part of a slide. The original heterogeneity of the rock is betrayed by the concentration of these minerals in streaks and patches. Some of the plagioclases show clouding like that in the gabbro hornfelses, but most have a dirty turbid look. Trails of amphibole and biotite occur in many. Iron ore is fairly common, and tourmaline, E = brown, O = inky blue, and epidote occur in places.

Closer to the red rock, although original textures may be still discerned in the outcrop, the fine ground mass is completely recrystallised to a fine mosaic of feldspar and some quartz, with small scattered flakes of biotite, fewer but larger rounded quartz grains, and some green amphibole. The interiors of feldspar phenocrysts are recrystallised to feldspar mosaics like that of the ground mass. In cases, the original feldspars have a narrow, highly zoned rim of oligoclase, separated sharply from the main plagioclase crystal, and with the outer margin crenulated by the recrystallised grains of the matrix. The original ferromagnesian phenocrysts are pseudomorphed by biotite, hornblende and iron ore. Iron ore and apatite are common and in higher grades, sphene and zircon, too. On the whole, the proportion of ferro-magnesian minerals is noticeable less than in the hornfelses of lower grade.

With further alteration, amoeboid grains of quartz become increasingly abundant. Several such grains, apparently isolated, may be optically continuous (Fig. 6). Small inclusions of apatite, sphene, ore, amphibole and biotite are not uncommon.

The feldspars are oligoclase, usually very turbid, with some progressive zoning, and a rim of clear material. They still possess the original lath shape of the feldspars in the andesite, but the margins are very crenulate. Near the red

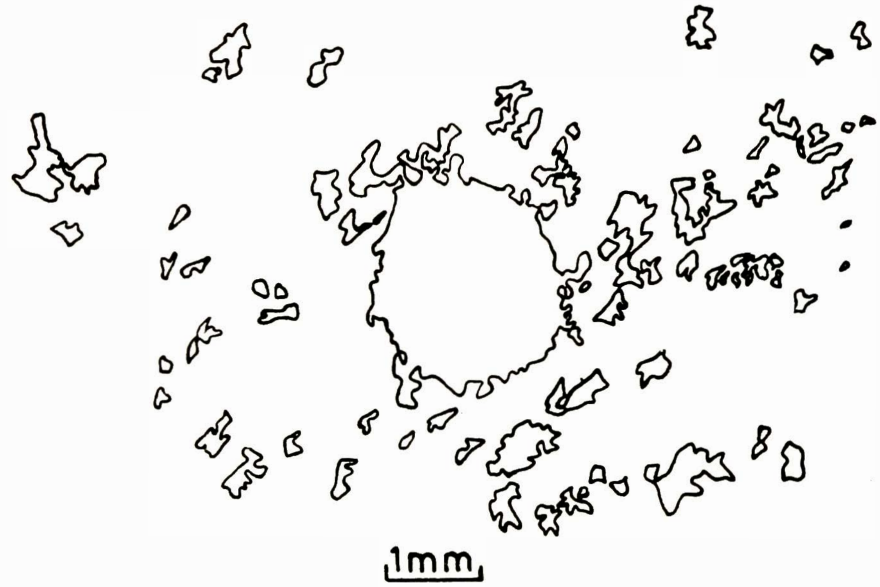

Fig. 6—Porphyroblast of amoeboid quartz in red rock hornfels, with optically continuous outliers.

rock they become more common, and tend to form glomeroporphyritic groups. A few show carlsbad twinning. Some are perthitic, others antiperthitic. There is no trace of the original ferromagnesian minerals. Shreds of biotite and green hornblende occur in small amount.

That these big feldspars in the hornfels are the result of feldspathisation, and not original phenocrysts in the andesites, is shown by :—

(1) They are pink or buff coloured; phenocrysts in the andesites are clear or white.
(2) They are mostly much larger than any phenocrysts seen in the andesites.
(3) No glomeroporphyritic aggregates were seen in the andesites.
(4) Twinning is rare; phenocrysts in the andesites are invariably well twinned.
(5) Some are perthitic (others possibly cryptoperthitic); andesite phenocrysts are zoned, but never perthitic.
(6) They occur only in the vicinity of the red rock, and become more common as this is approached.

A zoned plagioclase remnant in one of these big feldspars suggests that they may have originated, in part at least, by replacement of andesite phenocrysts.

The actual margin of the main red rock body was not found, but in Waterfall Gully, 15 yards from it, the hornfels contains veins of porphyritic red rock with well defined contacts. In thin section the contact is marked by a narrow zone of interlocking quartz and feldspar, in grains about .01 mm. in diameter, and texturally very like the felsites. A similar feature occurs along the margin of a granophyric vein at 663323.

At 681355 are several rounded "inclusions", each about 6 inches across, with a texture quite different to that of the enclosing high grade hornfels. It is rather coarser, and consists of pink feldspar, a little quartz, and very elongate needles of greenish black hornblende.

The feldspar of the "inclusions" is so turbid that its composition cannot be ascertained in thin section. Staining shows that a few are bordered by potash feldspar. Quartz is more abundant than in the hornfels, and forms larger very irregular grains. Inclusions, mainly apatite, are common in it. The hornblende is pale brownish green, pleochroic, $Z \wedge C = 24°$. The grain boundaries are notched by feldspar laths. Its pronounced acicularity is a striking feature. No preferred orientation of the needles was apparent. Apatite, also forming very elongate needles, is very common. There are a few biotite flakes, and small scattered iron ore grains.

The transition from hornfels to "inclusions" is well defined. It is marked by an increase in grain size, the presence of hornblende rather than biotite, and slightly greater abundance of quartz and iron ore.

Inclusions in the Red Rock

Only one inclusion was found, about 4 feet long and 3 feet wide, with very irregular but sharp margins, and a net of irregular acid veins in the outer parts. It is a dark rock, with phenocrysts of feldspar in a microcrystalline matrix.

In thin section, it shows surprisingly little alteration. Evidently it was originally agglomeratic, because parts of the matrix now consist of biotite with some sericite, others of feldspar (some of it potash feldspar) with scattered biotite. Iron ore is common. Circular aggregates of clear feldspar probably represent altered vesicle infilling. The original phenocrysts have been converted to blasto-porphyritic aggregates of sericite.

The acid veins are made up of phenocrysts of quartz and feldspar (perthite, with plagioclase rims) in a matrix of plagioclase, quartz, potash feldspar, sericite and iron ore. The margins of the quartz phenocrysts may be very crenulate, or smooth except for embayments very like those in the phenocrysts of acid lavas.

COMPARISON OF METAMORPHISM BY GABBRO AND RED ROCK

It is clear that the results of thermal metamorphism by gabbro and red rock are notably different, although, in each case, the hornfelses pass outwards into the andesitic Neara Volcanics. It will be useful to summarise the change in each case.

As the gabbro is approached, the andesites become darker; structures such as agglomerate fragments and vesicles are obscured, and recrystallisation gives the rock a granular appearance; plates of poikilitic biotite appear, patches of basic rock occur, and thin felsic veins are common; the original feldspar phenocrysts remain visible right to the margin of the gabbro.

The zone of metamorphism around the red rock is much narrower than that surrounding the gabbro. The ferromagnesian phenocrysts are pseudomorphed by fine flaky material, and original structures are lost; the rock becomes lighter in colour, and porphyroblasts of feldspar and quartz appear; these, particularly the former, become more common, and the feldspar tends to become glomeroporphyritic; pink aplitic patches and trails of euhedral feldspar develop; near the main mass, veins of red rock occur and original phenocrysts are absent.

The mineralogical changes are equally distinctive. In both cases, the first effect is the production of green amphibole and biotite. Thereafter, around the gabbro the grain-size of these new dark minerals increases, and the original plagioclase is clouded by minute inclusions; at the next stage, the place of the hornblende is taken by granoblasts of pyroxene; later still, olivine appears, the ground mass feldspar is partly recrystallised, producing a beerbachitic texture, and phenocrysts show incipient recrystallisation; remaining feldspar is still cloudy. Even at the gabbro margin, aggregates of pyroxene and iron ore mark original femic phenocrysts.

As alteration proceeds around the red rock, there is some clouding of the plagioclases, but most are turbid; biotite becomes common, amphibole uncommon; ferromagnesian phenocrysts are completely pseudomorphed by biotite. As metamorphism advances the proportion of dark minerals decreases; the original feldspar acquires a rim of less calcic material with a crenulated outer margin, and in some cases, is partly recrystallised; porphyroblasts of quartz and feldspar appear, and become more numerous, and apatite is common. Near the red rock the big feldspars are perthitic and form glomeroporphyritic groups, and ferromagnesian mineral is present in only small amount.

Thus, in the highest grades of metamorphism, distinctive mineral assemblages are produced; plagioclase, pyroxene, olivine and iron ore around the gabbro, and alkali-feldspar, quartz and biotite around the red rock. In other words, the hornfels resembles the rock which produced it.

This tendency has been noted by a number of writers, notably Schwartz (1924) and Grout (1933). Where the hornfels differs appreciably in composition from the rock producing it, chemical changes may tend to decrease this difference. This has been well established in the case of granite rocks (*e.g.*, Reynolds, 1947). Changes around basic rocks have received less attention, but nevertheless have been shown to occur for pelitic rocks, at least (Grout, *op. cit.*, p. 1018), Sadashivaiah, 1950, p. 129). The former has, in fact, commented (*op. cit.*, p. 1021): "Gabbro hornfelses resemble gabbro whatever their origin."

Where the original rock is andesitic, little chemical change is required to produce hornfelses like those around the gabbro at Somerset Dam. The high quartz content, perthitic feldspars (potash feldspar is not evident in the unaltered andesites) and small amount of dark mineral in the hornfelses around the red rock point to changes in the bulk composition of the andesites. Quantitative data is not available, but the changes indicated (*viz.*, addition of silica and alkalies, and decrease of femic constituents) do agree with those shown by Reynolds (1947, pp. 424, 425) as occurring when basic rocks are granitised.

THE FELSITES AND OTHER ACID DYKES AND VEINS

Under this heading are described the dykes and veins, essentially fine grained quartz-feldspar aggregates, which occur in and around the complex.

The felsite forms dykes varying in width from one to ten feet, but roughly constant in any one dyke. It is characterised by a pink colour and a felsitic texture without phenocrysts. In thin section it is essentially a fine grained mosaic of quartz and turbid feldspar. The grain size is uniform over small areas, but there is considerable variation within the area of a thin section. Some slides contain small scattered iron ore granules and biotite forms either scattered flakes or small aggregates, presumably the last vestiges of inclusions.

In the quarry, operations have exposed complex felsite-andesite relationships. The felsite has irregularly invaded the andesite, producing within it concentrations of rounded felsite patches a few inches across. Where the invasion of felsite has been even more intimate, there are only thin screens of andesite between the patches, giving the impression that the felsite has been invaded and brecciated by the andesite. The felsite "blocks" may contain fragments of andesite. The contact between the two appears quite sharp, the only change being a slight darkening of the felsite within a couple of millimetres of the andesite.

The andesite in the quarry has been hornfelsed to a fine aggregate of biotite, feldspar and iron ore, with the original andesine phenocrysts little affected. The junction between andesite and felsite may be quite sharp, the only effect being a slight decrease in the size of the biotite of the hornfels within .2 mm. of the felsite. In other cases, there may be some intermingling of the two over a fraction of a millimetre, small lenses and streaks of the quartz-feldspar mosaic occurring within the biotite-plagioclase-iron ore aggregate of the hornfels. One texture may be sharply separated from the other or there may be a rapid gradation between the two.

In places the felsite grades irregularly into a medium grained granodiorite made up of angular quartz with many grains in optical continuity, very sericitised feldspar (some, at least, andesine), chloritised biotite and ore. Near the junction, this rock contains blebs of felsitic texture, and, by an increase in the number and size of these, grades over a distance of a couple of inches into the felsite.

Thin veins of acid material are common in the hornfelses around the gabbro, and in the gabbro itself near its margin, with isolated representatives throughout the complex. At 649329 one cuts a dyke of quartz diorite. The width varies from very thin to several inches, and the length from a few inches to at least 10 feet. The longer veins are usually straight (Plate I, Fig. 6) and more or less uniform in width, with sharply defined margins; they have the features of veins emplaced along joints. The shorter veins tend to be thin and variable in width and direction (Plate I, Fig. 2), branch irregularly, and in places are numerous enough to form a network of acid material through the hornfels.

The veins are pink or white in colour, with a felsitic or aplitic texture. The centre of the vein is commonly marked by elongated cavities occupied by quartz prisms, and in places, epidote or tourmaline.

The microscopic texture varies from fine grained quartz-feldspar aggregates very like the felsites to medium grained micrographic material similar to parts of the red rock. In some cases, the texture varies between these two extremes even in the one slide. Along the margins of many veins, intergrowths of quartz and feldspar are elongated normal to the wall, and in one case a thin strip of very fine grained material is developed along part of the junction of vein and hornfels.

The feldspar for the most part is perthite, but apparently homongeneous grains of potash feldspar and albite are common. In one case the phenocrysts are oligoclase rimmed with perthite. Quartz not involved in micrographic growths is commonly interstitial, but many apparently isolated individuals are optically continuous. Iron ore, biotite, sericite, chlorite, calcite and apatite occur in small amount in various veins. One rock contains small flakes of biotite and grains of ore and partly recrystallised and broken up plagioclase crystals, looking very like xenocrystic material. This vein has apparently incorporated material from the surrounding hornfels, although its margins are quite sharp.

QUARTZ DIORITE DYKES

Included in this group are a number of dykes with characteristic textures. They are also distinguished by the presence in important amount of hornblende both as phenocrysts and in the ground mass. Most intrude the Neara Volcanics but two representatives were found intruding the gabbro in Brennan's Gully. The dykes are mostly a couple of feet wide, with fairly straight borders, but in several places form irregular shaped masses. The margin, wherever it could be seen, appeared quite sharp, except at one place in the quarry, where a shapeless mass grades into felsite.

The quartz diorites were not injected simultaneously, because at 683322 some dykes are cut and dilationally offset by others. A thin acid vein both cuts and is cut by the quartz diorite.

Macroscopically the quartz diorite is pink or light grey in colour. Some dykes contain phenocrysts of euhedral to subhedral pale greenish grey plagioclase and needles of hornblende, in a matrix of fine grained feldspar, and hornblende the size of which varies from minute grains to that of the phenocrysts. Biotite, invariably chloritised, occurs in places, and scales of pyrite at 664325. The finer grained ferromagnesian minerals tend to aggregate into patches about the size of the phenocrysts.

Other dykes are similar to these, but are medium grained, without phenocrysts.

The plagioclase is oligoclase-andesine with progressive zoning, especially marked towards the margin. Most of it is altered to micaceous and clayey material. Potash feldspar occurs as small interstitial patches, and in some cases, narrow rims around the plagioclase or small, poorly defined patches within it. Quartz occurs as small interstitial grains, forming optically continuous groups. Minute inclusions and cavities are common in it. Biotite is present as small irregular flakes, commonly concentrated in certain parts of the slide in association with small granules of iron ore; these patches are probably the last vestiges of inclusions. Apatite is a common accessory.

Several slides contain very fine equiangular aggregates of feldspar and quartz, texturally very like the felsite, but with much less quartz. These patches are several millimetres in extent, and pass quite rapidly into the coarser quartz diorite.

The presence of numerous inclusions is a characteristic feature of these dykes. They vary in size from less than $\frac{1}{4}$ inch to blocks 15 inches across (Plate I, Fig. 7). At 682323 they are so numerous that the dyke appears as a network of material through hornfels. The edges of adjoining xenoliths can be fitted together, but there has been some rotation of the pieces.

In appearance also, the xenoliths are variable. There are all gradations from dark fine grained individuals with sharply defined margins, to material very like the enclosing quartz diorite with ill-defined margins pinkish grey in colour and medium grained, with porphyroblasts of plagioclase rather like the phenocrysts in the quartz diorite. These differences in the xenoliths are probably due to differing degrees of incorporation rather than to a variety of source material.

In thin section the dark fine grained xenoliths resemble the hornfelses around the gabbro, and show similar variations in the degree of recrystallisation. In the more completely incorporated xenoliths, the feldspar is very turbid oligoclase-andesine; quartz forms interstitial grains, some in optical continuity, but not to the same extent as in the quartz diorite itself; the ferromagnesian minerals, originally biotite and pale brown amphibole, are almost entirely altered to deep green chlorite. Accessory minerals include iron ore, apatite, calcite and sphene. The boundary between these partly assimilated inclusions and the quartz diorite is gradational; the inclusion passes into the quartz diorite by increase in the amount of quartz and large feldspars, and decrease in the amount of apatite.

The dyke just below the bridge at 683322 contains several xenoliths of medium grained olivine gabbro, with sharp margins. In thin section their general appearance is not unlike some representatives of the olivine gabbro of the complex, although the plagioclase of the xenoliths is rather more sodic (basic andesine). They have been little affected by the enclosing magma.

A third type of quartz diorite occurs at 656323 and 654325. This is a pink or grey equigranular rock containing feldspar, hornblende and a small amount of quartz. The feldspar consists of zoned andesine cores with perthitic outgrowths.

Quartz forms interstitial grains, in optically continuous units, and in cases is intergrown with the feldspar. Hornblende forms anhedra, pleochroic X = brownish green, Y = green, Z = olive green; Z$\wedge$C = 24°; inclusions of apatite and iron ore are common in it. Many are quite fresh but others have been wholly or partly altered to aggregate of biotite and ore. Accessories include numerous iron ore grains and rods, and laths of apatite.

The hornblende of this rock is reminiscent of some types of partly altered hornblende in the quartz gabbro, and it may be that this rock is an offshoot from the main mass of gabbro.

OTHER IGNEOUS ACTIVITY

Apart from those described, dykes are not common in the area. A dyke of highly altered andesite was found at 642323. A basalt at 646328 shows no sign of alteration although it is emplaced in fairly strongly metamorphosed andesite, so may be an offshoot from the main mass.

During a reconnaissance down Waterfall Gully, a fine grained basaltic vein was found occupying a major joint in the red rock. Before it could be investigated further, cyclonic rains covered it with debris.

THE ORIGIN OF THE COMPLEX

The igneous complex at Somerset Dam is apparently yet another example of the gabbro-red rock association which has been described in many parts of the world. There is a general resemblance to many of these other occurrences, but nevertheless, when examined in detail, it shows several unusual features, which will be pointed out in the following discussion. Lack of chemical data, and doubt as to the inter-relationships of many members of the complex will necessarily involve some degree of speculation in any discussion of its evolution. For this reason, the interpretation which follows must be regarded as tentative.

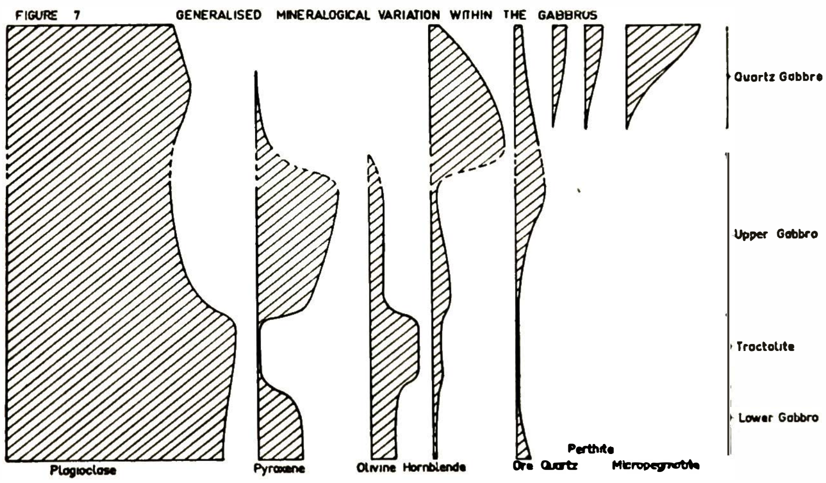

Fig. 7—Generalised variation in the proportions of minerals in the gabbro of the complex.

The Gabbro

There is little doubt that this is a discordant steepsided body; whether it is cylindrical or conical is not known.

Fig. 7 shows in very generalised form the variation in proportions of the various minerals in the exposed part of the mass. The most obvious feature is the increase in the proportion of olivine and reciprocal decrease in pyroxene in the troctolite horizon. Above this horizon there is a tendency for pyroxene, hornblende and ore to be more important than below it, and for a corresponding slight decrease in plagioclase and olivine. This feature occurs also in the upper part of the Skaergaard mass, but the increase in the amount of iron ore is much more marked in the case of the Somerset Dam body.

Banding due to variation in the relative proportions of light and dark minerals is a common feature of many basic masses. Almost all explanations proposed for this banding invoke gravational settling as the major control. Indeed, Wager (1953) has gone so far as to write "Some sinking of crystals through magma under the influence of gravity seems to be an essential part of any hypothesis of formation of layered intrusions." To this mechanism several workers have added the concept of stirring by magma movements to explain the rhythmic nature of the banding.

In the case of the Somerset Dam complex, features suggesting that the bands in the troctolite are due to gravitational settling of precipitated minerals are:—

(1) The feldspar tablets commonly show parallelism in an almost horizontal plane; this is analogous to deposition of platy minerals in sediments.

(2) Where there is a sudden change in rock types, the junction is in this plane (e.g. the variation at 663323).

(3) The feldspar grains are commonly bent or cracked, probably a result of slight settling of a crystal mesh under the weight of material deposited on it.

That this deposition of minerals took place in a moving magma is shown by:—

(4) The long axes of the feldspars are parallel in places; such a lineation is generally regarded as evidence of movement in the magma.

(5) The dark bands are impersistent; bands due to settling under stagnant conditions should extend across the top of the crystal mesh for considerable distances; lensing of sedimentary beds is regarded as an indication of turbulent conditions.

Banding such as that in the troctolites does not occur elsewhere in the gabbro, although lamination and lineation of the feldspars are fairly common. Possibly currents were strong enough to align settling crystals, but not strong enough to stir the crystal mush on the floor of the chamber.

In the case of the troctolite, the rarity of pyroxene and the slightly more basic composition and marked zoning of the feldspars suggest that there was a change in conditions in the magma chamber at the beginning of crystallisation of this horizon. In the Bushveld and Skye masses there are reversals in the trend of the plagioclase towards a sodic composition (Wager 1953 Plate 8) but no reason for these changes is given in descriptions of these bodies.

The variety of rock types at the edge of the gabbro in Brennans Gully must also be ascribed to changes in the proportions of minerals being precipitated . The fine grained dark rock and biotite troctolite here are unlikely to be dykes because:

(1) Their margins are parallel to the lamination of the gabbro.

(2) Their constituent minerals are similar to those in the gabbro, and the biotite troctolite is texturally like the gabbro.

(3) Mineral grains project from the base of the fine dark rock into the interstices of the feldspars of the coarse underlying rock.

Little can be said regarding the changes in conditions which produced these different rock types. Possible causes are removal of material from the chamber by vulcanicity or dyke formation, or compositional changes due to addition of material from another source.

A notable feature is that at Somerset Dam troctolites pass upwards into olivine gabbros, a feature of many sheetlike bodies, but are underlain by olivine gabbros similar to those above the troctolite and not, as is usually the case, by ultrabasic rocks. This suggests that the change which produced the troctolite brought about conditions resembling those when the magma was first intruded.

The absence of any progressive changes in the composition of particular mineral species (the cryptic layering of Wager and Deer, 1939) may be due to the exposure of only a small part of the vertical thickness of the gabbro. In the gabbroic bodies showing cryptic layering which have been studied in detail, much greater vertical sections are available, e.g. Skye 7,000 feet, Skaergaard 8,000 feet, Stillwater 17,000 feet, Bushveld, over 17,000 feet. On the other hand, it is not impossible that cryptic layering is absent. Rossman (1955) has described a gabbro mass in Alaska in which over 32,000 feet of branded rocks are exposed. Although there are small compositional differences, he considers that there is little, if any vertical change in the mean composition of the minerals in this mass (personal communication). The marked mineral changes in the quartz gabbro will be discussed later.

The Somerset Dam complex differs from most gabbro-red rock associations in the rarity of orthopyroxene and the common occurrence of brown primary hornblende, which increases slightly in amount towards the quartz gabbro, where it is very common. It may well be, that below the levels exposed, amphibole would be less common and orthopyroxene occur. Hall (1932, p. 306) notes that towards the top of the Bushveld basic rocks, there is an increase in hornblende and decrease of orthopyroxene and plagioclase, and Wager and Deer (1939, p. 82) found that orthopyroxene disappeared slightly more than half way up the Skaergaard body. Some of the uralite in the Somerset Dam rocks may originally have been orthopyroxene, but much of it is obviously pseudomorphing clinopyroxene. The order of crystallisation of the gabbro was more or less constant. Plagioclase was the first to crystallise, followed almost immediately by olivine and, in the upper gabbro, by clinopyroxene. In the lower gabbro clinopyroxene was rather later. The clinopyroxene then reacted with magma to give brown hornblende. Iron ore is rather earlier than hornblende, because hornblende surrounds several ore grains. The uralite and serpentine would be produced in the final stages of cooling.

The Relation of the Red Rock to the Gabbro

The close association of gabbro and red rock in so many parts of the world makes it certain that this relationship is a genetic one. It has been well established that crystallisation of a basic magma may produce a quarto-feldspathic residuum, but the amount so produced is small when compared with the volume of the original magma.

In the case of the associated gabbro and red rock at Somerset Dam, there are two problems:

(a) Is the red rock a direct differentiate of the gabbro now exposed, or is it derived from another source?

(b) If it is not a differentiate of the gabbro, is it earlier than this, and what effect has the gabbro had on it? If it is later, what effect has it had on the gabbro?

In the case of (a) the volume of red rock relative to the gabbro, and its spatial relations suggest it is not a differentiate. Acid rocks which can be shown to be differentiates of a basic mass are always volumetrically very much subordinate to the associated basic rocks, forming only a few per cent. of the total volume. It could be assumed that the gabbro increased greatly in size at depth, but there is no evidence for this.

Even if this volume increase were the case, the spatial relations of red rock and gabbro must still be explained. The quartzo-feldspathic differentiate of a basic magma commonly forms horizons in the basic rocks (usually at or near the top of the mass), or is distributed through it as dykes or irregular patches. At Somerset Dam, although part of the red rock appears to overlie the gabbro, the bulk of it forms a large plug-like mass beside the basic rocks, i.e. would have been intruded downwards from a horizon now represented by the trig point portion of the red rock.

Thus a hypothesis of differentiation in situ of the red rock from the gabbro involves several unlikely features, and separate emplacement of the two seems much more likely. Many of the thin acid veins in and around the margins of the gabbro probably do represent the residual solutions of its crystallisation. They must have been injected when the gabbro was solid but still hot, because marginal chilling was found only in one place and veins such as these are common around the margins of basic intrusions, e.g. Richey and Thomas (1930, pp. 218, 227), Wager and Deer (1939, pp. 204, 209), Bailey, et. al. (1924, p. 326).

The mineralogical changes in the quartz gabbro, including the presence of perthite, could be the result of either normal differentiation of the gabbro or introduction of material from the red rock (by contamination if this were the earlier, or by metasomatism if the red rock post dates the gabbro). Features pertinent to this are: (1) There is an upward decrease in the amount of dark minerals, and increase of alkali feldspar, quartz and micropegmatite. These changes are paralleled at Skaergaard (Wager and Deer, 1939, p. 65), Stillwater (Hess, 1938), Okonjeje (Simpson, 1955, pp. 132, 134) and the Palisades (Walker 1940, p. 1075). In all of these examples, no large body of granitic rock is known to be associated with the basic rocks.

Schwartz and Sandberg (1940) and Hotz (1953) have described cases of gabbro grading by differentiation into relatively large granophyre bodies.

On the other hand, Leighton (1954) has described a zone of "intermediate rock" grading into gabbro on one hand and granophyre on the other. This zone shows many of the features of the quartz gabbros at Somerset Dam, including perthite rims about plagioclase, micropegmatite, and uralitised pyroxene. Leighton (p. 439) concludes that it is due to contact action of intruded granophyre magma on the solidified gabbro.

(2) The quartz gabbros are abnormally rich in apatite. This feature, too, has been ascribed to both metasomatism and normal differentiation. Hotz, Simpson and Wager and Deer note an increased amount of apatite in the gabbros containing micropegmatite, but so does Leighton, who postulates a metasomatic origin for the intermediate rocks. Stewart (1947, p. 447) found that apatite was concentrated in the end stage rocks at Belhelvie, and the apatite rich granophyric material which so commonly veins and impregnates the basic rocks at Ardnamurchan is thought to be a residuum from crystallisation of the host rock (Richey and Thomas, 1930). Nockolds (1933) lists a number of examples of the concentration of apatite in basic rocks associated with acid magmas, ascribing this concentration to the action of volatiles.

(3) The micropegmatite is interstitial, many of the plagioclase cores rimmed by perthite are euhedral with sharp corners, the perthite rims have more or less uniform width throughout a slide, and the plagioclase component is optically continuous with the central plagioclase. These features suggest crystallisation from a residuum filling the interstices of a crystal mesh. In most cases, one of the first effects of metasomatism is a rounding of the grains being attacked.

(4) There is no trace of olivine in the quartz gabbros, even those texturally similar to the normal olivine gabbros, and pyroxene is uncommon. Instead, brown ophitic hornblende is common. This feature is best explained by crystallisation trends in the magma. If the pyroxene and olivine had been destroyed by metasomatising solutions, the product would most likely be fibrous or granular.

(5) The change from micropegmatitic "gabbro" to red rock takes place within a few feet and a sharp contact has been found, although the red rock of this is not proved to be part of the main mass. Hotz (1953) has described a gradation over a distance of 4 feet from granophyric diabase to hedenburgitic granophyre.

(6) The plagioclases just under the red rock are more sodic than elsewhere, and many display concentric oscillatory zoning. The plagioclase in the metasomatic transitional rocks described by Leighton (op. cit. p. 423) is very irregularly zoned, which is to be expected in metasomatically altered plagioclase; the production of regular concentric zoning would be highly unusual. Leighton himself writes (p. 432) "The feldspars of the gabbro commonly exhibit oscillatory zoning—a characteristic of crystallisation in a magma."

The sodic plagioclase is analogous to the case at Skaergaard, where Wager and Deer found a marked enrichment in soda in the final stages of crystallisation.

(7) Much of the brown hornblende has been recrystallised to decussate aggregates of pale brown amphibole and/or biotite. The texture of these newly formed minerals is quite different to that of secondary amphibole elsewhere in the gabbro, and is that of material recrystallised by thermal metamorphism, not by metasomatism.

If this alteration is thermal in origin, the obvious cause is the red rock, so that this would then be later than the gabbro. The very blotchy extinction of some of the plagioclases could also be ascribed to a later reheating. This is a common feature in hornfelses around the complex, where it is a sign of incipient recrystallisation.

Thus it appears that the red rock is later than the gabbro, as is the case at Wisconsin (Leighton op. cit.), Pigeon Point (Bastin, 1938), Brevan (Krokstrom, 1932, p. 311) and part, at least, of the Bushveld (Hall 1932).

It is difficult to assess the effect of the red rock on the quartz gabbros, but the evidence points to the conclusion that, except for the alteration of the primary hornblende and incipient recrystallisation of some feldspars, few obvious changes were induced in the gabbro by the emplacement of the red rock, and that the progressive changes in the upper levels of the gabbro body are primarily the result of differentiation.

The Red Rock

It has been suggested that the red rock does not represent a differentiate in situ from the gabbro, but was emplaced soon after this crystallised. The absence of exposures in critical areas and lack of chemical data makes any discussion of its origin largely conjectural. Nevertheless, several features are significant:

(1) The mineralogical constitution is remarkably constant, and quartz-filled mariolitic cavities are ubiquitous. These features suggest a magmatic origin.

(2) It shows considerable textural variation, but can be broadly divided into porphyritic and equigranular types. In other complexes, some textural variation seems to be a common feature of red rocks associated with basic masses. The junctions between red rock of different textures, which show features resembling chilling, suggest that the equigranular portion at least is magmatic, and was built up by a number of separate intrusions.

(3) The almost complete absence of inclusions, and the slight degree of alteration of the only inclusion found when compared with the hornfelses around the red rock, are more likely to be the result of magmatic than metasomatic action.

(4) The occurrence of the porphyritic type of red rock only near the margin or probable margin of the mass (although it shows all gradations to the equigranular type). A possible explanation is that the porphyritic type (which is mariolitic) represents the first accession of magma, which was cooled rapidly, the big feldspar and quartz grains being intratelluric in origin. However, a feature which must also be considered is:

(5) The presence in the hornfels of large grains of quartz and feldspar like those in the porphyritic red rock. This feature has long been seized upon as evidence of transformation by those favouring granitisation e.g. Read (1944, pp. 80-87).

(6) The apparent chemical changes (deduced from the mineralogical changes) in the hornfels as the red rock is approached. This suggests there has been some migration of material across the boundary of the red rock.

The writer considers that part, (and probably the major portion) of the red rock is magmatic in origin. There may have been transformation of the andesites around the margins of the igneous body, but in the absence of chemical data, any estimate of the extent of such changes would be pure speculation.

Although many theories have been put forward, no-one has yet satisfactorily explained why the quartz and feldspar of the granitic rocks associated with basic bodies is so commonly intergrown, to produce micropegmatite. A feature common to these bodies is their occurrence in parts of the crust subjected to an elevation in temperature without concomitant regional stress. This rise in temperature can be produced by a single large basic mass or be the cumulative effect of numerous small injections such as occurred in the British central complexes.

The Quartz Diorite Dykes

These are thought to be part of the complex because:

(1) They show a general mineralogical similarity to the upper parts of the gabbro, particularly the presence of apatite in unusually large amounts.

(2) They both cut and are cut by the thin quartzo-feldspathic veins derived from the gabbro.

These features, the last particularly, suggest that they were injected at much the same time as the gabbro. That the latter had partly solidified is shown by the occurrence of gabbroic xenoliths and the parallel sided form of the quartz diorite dykes in the gabbro. The gabbro could not have consolidated completely, because thin felsic veins from it were found in the quartz diorites, hence these must have been injected during the latter stages of crystallisation of the gabbro.

That the quartz diorites are magmatic is shown by the occurrence of gabbroic xenoliths in a dyke emplaced in hornfels, and the dilational effects found at 683322.

The Felsites

The occurrence of these dykes only near the edge of the gabbro makes it probable that they are part of the complex. Unfortunately, they were found only in andesites, so no definite age relationships could be established.

In the quarry, the felsite shows a gradational contact with a medium grained granitic rock, which appears to be the later, forming veins in the felsite and containing small felsite patches. The margins of the granitic rock against hornfelsed andesites are irregular but sharp. The coarser rock is similar to parts of the red rock and may be an offshoot from it. If so, its irregular shape is unusual because most red rock offshoots are parallel sided dykes. The felsites would then be earlier than the red rock.

The relations between felsite and granite could also be explained by partial recrystallisation of the former, but the very localised occurrence of granite renders this possibility unlikely.

Despite the rather complex felsite-andesite relationship, the writer feels that the felsites are magmatic. None of the reasons for this opinion are in themselves conclusive, but, taken together, point to this being the case:

(1) The absence of any transition between dyke and andesite. The one appears to have had not the slightest mineralogical effect on the other, and junctions are sharp, even knife-edged.

(2) The parallel sided form of many of the dykes. This is most obvious in cuttings along the Kilcoy road.

(3) The mineralogical and textural uniformity of the dykes.

(4) The mineralogical similarity to the red rock which is probably magmatic.

Summary of Conclusions on the Origin of the Complex

Although the conclusions drawn in the preceding pages are here summarised as statements of fact, it is emphasised that most are still tentative, and further knowledge, particularly of the chemical composition of the various types, is essential before conclusions can be made with certainty.

(a) The main part of the complex consists of a plug-like body of gabbroic rocks and a large irregular shaped mass of red rock.

(b) Gravitational settling of crystals (especially of feldspar) from a magma circulating as convection currents, was important in the consolidation of the gabbro.

(c) The mineralogical variation in the gabbro can be explained by differentiation processes.

(d) The final quartzo-feldspathic solutions were squeezed out from the crystal mesh, and form thin veins.

(e) The red rock is dominantly magmatic, with some transformation around its margin.

(f) The red rock was emplaced slightly later than the gabbro, and has had little effect on it.

(g) The quartz diorite dykes were magmatic, and were injected during the latter stages of crystallisation of the gabbro.

(h) The felsites are probably magmatic and were emplaced at least before the intrusion of the red rock.

(i) The source of the various components is unknown. They may be derived from a large igneous body at a deeper level in the crust.

The Age of the Complex

The only definite evidence of the age of the complex is that it is emplaced in the Lower Triassic Neara Volcanics. No upper limit to its age can be fixed by geological means.

However, Mr. R. Green, B.Sc., of the Department of Physical Sciences, Australian National University, kindly determined the palaeomagnetic directions of magnetism of some specimens of the gabbro, and considers that the directions are diagnostic of a pre-Jurassic age for the gabbro.

This means that the complex was emplaced in the Neara Volcanics shortly after these were extruded, a feature comparable with certain other basic complexes, such as the Bushveld and Skaergaard. In these, one of the first manifestations of igneous activity is the eruption of basic and intermediate volcanics, in which the basic plutons are emplaced at a later stage of the development of the complex.

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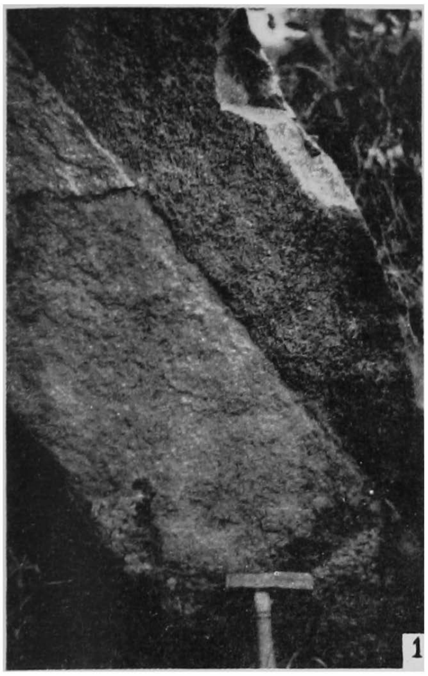
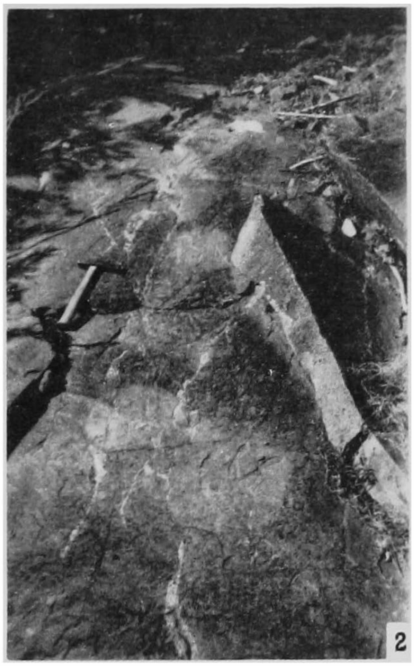
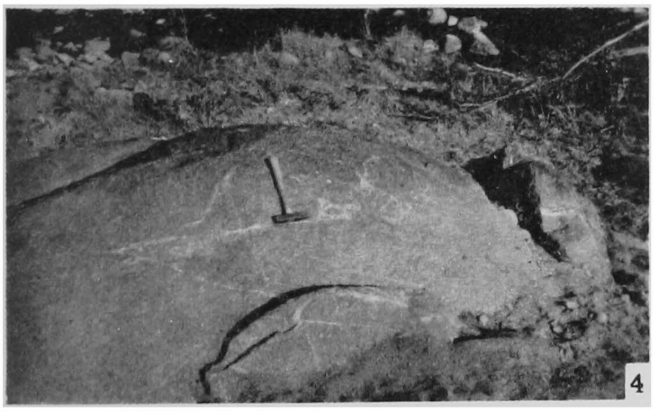
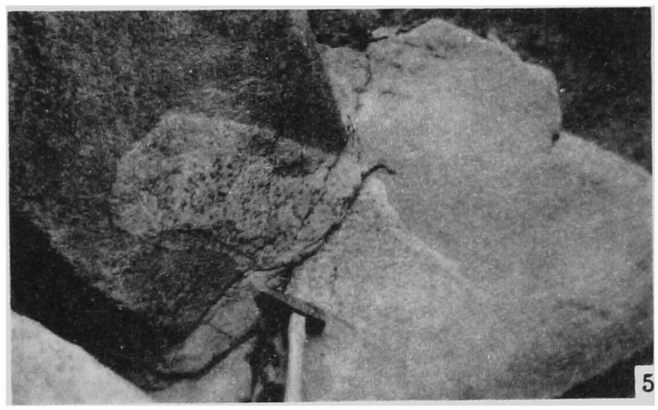
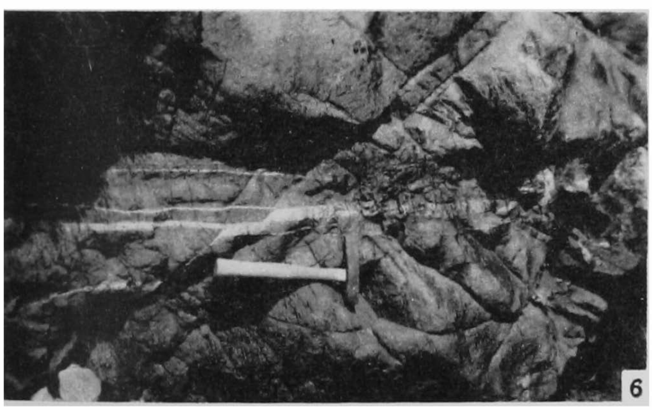
PLATE I











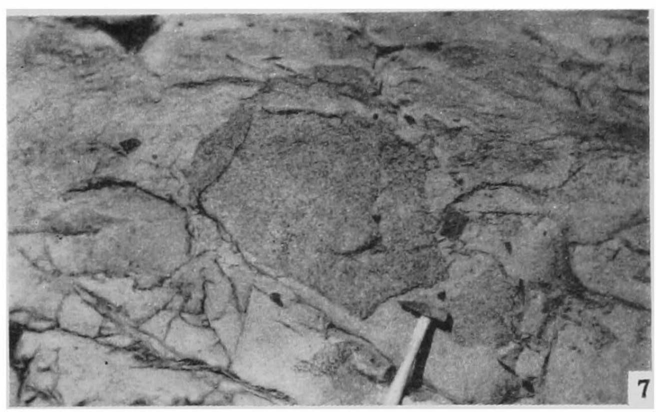


Fig. 1—Contact between red rock (left) and gabbro (right) in a boulder at 680349.

Fig. 2—Irregular quartzo-feldspathic veins in hornfels at 678321.

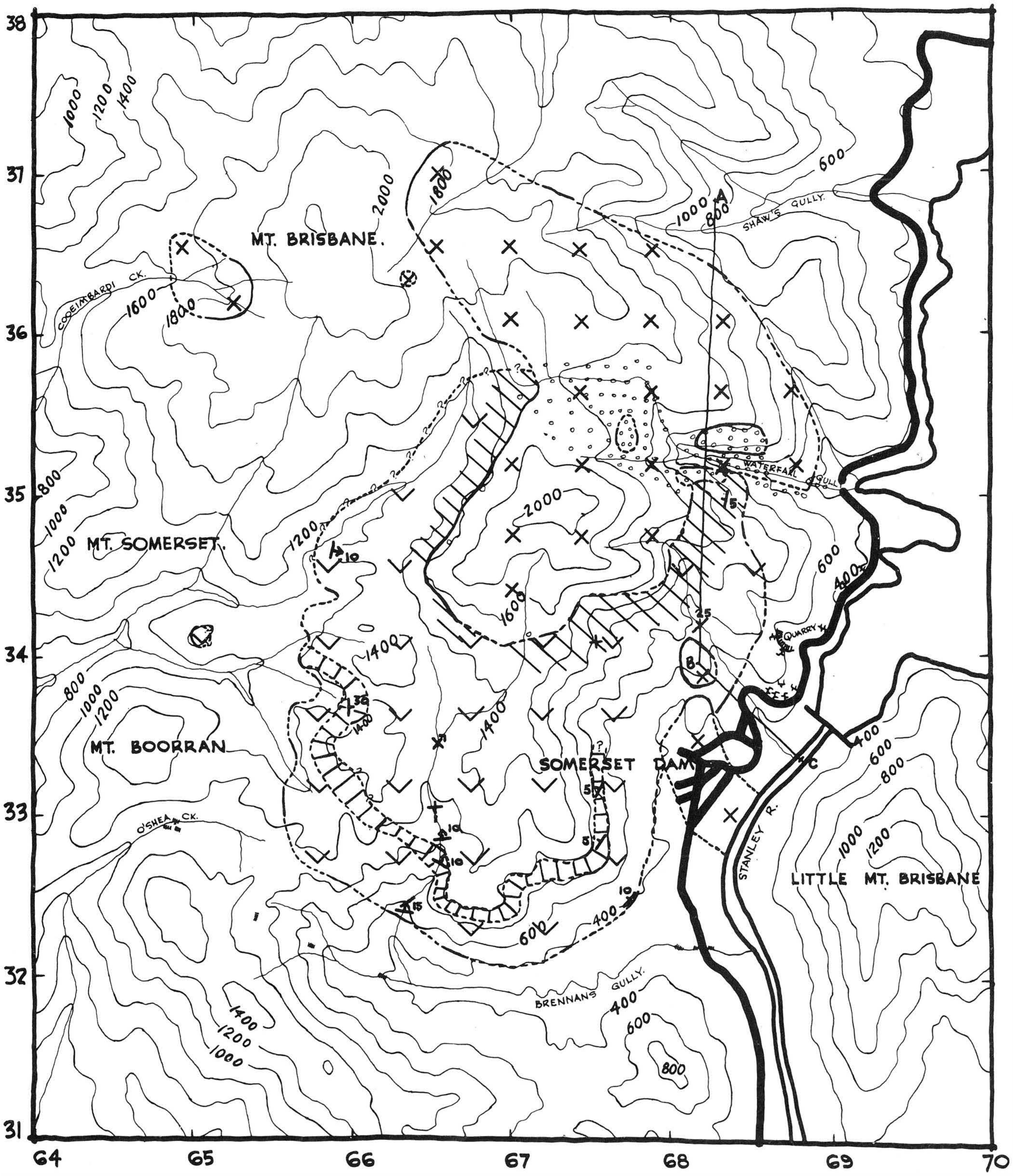
Fig. 3—Xenoliths in quartz gabbro at 675338

Fig. 4—Network of fine grained diorite veins in hornfels at 677320.

Fig. 5—Troctolitic enclosure in troctolite at 665325.

Fig. 6—Straight quartzo-feldspathic veins in hornfels at 678321.

Fig. 7—Xenoliths in quartz diorite at 682322. The large xenolith is pale coloured and medium grained with feldspar porphyroblasts. Near it can be seen smaller dark xenoliths of fine grained granulitic hornfels.



THE SOMERSET DAM IGNEOUS COMPLEX

0 1/4 1/2 3/4 1

MILES

FORM LINE INTERVAL 200 FEET

LEGEND

QUARTZ DIORITE DYKES.

FELSITE DYKES.

RED ROCK.

PORPHYRITIC RED ROCK.

QUARTZ GABBRO.

OLIVINE GABBRO.

TROCTOLITE.

NEARA VOLCANICS.

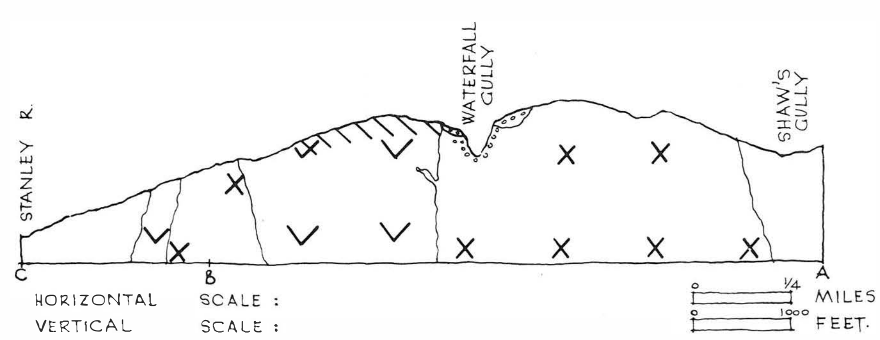
PORPHYROBLASTIC HORNFELS.

Strike and dip of lamination

Strike of lamination and plunge of lineation.

Horizontal lamination.

Horizontal lamination and direction of lineation.



SKETCH SECTION.