BASIC AND ULTRABASIC ROCKS NEAR HAPPY JACKS AND TUMUT POND IN THE SNOWY MOUNTAINS OF NEW SOUTH WALES.

By GERMAINE A. JOPLIN,
Department of Geophysics,
Australian National University.

With Seven Text-Figures.

Manuscript received, June 26, 1957. Read, August 7, 1957.

ABSTRACT.

A number of basic and ultrabasic rocks occurring within the area drained by the Upper Tumut and Happy Jacks Rivers have been described. These include pyroxenites, hornblendites, gabbros, diorites, monzonites, lamprophyres and a number of other types occurring as minor dykes and veins.

It is believed that they are all related, and that they have been derived partly by differentiation and partly by assimilation during the Bowning Orogeny just prior to the emplacement of the granite.

It is suggested that the basic parent is an earlier intrusion of Ordovician age, possibly related to the Porphyritic Central Magma type, and that the acid parent is the (?) Silurian granite magma or partial magma.

CONTENTS

INTRODUCTION.

Andrews (1901) briefly referred to the occurrence of norite and of syenitic diorites at Kiandra, and later Browne and Greig (1923) described the so-called norite in detail and designated it an olivine-bearing quartz-monzonite. Recent work by the Geological Survey of New South Wales (Hall and Lloyd, 1954) and by the Engineering Geology Section of the Snowy Mountains Hydro-Electric

Authority has revealed many occurrences of closely related rocks to the south of Kiandra, including ultrabasic, basic and intermediate types. Many of these have been mapped at the surface and others have been encountered in the tunnels and in the exploratory drill holes.

According to Vallance (1953) similar types occur 34 miles to the north-north-west on the same line of strike. To the east, near Cooma, and in the region north of Cooma, several small basic and ultrabasic masses are recorded (Browne, 1914 ; Joplin, 1939, 1942). These bear no close resemblance to the Snowy Mountains rocks and appear to be of Ordovician age. Basic granulites of probable Ordovician age are also recorded near Cooma and later work (Browne, 1944 and Joplin, 1943) shows that several of these masses occur to the north of Murrumbucca, and the former presence of others is suggested by the occurrence of numerous basic xenoliths in the (?) Silurian granite. N. J. Snelling, of this department, is at present engaged on a very complete study of this granite and has kindly made available several analyses of the basic xenoliths, some of which he suggests are of sedimentary origin. Recent work in the Mt. Isa-Cloncurry district of Queensland has raised the problem of distinguishing between metamorphosed basic igneous and calcsilicate rocks (Walker and Joplin in MS.) and it is indeed possible that some of the Cooma granulites are in fact highly altered banded calcareous rocks.

In the present paper an attempt is made to examine the relation between the different basic types within the Tumut Pond and Happy Jacks area and then to compare them with the other basic types recorded to the north and to the east. Their origin and their relation to the granite are also discussed in relation to the diastrophism with which they are believed to be associated.

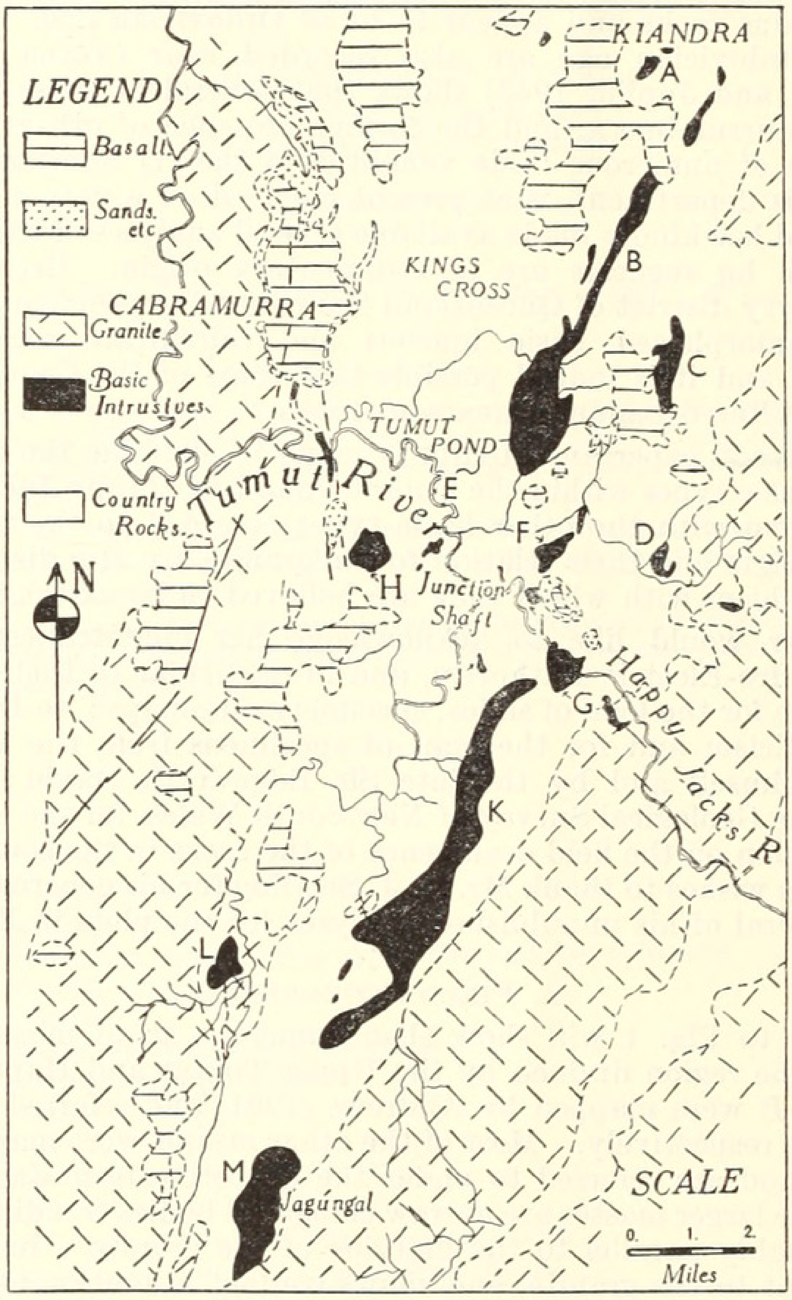
The writer would like to acknowledge her indebtedness to the Snowy Mountains Hydro-Electric Authority, and in particular to their Chief Geologist, Mr. D. G. Moye for the loan of slides, specimens and maps ; to Dr. W. R. Browne for kindly criticism and for the loan of specimens from the Kosciusko region collected by himself and by the late Sir Edgeworth David ; and to Mr. C. McElroy, of the Geological Survey of New South Wales, for the loan of specimens and for discussion on the field occurrence of the rocks in the southern part of the area. She also wishes to thank Mr. N. J. Snelling for his generosity in permitting her to use several of his unpublished analyses for the plots in Fig. 7.

2. Field Occurrence.

Reference to Fig. 1 will show that numerous small masses of basic rock occur within the region drained by the Upper Tumut and Happy Jacks Rivers. Masses A and B were mapped by Andrews (1901) and referred to as norite and syenitic diorite respectively. Most of the other masses were mapped by Hall and Lloyd (1954) and are referred to under the collective term Jagungal-Nine Mile Complex. The larger masses are narrow elongated bodies trending approximately N. 60° E., roughly parallel to the margins of the granite. In places the basic rock is adjacent to the granite, and shows contact alteration as a result. Both within and outside the area delineated in Fig. 1, small basic dykes invade the country rocks. Some of these are possibly of Tertiary age, but many are older and closely allied to the basic types described in this paper. Dykes of lamprophyre cutting both country rocks and granite have been examined by the late Sir Edgeworth David and by Dr. W. R. Browne in the Kosciusko area, and these are briefly referred to in the petrography.

Just north of Tumut Pond, an elongated mass of serpentine trends N. 5° W., but as the strike is different and it is magmatically dissimilar to the rocks here considered, it is not discussed herein.

Although specimens from bores and tunnels and from several different outcrops have been lent by the Snowy Mountains Hydro-Electric Authority, the writer herself has examined only three outcrops in the field. Her impression is that, with but few exceptions, the different types grade one into the other and rarely show clear boundaries. Thus in the elongated mass parallel to the Tumut River, and about 2 miles south of Junction Shaft (Locality K), large patches of pyroxenite contain patches and veins of coarse hornblendite and both grade out into gabbro and finer grained dioritic types, all being intersected by veins of



Text-fig. 1.—Map of the Tumut Pond-Happy Jacks area showing localities of basic rocks.

epidote, quartz, calcite and fine hornblende rock. Only the most detailed mapping could delimit these types, and even then junctions would probably prove indefinite and unsatisfactory.

In the " Diorite " quarry within the small heart-shaped mass 2 miles south-south-east of Junction Shaft (Locality G), two types predominate, a fine grained hornblendic rock cut by a lighter type with large uralitized pyroxene phenocrysts. Both are orthoclase-bearing and show affinities to the monzonite, and in places both assume a pinkish colour which appears to be due to the invasion of later solutions. The core of a bore (5193) put down though this mass shows that it consists mainly of these types and that alteration is very common. Dolerites, mica lamprophyres and porphyrites are also found in the core and probably represent small dykes or veins. As both a quarry and a bore core are available at this locality, much of the described and analysed material comes from this mass.

Most of the other masses consist predominantly of orthoclase-bearing diorites or monzonites, but the other types are commonly associated in small amount, and again the field relations are not clear, though it is possible that some order of intrusion might be established if other quarry exposures were available.

Small irregular bodies of pyroxenite and of monzonite and numerous dykes of dolerite, lamprophyre and porphyrite have been encountered in the Eucumbene-Tumut Tunnel, and a number of such dykes are exposed in the road cuttings near Junction Shaft. These, together with small veins of similar type, as well as of epidote, calcite and quartz, appear to be the only well-defined discrete injections. Veining by acid material even close to the granite is rare, though the pink coloration due to alteration may be mistaken for it in places. Except for the absence of this feature, the field relations of the basic and ultrabasic rocks show a remarkable resemblance to those of the Ach'uaine hybrids of Sutherland, Scotland (Read, 1931). Though genetically unrelated, the field occurrence is not unlike that of a group of basic rocks at Cooma (Joplin, 1939).

3. Petrography.

Pyroxenites, Hornblende-pyroxenites and Hornblendites.

Pyroxenites, hornblende-pyroxenites and hornblendites show all gradations from one into the other and are here described together.

They form small areas within some of the basic intrusions, and are commonly surrounded by and grade out into less basic types. A large mass crops out near the road about 2 miles south-south-east of Junction Shaft and a smaller irregular intrusion is found between stations 506+70 and 508+50 in the Eucumbene-Tumut Tunnel. Dr. W. R. Browne (pers. comm.) has also found pyroxenite included in granite and impregnated with tourmaline near Seaman's Hut in the Kosciusko area. It is also of interest to note that Vallance (1953) found an ultra-basic inclusion, with a chemical composition approximating to that of the pyroxenite, in the Wantabadgery granite about 30 miles north-north-west of Kiandra.

In hand specimens these rocks are dark and coarse-grained with hornblende crystals in some specimens measuring up to 15 mm. Under the microscope the pyroxenites have a fairly even grain size which may range in different specimens from 1 to 6 mm., and the fabric is from allotriomorphic granular to hypidiomorphic granular (Fig. 2*A*). The bulk of the pyroxene is pale green, optically positive witn $Z \wedge c = 54°$ and a slight polysynthetic twinning sometimes apparent. It thus appears to be diopsidic. A negative, slightly pleochroic pink pyroxene is also present in small amount. Some sections show an oblique extinction and it was suggested by Browne and Greig (1923), who found the same variety in the Kiandra monzonite, that it is a monoclinic clino-hypersthene. Both pyroxenes contain inclusions of magnetite which may grow outwards and link with schiller inclusions of the same material. Flecking with small patches of green hornblende is common and the pyroxenes are often wrapped by irregular grains (1mm.) of brown hornblende with Z=dark olive green, Y=golden yellow and X=pale yellow. Green hornblende may also form independent grains with Z=dark green, Y=olive green and X=greenish yellow, $Z < Y < X$, $Z \wedge c = 29°$.

The hornblendites consist of large interlocking grains or subidiomorphic prisms of both or either brown or green hornblende (Fig. 3*A*) and commonly occur as veins or patches in the pyroxenite or gabbro. The hornblende crystals are not infrequently up to an inch in length and Mr. C. McElroy (pers. comm.) of the Geological Survey of New South Wales reports that he has seen them at Locality K measuring up to about 5 inches in length. They alter to chlorite and epidote, and in one specimen elongated needles of epidote were noted parallel to the cleavage of the amphibole.

In a few specimens large chloritized flakes of mica occur and pseudomorphs consisting of chlorite, serpentine and iron ore suggest the former presence of a little hypersthene or olivine (see Fig. 3*A*) ; though no fresh olivine has been noted in these rocks, it has been detected in some of the monzonites.

TABLE I.

	I.	II.	III.
SiO_2 ..	39·49	39·97	37·33
Al_2O_3 ..	6·61	8·68	7·27
Fe_2O_3 ..	16·03	8·63	13·41
FeO ..	7·30	7·99	9·24
MgO ..	10·72	10·32	12·27
CaO ..	16·51	15·18	16·50
Na_2O ..	1·07	1·19	0·45
K_2O ..	0·25	0·74	0·03
H_2O+ ..	0·57	} 0·57	1·03
H_2O- ..	0·01		0·10
TiO_2 ..	1·55	4·05	1·66
P_2O_5 ..	tr.	0·10	—
MnO ..	abs.	0·19	0·07
CO_2 ..	abs.	1·15	—
FeS_2 ..	—	1·01	—
	100·11	99·77	99·63

I. *Pyroxenite*, 2 miles south-south-east of Junction Shaft (Locality K). Anal. J. K. Burnett.
II. *Yamaskite* (Hornblende Jacupirangite), Mount Yamaska, Quebec. Anal. G. A. Young. *Can. Geol. Surv. Ann. Rept.* (1904), 1906, 33. In W.T., p. 717.
III. *Pyroxenite*. Olivine Mountain, Tulameen District, British Columbia. Anal. F. M. Connor. C. Camsel, *Can. Geol. Surv. Mem.* **26**, 61, 1913. In W.T., p. 719.

Magnetite is abundant in some rocks (Fig. 2*A*) and in others almost absent. It occurs as inclusions in the ferromagnesian minerals, as independent interstitial grains and as fine aggregates of secondary origin. Commonly it is surrounded by narrow rims of brown hornblende, epidote, chlorite and sphene. Apatite and sphene are present as accessories and most rocks contain traces of much saussuritized plagioclase (Fig. 3*A*). With an increase in plagioclase the ultrabasic rocks pass into gabbros. When plagioclase is present both pyroxene and amphibole are idiomorphic against it.

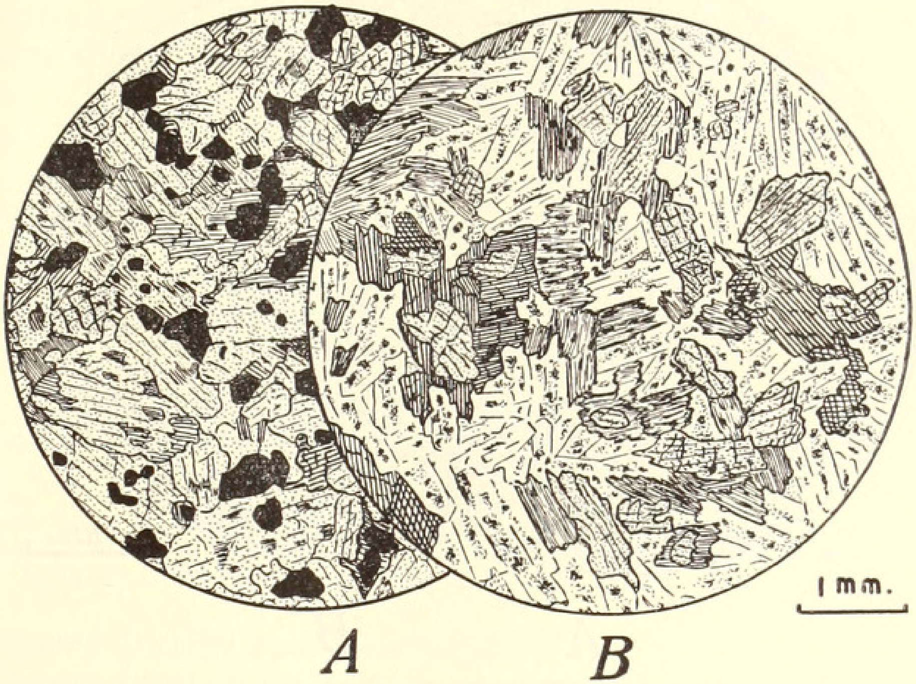
In Table 1 the chemical composition of a Pyroxenite is given, with analyses of two similar rocks for comparison.

Hornblende-Gabbros.

In handspecimen these are dark rocks of very variable grain size. They commonly have a speckled appearance due to the presence of numerous small hornblende crystals.

Under the microscope they are seen to consist of pyroxene, hornblende and plagioclase with accessory magnetite, apatite, sphene and sometimes a little quartz.

The pyroxene forms stout prisms up to 4 mm. in length, but more commonly about 0·6 mm. It is usually uralitized and surrounded by a fringe of either brown or green hornblende (Fig. 2*B*). In some specimens little or no pyroxene is present and the hornblende forms large independent poikilitic subidiomorphic prisms (Fig. 3*B*). Slight bending of the more elongated crystals has been noted. Two varieties of hornblende-gabbro occur, but there is a merging of one into the other. One contains uralitized pyroxene and shows close affinities to the



Text-fig. 2.

(*A*) Pyroxenite, two miles south-south-west of Junction Shaft (Locality K), showing large subidiomorphic crystals of pyroxene intergrown with magnetite and flecked by hornblende. Just above the centre of the figure pyroxene is moulded by hornblende. × 10.

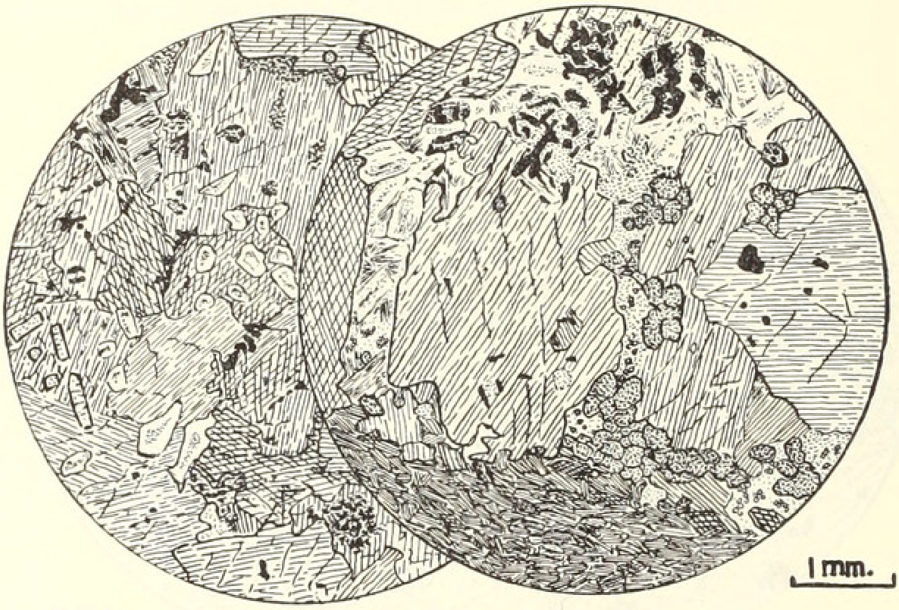
(*B*) Hornblende-pyroxene-gabbro from Locality H, showing subidiomorphic prisms of pyroxene and of uralitized pyroxene, many of them moulded by brownish-green hornblende. Plagioclase forms subidiomorphic prisms and is partly moulded by hornblende ; its alteration products, mainly clinozoisite, tend to form small segregations throughout the crystals. A few grains of magnetite are also present. × 10.

pyroxenites (Fig. 2*B*) : the other, with large crystals of amphibole, shows some relation to the hornblendites (Fig.3*B*). When the latter type contains a notable quantity of green idiomorphic hornblende it passes into the hornblende-lamprophyres described below.

Felspar occurs in irregular grains or as subidiomorphic tabular crystals or laths. The crystals are zoned with a core of labradorite ($Ab_{35}An_{65}$) and an outer margin of basic andesine ($Ab_{55}An_{45}$). Andesine also forms separate unzoned laths or small tabular crystals. Bending of twin lamellæ is present in some crystals and basic cores are commonly saussuritized. In some rocks the plagioclase is entirely altered to clinozoisite, epidote and chlorite ; in others the alteration products are not identifiable and in some cases are segregated into small patches which are flecked through the felspar (Fig. 2*B*). One specimen shows quartz replacing felspar in the form of minute droplets arranged in a regular dactylitic pattern (Joplin, 1939).

Quartz is present in most gabbros and occurs as large irregular, interstitial grains or as vein infillings. A quartz-bearing type from the core of bore 5057, about 1 mile upstream from the Tumut Pond Dam site, contains vein quartz and interstitial grains show undulose extinction while the whole rock bears evidence of strain.

Calcite occurs in the same manner as quartz and in some rocks epidote is present as vein infillings or partly or wholly replacing felspar. Chlorite is very abundant in rocks containing calcite, epidote and quartz, which have obviously suffered alteration.



A *B*

Text-fig. 3.

(*A*) Hornblendite, from Locality F, showing large interlocking grains of brownish-green hornblende enclosing accessory apatite and magnetite. Small inclusions of altered olivine also occur and a number of laths of altered plagioclase are present. ×10.

(*B*) Hornblende-gabbro with vein of hornblende rock (bottom of figure), two miles south-south-east of Junction Shaft (Locality K), showing large interlocking grains of hornblende, in places moulding altered plagioclase. Clinozoisite, epidote and fibrous chlorite are abundant as alteration products of the felspar. Small pseudomorphs consisting of deep bluish-green chlorite and magnetite mark the former presence of a ferromagnesian mineral, which may have been hypersthene or olivine. Elsewhere in the slide diopsidic pyroxene, partly uralitized, is present and the rock has some affinities to the other figured gabbro (Text-fig. 2*B*). ×10.

The mode of a hornblende-pyroxene-gabbro is compared with those of three diorites in Table II.

Diorites.

In handspecimen these are medium-grained light and dark speckled rocks, in some cases indistinguishable from monzonites.

Under the microscope they are seen to consist of plagioclase, hornblende and a little quartz and magnetite. Uralitized pyroxene and much chloritized biotite have been detected in some specimens.

The plagioclase occurs as tabular crystals about 1 mm. in length, or as laths about 0·4 mm. Rare tabular phenocrysts (about 3 mm.) occur in some rocks and these types pass into the diorite-porphyrites. Plagioclase is commonly zoned, the cores being a good deal altered. The composition ranges from $Ab_{60}An_{40}$ to $Ab_{66}An_{34}$.

Green hornblende may occur as large (1 to 1·5 mm.) grains or as subidiomorphic prisms (about 1 mm.), and when pyroxene is present it is fringed by hornblende and chloritized biotite. When much idiomorphic green hornblende is present the diorite closely resembles a hornblende-lamprophyre.

Epidote and chlorite are common alteration products of the amphibole, and cores of pyroxene are pseudomorphed by chlorite, epidote and carbonates. Quartz is present in most specimens and occurs as small interstitial grains or as large irregular grains wrapping the other minerals.

In general these rocks show much alteration, and it is possible that because of this alteration small quantities of orthoclase have been overlooked and that some of them should be classified as orthoclase-bearing diorites or as altered monzonites.

TABLE II.

	Pyroxene.	Uralite.	Hornblende.	Biotite.	Plagioclase.	Quartz.	Magnetite.	Total Ferromagnesian.
1.	23	20	17	—	40	—	—	60
2.	25·4		26·1	4·3	38·4	4·3	1·5	55·8
3.	25·8		16·6	6·4	39·9	7·3	4·0	48·8
4.	8·9		10·5	11·6	53·7	13·2	1·8	31·0

1. *Hornblende gabbro.* Locality J, 1 mile south-south-east of Junction Shaft.
2–4. *Diorite.* Locality G, 2½ miles south-east of Junction Shaft.

Orthoclase-bearing Diorites and Monzonites.

In handspecimen these are medium-grained dark rocks consisting of pyroxene, hornblende, biotite, plagioclase, orthoclase and quartz. Some varieties are porphyritic and contain small phenocrysts of pyroxene discernible in handspecimen.

Under the microscope types rich in orthoclase show a distinct monzonitic fabric with idiomorphic to subidiomorphic laths of plagioclase wrapped by large irregular grains of orthoclase and quartz. The proportions of these minerals are very variable, as may be seen by reference to Table IV. The monzonite porphyry contains large crystals of pyroxene fringed with reaction borders of hornblende and biotite, and even the normal types have a slightly porphyritic appearance in that the ferromagnesian minerals tend to form clots, and these too are surrounded by reaction borders (Fig. 4*A*).

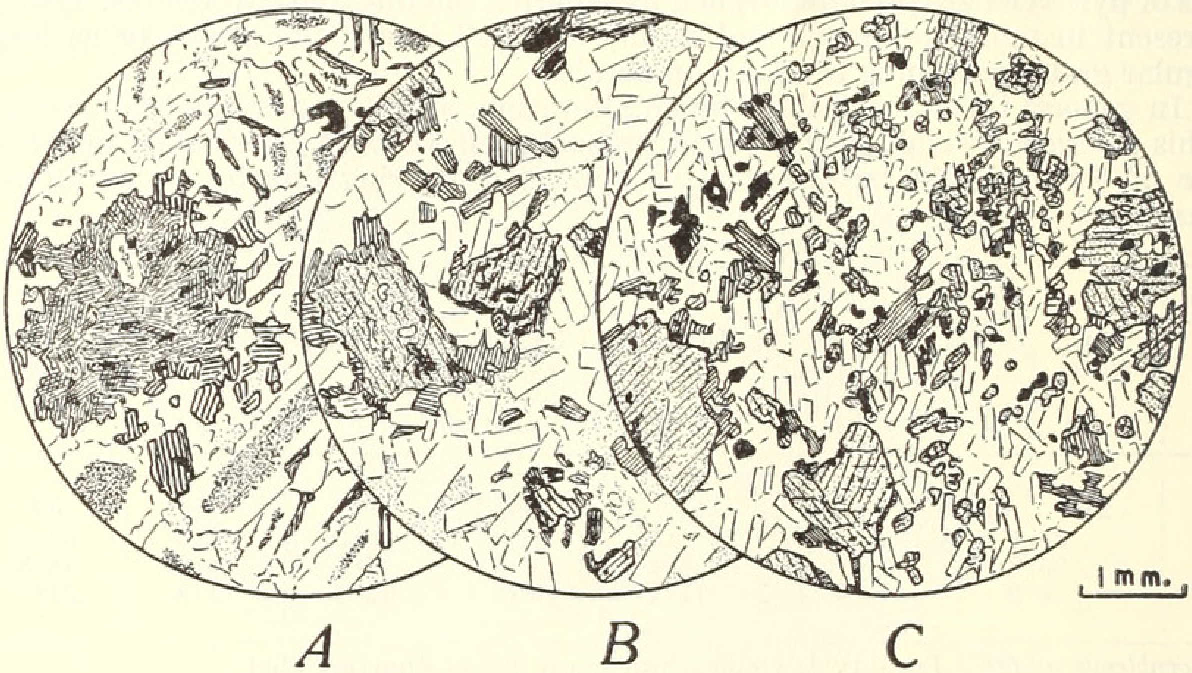
Both augite and clino-hypersthene (Browne and Greig, 1923) are present and both commonly alter to uralite. As well as fringing the pyroxene crystals and their uralitized pseudomorphs, hornblende and biotite occur as independent crystals, the latter altered to chlorite in a number of specimens. Rocks showing pink alteration in handspecimen contain little or no recognisable pyroxene, wholly chloritized biotite and partly chloritized hornblende.

Plagioclase crystals range from 2 to 0·5 mm. in length and commonly show zoning. The cores are heavily saussuritized, but when the composition can be determined it is usually labradorite. The fresh outer zone is commonly oligoclase and independent crystals of andesine also occur. In the pink altered rocks the plagioclase is altered to sericite and to kaolin and stained a deep reddish colour by hæmatite. Plagioclase has suffered greater alteration than orthoclase, though in some specimens both felspars have been much altered and it is almost impossible to make accurate micrometric measurements.

Apatite and magnetite are accessories, the latter forming small prismatic crystals or more commonly long acicular crystals up to 0·5 mm. in length.

Small crystals of alterated olivine occur as inclusions in the pyroxene in many of the Kiandra rocks and at Locality H., but have not been detected elsewhere (Fig. 4, *B* and *C*).

Analyses of diorites and monzonitic rocks are given in Table III.



Text-fig. 4.

(*A*) Orthoclase-bearing diorite, from Locality I, showing prismatic crystals of plagioclase, interstitial grains of quartz and orthoclase and large crystal-aggregates of uralitized pyroxene fringed with green hornblende and biotite. Independent crystals of both hornblende and biotite also occur, the biotite being the more abundant and occurring as flat crystals giving sections the appearance of elongated flakes (compare mica-lamprophyre, Text-fig. 5*B*). ×10.

(*B*) Monzonite from Kiandra (Locality A) showing pyroxene fringed with hornblende and biotite and containing inclusions of altered olivine and plagioclase. Small stout prisms of plagioclase are moulded by orthoclase and quartz to give a monzonitic fabric. ×10.

(*C*) Monzonite porphyry from Locality H showing large crystals of pyroxene, partly fringed by biotite and containing inclusions of altered olivine, in a finer groundmass of pyroxene, biotite, orthoclase, quartz and magnetite. The groundmass shows a monzonitic fabric. ×10.

Hornblende-Lamprophyres.

These rocks occur as small dykes and veins invading country rocks and basic igneous masses, but in places the field occurrence is not clear and their petrography suggests that they may merge into either diorites or hornblende-gabbros, as has been noted in describing these two groups. In the Kosciusko area Dr. W. R. Browne has found them as dykes invading granite, and the late Sir Edgeworth David found them as dykes at Boggy Plains and on the Porcupine Ridge.

In handspecimen they are dark rocks containing small elongated crystals of hornblende in a fine groundmass.

Under the microscope it may be seen that the hornblende, whether it occurs as phenocrysts or in the groundmass, has an elongated habit (Fig. 5*A*). Certain rocks described under this heading are not strictly lamprophyres because the phenocrysts are lacking, but in every respect they resemble the groundmass of the true lamprophyres ; so that all rocks containing idiomorphic hornblende with an elongated habit are described hereunder.

In different specimens the phenocrysts may range in size from about 5 mm.×0·5 mm. to about 0·75 mm.×0·2 mm. The hornblende is brownish green with X=light brownish green, Y=olive green and Z=dark bluish green, $Z \wedge c = 24°$. The hornblende of the groundmass is the same variety and crystals measure about 0·15 mm.×0·1 mm. or even smaller in the finer grained types. The rock from Boggy Plains contains no hornblende in the groundmass, but both small stout equidimensional and elongated linear phenocrysts are present.

TABLE III.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2 ..	53·09	53·82	55·56	55·73	56·65	57·08	57·18
Al_2O_3 ..	14·53	15·59	17·97	17·65	15·80	13·62	14·13
Fe_2O_3 ..	2·49	1·55	2·01	3·12	4·78	1·30	1·90
FeO ..	6·51	6·24	4·74	3·98	4·46	6·21	5·85
MgO ..	7·64	7·12	4·21	3·55	3·98	8·07	7·00
CaO ..	7·93	6·72	6·36	6·66	7·61	7·54	7·64
Na_2O ..	2·24	3·17	2·65	2·99	1·64	2·50	2·36
K_2O ..	1·55	1·69	2·34	2·98	2·94	2·50	2·30
H_2O+ ..	1·71	1·72	0·45	1·69	0·62	0·19	0·45
H_2O- ..		0·13	0·09	0·14	0·06	0·05	0·07
TiO_2 ..	1·08	1·22	0·82	0·53	0·69	0·65	0·60
P_2O_5 ..	0·41	0·46	abs.	abs.	abs.	0·21	0·21
MnO ..	n.d.	n.d.	0·06	0·10	0·07	0·14	0·11
Co_2 ..	1·37	0·31	3·60	1·25	0·94	abs.	abs.
Etc. ..	—	—	—	—	—	0·18	0·22
	100·55	99·74	100·86	100·37	100·24	100·24	100·02
Sp. Gr. ..	2·915	2·879	—	—	—	2·937	2·927

I. *Orthoclase-bearing Diorite,* "Diorite" Quarry, Locality G. (see No. 15, Table IV). Anal. G. A. Joplin.

II. *Orthoclase-bearing Diorite.* "Diorite" Quarry, Locality G. (see No. 19, Table IV). Anal. G. A. Joplin.

III. *Altered Orthoclase-bearing Diorite* or *Monzonite,* Locality G. Bore 5193 at 248 feet (see No. 13, Table IV). Anal. J. K. Burnett.

IV. *Altered Orthoclase-bearing Diorite* or *Monzonite,* Locality G. Bore 5193 at 428 feet (see No. 8, Table IV). Anal. J. K. Burnett.

V. *Altered Orthoclase-bearing Diorite* or *Monzonite,* Locality G. Bore 5193 at 170 feet (see Nos. 9 and 10, Table IV). Anal. J. K. Burnett.

VI. *Monzonite Porphyry,* Kiandra, Locality A. Anal. W. A. Greig. Browne, W. R., and Greig, W. A., *Journ.Roy. Soc. N.S.W.*, 1923, **56**, 269.

VII. *Quartz Monzonite,* Kiandra, Locality A. Anal. W. A. Greig. *Ibid.*

A specimen from the Kosciusko region contains phenocrysts of pyroxene in addition to those of hornblende.

Chlorite and epidote are common alteration products of the hornblende, and these rocks are characteristically much altered, and in some cases original phenocrysts are completely pseudomorphed.

Phenocrysts of plagioclase are uncommon, and in the rare cases when they occur the felspar is partly altered to calcite. One specimen from Locality G. contains only tabular, zoned crystals of plagioclase as phenocrysts, but the groundmass contains the characteristic elongated hornblendes and thus shows an affinity to the lamprophyre group though it might more appropriately be classed a diorite porphyrite. In the normal hornblende-lamprophyres plagioclase occurs only in the groundmass. The finer grained types contain laths or needles forming a plexus with the amphibole crystals, but in the rocks of slightly coarser

TABLE IV.

Micrometric Analyses of some Snowy Mountains Rocks arranged in order of decreasing abundance of Orthoclase.

	Orthoclase.	Plagioclase.	Quartz.	Pyroxene	Hornblende.	Biotite.	Olivine.	Magnetite.	Epidote.	Total Ferro-magnesian.
1.	17·9	40·1	5·9	21·3	7·2	6·3	0·6	0·7	—	35·4
2.	14·7	44·2	5·5	22·8	5·3	6·2	Tr.	1·3	—	34·3
3.	12·4	39·3	6·7	26·7	8·0	5·1	—	1·9	—	39·8
4.	11·4	42·4	7·9	22·9	7·6	5·6	0·3	1·9	—	36·1
5.	11·2	47·6	8·6	13·6	13·8	3·6	—	1·6	—	31·0
6.	10·7	47·7	19·8	2·6	11·9	5·1	—	1·6	—	19·6
7.	9·2	52·7	12·5	—	9·0	15·1	—	0·6	—	24·1
8.	8·6	36·8	5·2	—	35·8*	5·2†‡	—	—	8·6	41·0
9.	7·6	46·1	9·8	8·8	11·9	13·2	—	2·7	—	33·9
10.	7·2	49·0	21·6	8·9	7·6	5·3	—	0·4	—	21·8
11.	7·1	52·4	7·5	9·0	9·5	11·5	—	2·6	—	30·0
12.	6·3	49·5	19·4	6·1	8·5	9·2	—	0·9	—	23·8
13.	4·7	48·7	7·6	—	28·4*	10·0†	—	0·7	—	38·4
14.	4·4	44·9	13·9	5·2	17·4	10·8	—	2·5	0·7	34·1
15.	4·3	30·5	8·9	10·3	42·7*	2·0†‡	—	1·1	—	55·0
16.	4·3	43·8	15·8	1·2	20·6	5·8	—	1·8	6·7	27·6
17.	3·7	56·3	5·6	5·0	18·5	8·4	—	2·5	—	31·9
18.	3·6	46·8	13·0	3·6	20·4	9·8	—	2·8	—	33·8
19.	1·4	54·4	5·6	29·2	1·9	5·1	—	2·3	—	36·2
20.	1·4	30·7	3·9	4·1	54·3*	5·1†‡	—	0·5	—	63·5

Note : Uralite has been counted as pyroxene when it was obviously so derived. Doubtful cases have been counted as hornblende.

* Partly chloritized.

† Wholly chloritized.

‡ Epidotized.

1. Kiandra (Locality A), Anal. W. R. Browne, *Journ. Roy. Soc. N.S.W.*, **56**, 1922, 261. (Anal. VII, Table III).

2–3. Kiandra, Anal. G. A. Joplin.

4. Kiandra (Locality A), Anal. G. A. Joplin.

5. Locality G. 2½ miles S.E. of Junction Shaft. Anal. G. A. Joplin.

6. Locality J. One mile S.S.E. of Junction Shaft. Anal. G. A. Joplin.

7. Locality I. One mile East of Junction Shaft. Anal. G. A. Joplin.

8. Locality G. Bore 5193 at 428 ft. (Anal. IV, Table III). Anal. G. A. Joplin.

9–10. Locality G. Bore 5193 at 170 ft. (Anal. V, Table III). Anal. G. A. Joplin.

11. Locality J. Anal. G. A. Joplin.

12. Locality G. " Diorite " Quarry. Anal. G. A. Joplin.

13. Locality G. Bore 5193 at 248 ft. (Anal. III, Table III). Anal. G. A. Joplin.

14. Locality G. Bore 5193 at 470 ft. Anal. G. A. Joplin.

15. Locality G. " Diorite " Quarry (Anal. I, Table III). Anal. G. A. Joplin.

16. Locality G. " Diorite " Quarry. Anal. G. A. Joplin.

17. Locality G. Bore 5191 at 290 fr. Anal. G. A. Joplin.

18. Locality G. Bore 5193 at 90 ft. Anal. G. A. Joplin.

19. Locality G. " Diorite " Quarry. (Anal. II, Table III). Anal. F. A. Joplin.

20. Locality I. One mile east of Junction Shaft. Anal. G. A. Joplin.

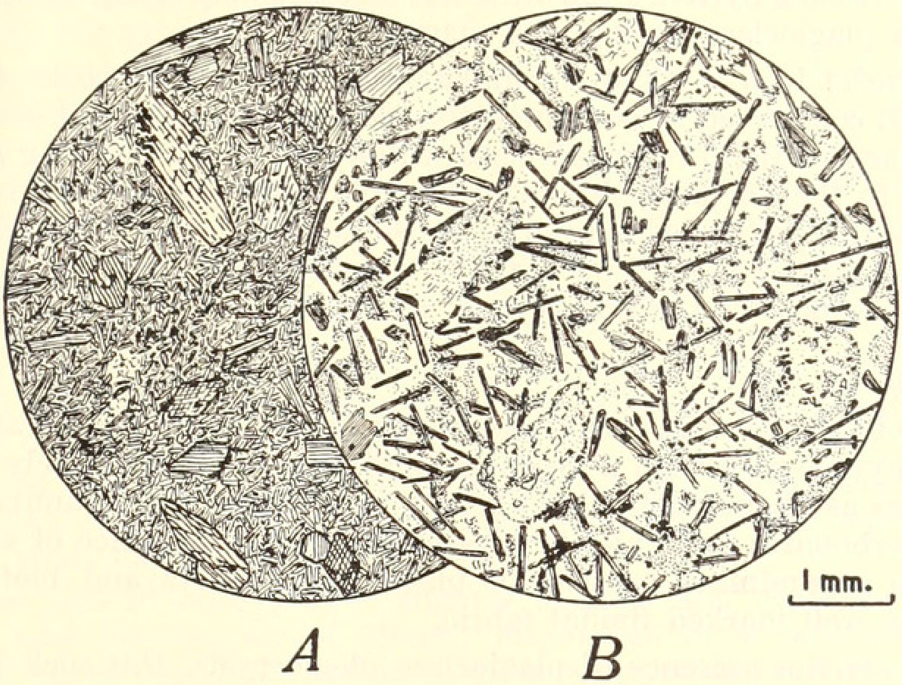
texture the felspar forms small tabular crystals that measure from 0·3 to 0·75 × 0·2 mm. Much of the felspar is saussuritized and alteration to calcite is common.

Quartz is present in most of these rocks, and many of them show a fine quartz veining. In the finer grainer types quartz is present in small fine grained aggregates (see Fig. 5*A*), and in the coarser groundmasses it occurs interstitially amongst plagioclase crystals. Except for the habit of the amphibole, the coarser groundmasses resemble fine grained quartz-diorites.

According to Iddings (1913, p. 200), such rocks are more closely related to spessartites than to camptonites on account of the larger amount of amphibole in their groundmass and of the presence of quartz.

Mica-Lamprophyre.

This rock occurs in the borehole at Locality G. and is also met with as dykes at stations 452+75 and 532+00 in the Eucumbene-Tumut Tunnel. As yet it has not been recognized as a surface outcrop in the Tumut Pond area, but the



Text-fig. 5.

(*A*) Hornblende-lamprophyre from Locality I, showing large idiomorphic phenocrysts of greenish-brown hornblende in a plexus of small idiomorphic laths of hornblende and plagioclase. Magnetite is accessory and in places small aggregates of quartz grains occur, and elsewhere this rock is veined with quartz. $\times 10$.

(*B*) Mica-lamprophyre from Locality G, showing large phenocrysts pseudomorphed by carbonates, quartz, chlorite and magnetite, smaller phenocrysts of biotite in a groundmass of plagioclase, elongated plates of biotite, chlorite and magnetite. $\times 10$.

writer has examined a similar rock collected from a dyke by the late Sir Edgeworth David at Thompson's Flat, near Kosciusko, and two closely related types collected by Dr. W. R. Browne east of Boggy Plains from dykes intruding the granite.

The specimen from the borehole occurs at the 329-foot level and possibly represents a vein intrusive into monzonites. It is porphyritic with idiomorphic phenocrysts up to 4·5 mm. completely pseudomorphed by aggregates of carbonate, quartz, chlorite and magnetite (Fig. 5*B*) suggesting original pyroxene. In the Thompson's Flat rock a little fresh pyroxene remains as cores, though most of it is altered to uralite and chlorite with a trace of carbonate. Both of the Boggy Plains specimens contain much fresh pyroxene, though some phenocrysts are entirely altered to chlorite. One of these rocks contains a pyroxene phenocryst with a completely serpentinized inclusion suggesting the former presence of olivine. Phenocrysts in the rocks from the Eucumbene-Tumut Tunnel are also altered to chlorite, but a little carbonate is also present, the dyke at station 523+00 being the more altered and less characteristic of the group.

One of the Boggy Plains rocks contains a few altered phenocrysts of plagioclase. In the borehole specimen biotite also occurs as small phenocrysts in extremely elongated thin plates which show every gradation into the smaller flakes of the groundmass.

In this rock the groundmass has an average grain size of 0·75 mm. and consists of plagioclase, biotite, chlorite, carbonates and quartz with accessory magnetite. The Boggy Plains rocks differ from one another in regard to the groundmass. One contains almost completely chloritized flakes of biotite and is slightly more felspathic with some pyrites ; the other has an extremely fine grained groundmass consisting of plagioclase, augite and magnetite.

These rocks bear a close resemblance to kersantites—rocks that Iddings (1913, p. 199) considered to be related to the monzonites—and it is of interest to note that Harper (1919) recorded kersantite dykes in the Adelong granite some thirty miles to the north-north-west, where Vallance (1953) has described other types comparable to the basic rocks in the Snowy Mts. area. The analysis of the Adelong kersantite is plotted on the AFC diagram (Fig. 7) at point 10 and thus falls within the field of the Snowy Mts. rocks.

Mica-Porphyrites.

A vein of this material occurs at 409 feet in the borehole 5193 at Locality G. It is a porphyritic rock with a fluidal groundmass. Comparatively fresh, zoned felspar occurs as phenocrysts about 2 mm. in diameter and granular aggregates of quartz, carbonates and chlorite suggest the former presence of augite phenocrysts. The groundmass consists of plagioclase, quartz and biotite, the last delineating a well marked fluidal fabric.

Except for the presence of plagioclase phenocrysts, this rock is not unlike the mica-lamprophyre occurring 80 feet above it.

Hornblende-quartz-porphyrites.

At stations 654+00 and 649+50 in the Eucumbene-Tumut Tunnel an irregular-shaped body occurs which appears to be contact-altered and in places sheared.

It is a porphyritic rock with phenocrysts of plagioclase, quartz and an altered ferromagnesian mineral, presumably hornblende, in a very fine groundmass.

In the contact-altered rock the ferromagnesian phenocrysts consist of aggregates of criss-cross flakes of reddish brown biotite, obviously pseudomorphing an idiomorphic mineral suggesting hornblende. In the sheared rock these phenocrysts are not well defined and consist of elongated patches of chlorite and iron ores.

Quartz forms idiomorphic crystals (up to 3 mm.) slightly corroded and in the sheared rock it is granulated and strained, although some evidence of strain is also apparent in the thermally altered type.

Plagioclase forms tabular crystals up to 2·5 mm. and is slightly sericitized in the contact rock, but in the sheared specimen it is only just recognisable as an aggregate of sericite, quartz, chlorite and iron ore which merges into a groundmass consisting of the same minerals. The groundmass of the contact-altered rock forms an exceedingly fine crystalline mosaic.

Before alteration these rocks possibly showed some resemblance to the hornblende-lamprophyres, though the characteristic elongated amphibole crystals do not appear to have been present.

Dolerites.

Doleritic rocks occur in the bore 5193 at Locality G., in the bore 5057 about 1 mile upstream from the Tumut Pond dam site, and also as dykes in the Eucumbene-Tumut Tunnel. All are much altered and their identification is difficult and unsatisfactory. Furthermore, there are many individual differences between the rocks that are here grouped together. Unfortunately the present writer has not been able to examine specimens from Jagungal, but this rock has been described by Whitworth (1954) as an amphibolized dolerite with ophitic fabric and the mass is reported to be hornfelsed at the southern end where it is adjacent to the granite.

In bore 5193 these rocks occur at 140 feet and at 177 feet. The upper one consists of laths and small tabular crystals (about 0·2 mm.) of plagioclase much altered to carbonates. These appear to have been wrapped by a ferromagnesian mineral now entirely altered to chlorite with small inclusions of magnetite. Quartz is interstitial. Small (about 2·5 mm. in diameter) ellipsoidal bodies infilled with plagioclase, quartz, carbonates and radiating chlorite were possibly original amygdules or vughs. Some of these have small acicular crystals of magnetite arranged around the outer margin.

At 177 feet the rock is slightly coarser and contains a few much altered elongated crystals of mica suggesting a link with the mica-lamprophyre. This rock also contains epidote and pyrite.

Several very similar rocks occur as dykes in the Eucumbene-Tumut Tunnel. They contain a great deal of calcite and are much altered, but individual descriptions seem unnecessary.

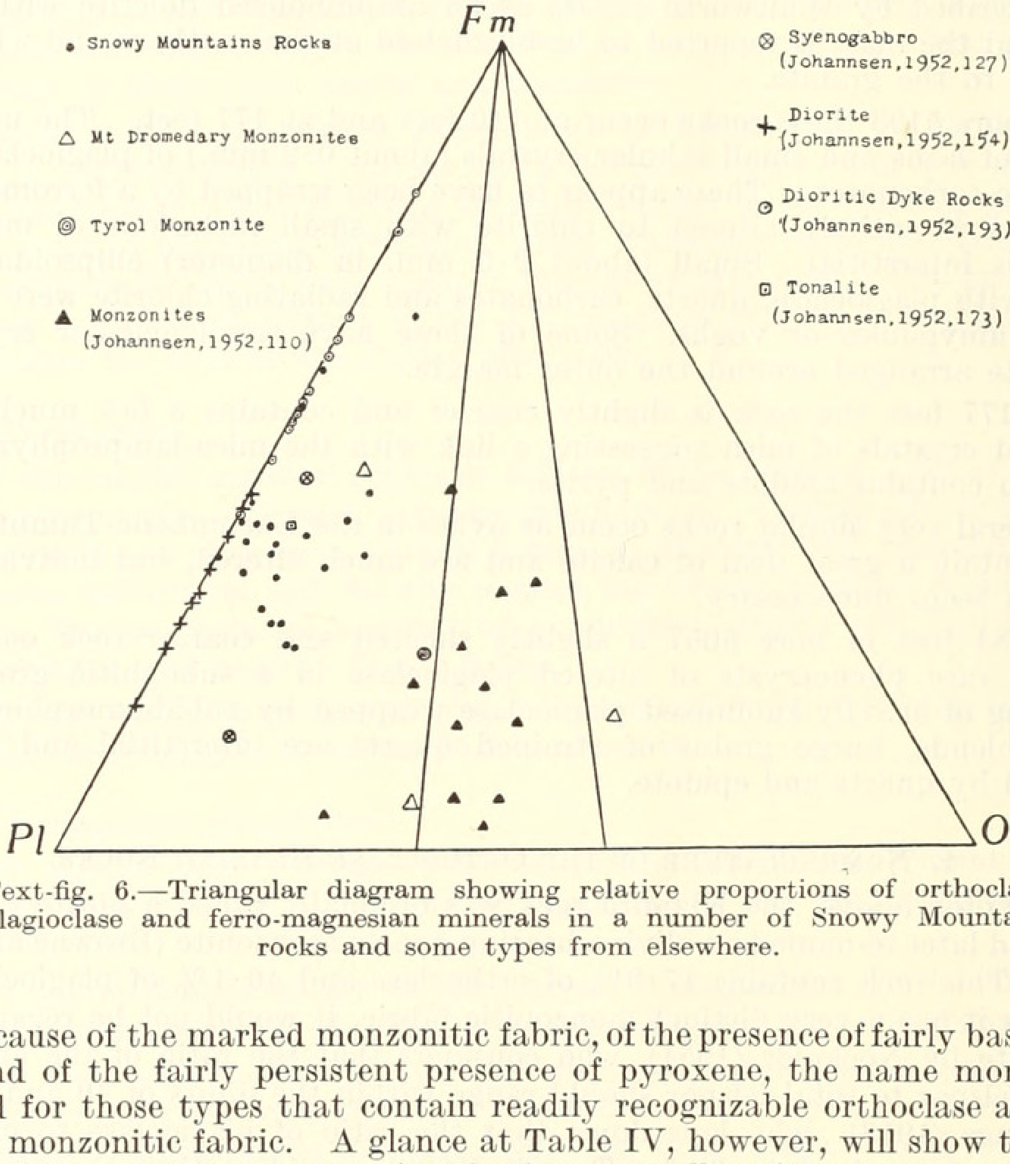
At 84 feet in bore 5057 a slightly sheared and coarser rock occurs. It contains rare phenocrysts of altered plagioclase in a subophitic groundmass consisting of heavily kaolinized plagioclase wrapped by subidiomorphic crystals of hornblende. Large grains of strained quartz are interstitial and the rock is veined by quartz and epidote.

4. Nomenclature of the Orthoclase-Bearing Rocks.

As noted above, the Kiandra rock was originally called a norite (Andrews, 1901) and later re-named an olivine-bearing quartz monzonite (Browne and Greig, 1923). This rock contains 17·9% of orthoclase and 40·1% of plagioclase, and although it has a very distinct monzonitic fabric, it would not be regarded as a monzonite by Nockolds (1954), who considers that the ratio of the amount of potash felspar to total felspar should range within the limits of 40 and 60%, or by Iddings (1913) who lays down that the ratio of plagioclase to orthoclase should be from 5 : 3 to 3 : 5. Tyrrell (1928) considers that the amounts of plagioclase and of orthoclase should be about equal in the monzonites, and he points out that these rocks, as compared with the syenites, show an increase in ferromagnesian minerals and a more calcic plagioclase. Harker (1919), following Brøgger, defines the monzonites as a group with orthoclase and plagioclase in approximately equal proportions.

Reference to Table IV indicates that the volume percentage of orthoclase in a number of the Snowy rocks shows a wide range. These modal analyses are plotted on a triangular diagram in Fig. 6 to show the relative amounts of plagioclase, orthoclase and ferromagnesian minerals. The diagram shows that none of the Snowy Mts. rocks falls within the area prescribed as that of the monzonites by

Nockolds. Modal analyses have also been made of four specimens from the geological collections of the University of Sydney, namely, three monzonites from Mount Dromedary, N.S.W. (Brown, 1930) and one from the Tyrol. It will be noted that the Tyrol rock and one of the Dromedary rocks closely approach Nockolds' boundary, that another Dromedary specimen falls among the Snowy Mts. rocks and that the third has an excess of orthoclase and approaches the syenites. A number of modal analyses have also been taken from tables (Johannsen, 1952) and plotted, and it will be seen that the monzonites mostly fall within the area between 40 and 60% of orthoclase, whereas the Snowy Mts. rocks bear some relation to the tonalites, syenogabbros, diorites and dioritic dyke rocks.



Text-fig. 6.—Triangular diagram showing relative proportions of orthoclase, plagioclase and ferro-magnesian minerals in a number of Snowy Mountains rocks and some types from elsewhere.

Because of the marked monzonitic fabric, of the presence of fairly basic plagioclase and of the fairly persistent presence of pyroxene, the name monzonite is retained for those types that contain readily recognizable orthoclase and a well marked monzonitic fabric. A glance at Table IV, however, will show that there is a gradation in the amount of orthoclase as well as in pyroxene, and many types rich in hornblende and poor in orthoclase might more appropriately be called orthoclase-bearing diorites.

5. Mutual Relations of the Different Rock Types.

As pointed out above, the field relations have not been examined in very much detail, but the rapid changes from one type to another suggest that large units of the more basic rocks are surrounded by the less basic, and that there are all transitions between them. In the " Diorite " quarry intrusive relations between a monzonite and an orthoclase-bearing diorite are apparent in places, but the only discrete injections are comparatively small dykes and veins.

Reference to the petrography also shows that microscope examination and modal analyses point to a gradation of one type into another ; thus the headings under which each type has been described above are only arbitrary.

The following scheme is an attempt to show these relationships as indicated by the petrography, though no direct genetic connection is necessarily implied.

```
Pyroxenite ——> Hornblende-pyroxenite ——> Hornblendite
                        |
                        v
               Hornblende-gabbro
                        |  \         ( Dolerite
                        v   \——————> { Hornblende-Porphyrite
                     Diorite ——————> ( Hornblende-Lamprophyre
                        |    \
                        |     \————> Diorite-Porphyrite
                        v
               Orthoclase-diorite
                        |  \         ( Mica-Porphyrite
                        v   \——————> {
                    Monzonite ——————> ( Mica-Lamprophyre
```

It is evident that these rocks are all related in space and in time and thus they might be said to belong to a petrological province. Although the monzonites are not commonly considered as normal members of the granodiorite stem, and by some are regarded as belonging to a separate magma type, where monzonites may occur, together with latites, in a distinct petrological province (Brown, 1930 ; Hanlon, Joplin and Noakes, 1952), the literature nevertheless reveals that they are not infrequently associated with diorites and with syenites in many parts of the world. In referring to the Predazzo and Monzoni occurrence, from which the monzonites take their name, Shand (1949) pointed out that a number of rock types occur together and he discussed a hybrid origin.

6. Origin of the Basic Rocks.

The origin of the basic and ultrabasic rocks of the Tumut Pond area is a little obscure, and three possibilities suggest themselves : (1) they are original sills interbedded with the sediments and bear no relation to the contiguous granite ; (2) they are earlier differentiates of the granite magma ; (3) they are products of assimilation, one parent being granite, and the other either a basic rock or a calcareous sediment.

Reference to Fig. 1 will show that they are in very close proximity to the granite and the same relation exists further north (Vallance, 1953), so it seems that their association with the granite is not a fortuitous one, as suggested by (1).

Differentiation versus *Assimilation.*

Unfortunately the field evidence throws little light on the problem though in the " Diorite " quarry at Locality G., where good exposures are available, some intrusive relations are evident and some order of succession can be established. Elsewhere, however, and indeed in many places within this quarry, types appear to grade one into the other as though large blocks of more basic material were completely surrounded by less basic ; the petrography supports this field observation. It is also of interest to note that Vallance (1953) in describing the Adelong norite, which he compares with the Kiandra monzonite, remarks upon the presence of basic clots enriched in olivine and pyroxene that appear to be closely related to the host rocks.

Although some contacts have been observed, and a magmatic origin for at least some of these rocks is beyond dispute, the capricious distribution of the component minerals also suggests partial assimilation of solid material by a magma. Furthermore, the development of large hornblende crystals in the hornblende-pyroxenites and the segregation of such crystals to form patches of hornblendite are reminiscent of the Ach'uaine Hybrids of Sutherland (Read, 1931), and similar observations have been made among hybrid rocks by Deer (1938) and by Joplin (1939).

Many of these rocks, particularly the monzonites, show excellent examples of a discontinuous reaction-series, and in fact the Kiandra rock was used for many years in the Department of Geology, University of Sydney, as an illustration of Bowen's Reaction Principle. Bowen (1922 *a* and *b*) discussed this principle with reference both to differentiation and to reaction between acid magma and solid basic material. In a normal differentiation series it would be unusual for a complete sequence of discontinuous reaction minerals to be present in a single specimen, yet such is the case in many of the monzonites. If this took place during differentiation, it would suggest great and sudden variations of temperature during cooling, whereas it could be regarded as fairly normal in the case of solid material that was undergoing both mechanical and chemical assimilation in an acid magma.

Zoned plagioclase, though present in most rocks, is not the continuous type that might be expected in a differentiation series. A rapidly fluctuating temperature might explain this too, but it would not explain the fact that a plagioclase of intermediate composition normally surrounds the zoned crystals. Such an arrangement, on the other hand, can be explained readily by assimilation. The basic, somewhat altered cores of labradorite represent the original felspar of the basic parent, the fresh oligoclase rims represent the phase which is being deposited by the magma at the time of incorporation of the basic material, and the surrounding andesine has formed as a result of some assimilation and has been deposited later from a basified magma.

Although a monzonitic fabric may develop during the course of crystallization from a differentiating magma, it is a fabric that might well be expected in a rock of hybrid origin, especially when the amount of orthoclase and of quartz shows such marked variation. Further reference to Table IV will show that although it has been arranged in order of decreasing orthoclase, there is no corresponding regular gradation in the volume percentages of other minerals ; this again is a departure from a normal differentiation series.

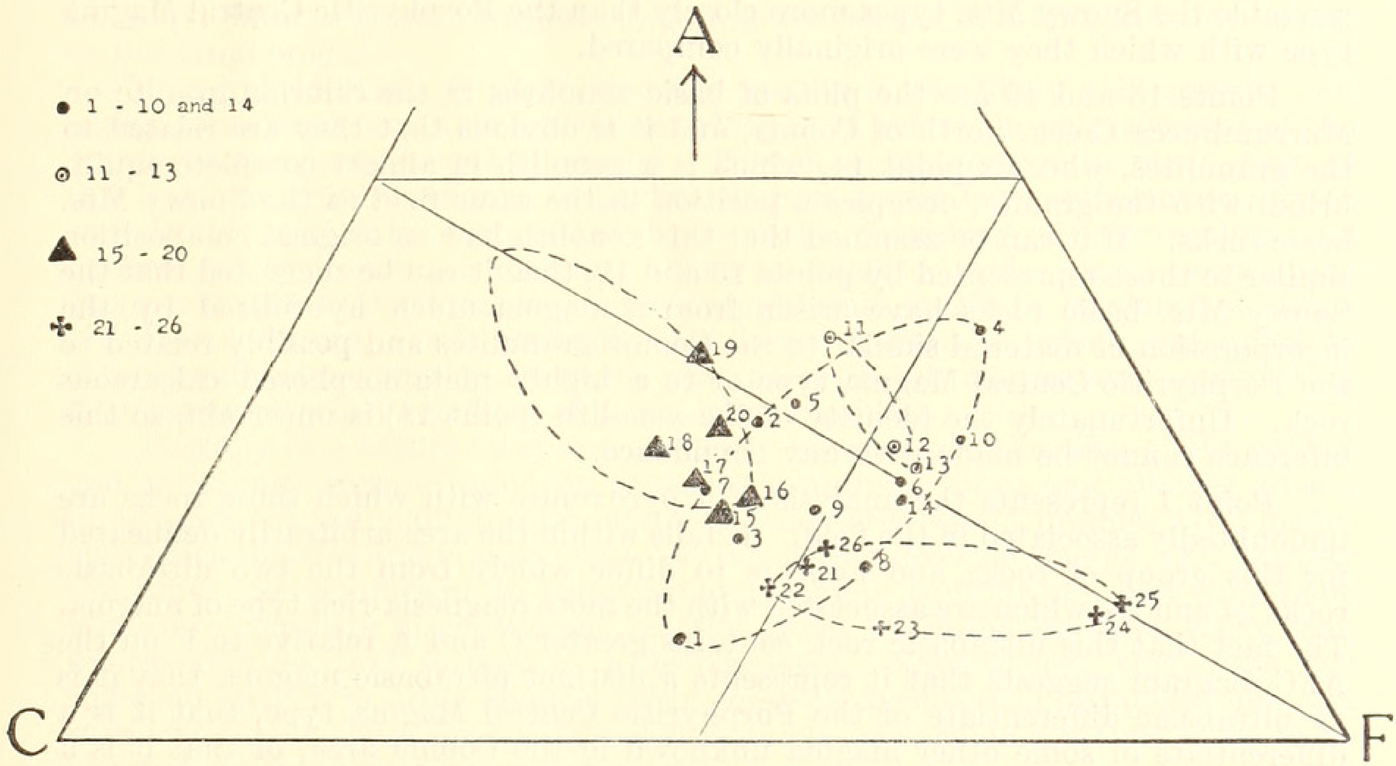
In Table II three modal analyses of diorites and one of hornblende-gabbro are compared. Unfortunately this is an insufficient number of analyses upon which to base conclusions regarding origin, but it is evident that the volume percentages show some regular gradation, and there appears to be more evidence of differentiation here than among the orthoclase-bearing types in Table IV. Diorites of doubtful origin have been found among the Ach'uaine Hybrids and Read (1931) has pointed out that they have some resemblances to the intermediate type of Ach'uaine Hybrid and are probably related. Although the origin of the Snowy Mts. diorites is also doubtful, they are most certainly related both to the ultrabasic rocks and to the monzonites.

Thus the weight of evidence seems to favour assimilation rather than differentiation for the origin of these rocks, and if such is the case then the nature of the basic parent must now be considered.

Nature of the Basic Parent.

As indicated above (p. 121), two types of basic magma appear to have antedated the granite at Cooma. One, related to a norite, has given rise to ultrabasic types and is itself metasomatized by the granite (Browne, 1914 ;

Joplin, 1939, 1942), and the other, a basic granulite, appears to have affinities to the Porphyritic Central Magma type, and is found only as inclusions within the granite (Joplin, 1942) ; furthermore, recent work (Walker and Joplin in MS.) suggests that some of these basic granulites may be of sedimentary origin. Although neither of these types is known to crop out in the Tumut Pond–Happy Jacks area, either may occur among the deeper-seated rocks and must be considered as a possible parent of the hybrids.



Text-fig. 7.—AFC diagram showing fields for Porphyritic Central Magma type, magnesia-rich amphibolites at Cooma and Snowy Mts. and Adelong rocks.

1. Pyroxenite, Locality K.
2. Altered monzonite, Locality G.
3. Orthoclase-bearing diorite, Locality G.
4. Altered monzonite, Locality G.
5. Altered monzonite, Locality G.
6. Orthoclase-bearing diorite or monzonite, Locality G.
7. Quartz-bearing olivine-monzonite, Kiandra, Locality A.
8. Monzonite-Porphyry, Kiandra, Locality A.
9. Norite, Adelong.
10. Kersantite, Adelong.
11. Pyroxene-granulite, Hume Weir, Albury.
12. Altered basic rock, Hume Weir, Albury.
13. " Trachytic " rock, Albury.
14. Xenolith in equilibrium with granite, Murrumbucca.
15. Basic xenolith, Murrumbucca.
16. Hornblende-granulite, Cooma.
17. Amphibolite, Adelong area.
18. Hornblende-pyroxene granulite, Cooma.
19. Basic xenolith, Murrumbucca.
20. Basic xenolith, Murrumbucca.
21. Coarse phase of heterogeneous amphibolite, Cooma.
22. Amphibolite (relict gabbro), Cooma.
23. Fine-grained granoblastic amphibolite, Cooma.
24. Ultrabasic inclusion, Adelong area.
25. Tremolite-chlorite schist, Cooma.
26. Fine phase of heterogeneous amphibolite.

Again there is little doubt that the hybrids are very closely associated with the pyroxenite, which appears to have a magmatic origin since a mass of it occurs as a small irregular intrusion with sound contacts at stations 506+70 to 508+50 in the Eucumbene-Tumut Tunnel. Thus this too must be considered in a discussion on the ancestry of the hybrids.

It was shown on an AFC diagram (Joplin, 1942) that the basic rocks at Cooma fall into two well-defined separate fields. These have been re-plotted in Fig. 7, and the field for the magnesia-rich type extended to include two ultrabasic rocks, one from the Cooma area and one from Wantabadgery to the north-north-west (Vallance, 1953). Basic rocks from the Snowy Mts. region, from the Adelong area 34 miles north, and from the Albury district about 150 miles west, are also plotted, as well as several xenoliths from the Silurian granite north of Cooma. It is clear that these occupy a separate field which is distinct from the other two, but which slightly overlaps them. It was suggested (Joplin, 1946) that the three basic rocks from Albury might compare with the pyroxene-granulites of Cooma, but it is now apparent that they fall into a smaller separate field and resemble the Snowy Mts. types more closely than the Porphyritic Central Magma type with which they were originally compared.

Points 15 and 19 are the plots of basic xenoliths in the Silurian granite on Murrumbucca Creek, north of Cooma, and it is obvious that they are related to the granulites, whereas point 14, which is a xenolith in almost complete equilibrium with the granite, occupies a position in the same field as the Snowy Mts. basic rocks. If it can be assumed that this xenolith had an original composition similar to those represented by points 15 and 19, then it can be suggested that the Snowy Mts. basic rocks have arisen from a magma much hybridized by the incorporation of material similar to the Cooma granulites and possibly related to the Porphyritic Central Magma type or to a highly metamorphosed calcareous rock. Unfortunately the identity of the xenolith (point 14) is uncertain, so this inference cannot be made with any confidence.

Point 1 represents the analysis of a pyroxenite with which these rocks are undoubtedly associated in the field. It falls within the area arbitrarily delineated for this group of rocks, and appears to differ widely from the two ultrabasic rocks 24 and 25, which are associated with the more magnesia-rich type of magma. The fact that this ultrabasic rock contains greater C and A relative to F on the AFC diagram suggests that it represents a distinct ultrabasic magma, that it is an ultrabasic differentiate of the Porphyritic Central Magma type, that it is a differentiate of some other magma unknown in the Cooma area, or that it is a metasomatized calcareous rock. Unfortunately there is no means of solving this problem, but two observations are pertinent, namely, the relatively small amount of pyroxenite and the suggestive positions of points 14, 15 and 19 on the AFC diagram. The limited amount of pyroxenite and its persistent association with the other basic rocks strengthen the view that it is a differentiate rather than a separate ultrabasic magma, whilst its position on the diagram relative to those of the three xenoliths, and its close field relation to the gabbros, lend slight support to the view that it is a differentiate of the Porphyritic Central Magma type.

Although hornblende is present in most of the rocks described in this paper, it is noteworthy that pyroxene is a prominent mineral, and that much of the hornblende is either pseudomorphing or moulded on to original pyroxene. Pyroxene is the typical ferromagnesian mineral of the basic extrusives and of the intrusives associated with the stable areas of the crust, while hornblende is more common in the granitic complexes of the geosynclines, where hornblendites are typically developed and where pyroxenites are rare. For this reason the writer has some hesitation in suggesting that the pyroxenite is genetically related to the Silurian granite. On the other hand, pyroxenites are not unknown as associates of the Porphyritic Central Magma, a magma characterized by the presence of pyroxene. The essential minerals of rocks belonging to the Porphyritic Central Magma type are basic plagioclase, augite and iron ores. This magma is distinguished by the early separation of basic felspar, thus the normal basic differentiate is an anorthosite, though veins of pyroxenite are recorded in the Great Eucrite Ring-dyke of Ardnamurchan (Richey and Thomas, 1930). There is some evidence that such a magma gave rise to small sills or flows in the Cooma area, so it is not unreasonable to assume that a series of slightly larger differentiated sills occurred at some depth below the present level of erosion in the Snowy Mts. area.

The Hybridization Process.

In a few places the basic rocks have been altered by the granite and, with the exception of the lamprophyres, there is little doubt that they antedate most of the granites in the Snowy Mts. area. Furthermore, their marginal disposition to the (?) Silurian granite suggests that they are related to it and probably belong to the same orogeny.

If a hybrid origin is postulated the granite is the likely acid parent, and assimilation must have taken place at a deep level before the emplacement of the granite at the present level of erosion. If such an assumption be made, then at this level the granite magma, or partial magma, would have sufficient energy to completely assimilate deep-seated basic rocks consisting of pyroxenites and gabbro by a process of reaction. Thus a basified acid magma, containing fragments with which it was in complete equilibrium, might be emplaced at higher levels as a diorite. It is probable that larger fragments, which had failed to attain equilibrium, would also travel upwards with this magma and occur within it as partly resorbed xenoliths of pyroxenite or gabbro.

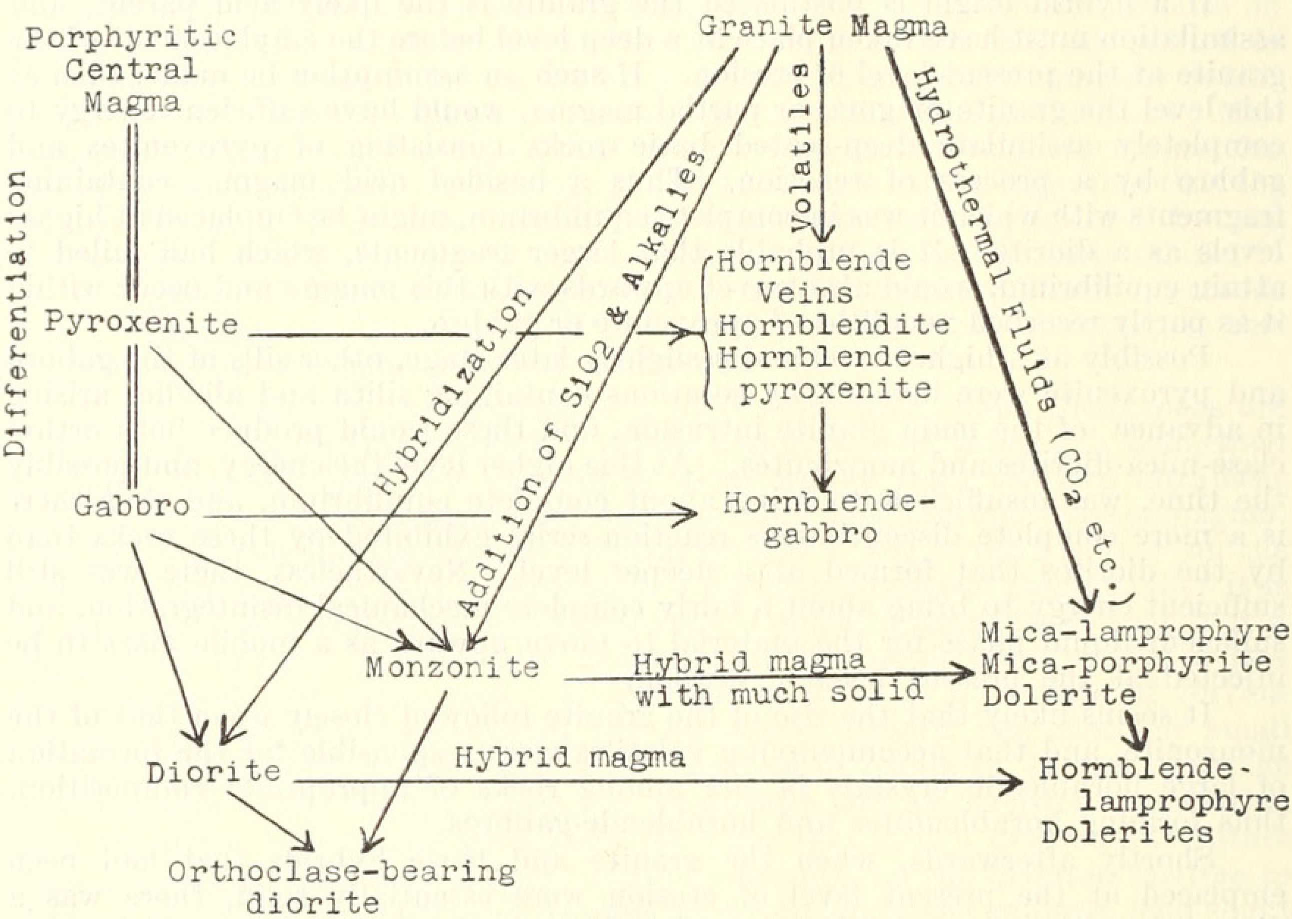
Possibly at a higher level and a slightly later stage, other sills of the gabbro and pyroxenite were invaded by solutions containing silica and alkalies arising in advance of the main granite intrusion, and these would produce both orthoclase-mica-diorites and monzonites. At this higher level the energy, and possibly the time, was insufficient to bring about complete equilibrium, and thus there is a more complete discontinuous reaction-series exhibited by these rocks than by the diorites that formed at a deeper level. Nevertheless, there was still sufficient energy to bring about a fairly complete mechanical disintegration, and sufficient liquid phase for the material to move upward as a mobile mass to be injected at the present level of erosion.

It seems likely that the rise of the granite followed closely upon that of the monzonite, and that accompanying volatiles were responsible for the formation of large hornblende crystals *in situ* among rocks of appropriate composition, thus forming hornblendites and hornblende-gabbros.

Shortly afterwards, when the granite and basic hybrids that had been emplaced at the present level of erosion were essentially solid, there was a discrete injection of small dykes and veins of lamprophyre, porphyrite and dolerite. These are highly altered rocks, and it is obvious that carbon dioxide played an important rôle in their formation. It seems likely that they were derived from a deeper level of hybrid magma and subjected to hydrothermal action at the end stage of the consolidation of the granite after emplacement.

Reference to Table III shows that two of the altered orthoclase-diorites or monzonites (Anal. IV, V) contain higher potash than the two fresh monzonites (Anal. VI and VII), yet if the corresponding modes be compared (Table IV, Nos. 8, 9, 10, 2 and 1), it will be seen that the orthoclase and biotite content is much lower in the altered rocks and in fact bears no relation to the amount of potash present. It may be further noted that the altered rocks contain lower silica and higher alumina as compared with the fresh monzonites, and though this may be due to alteration it seems more likely that the altered rocks were more closely allied to the orthoclase-diorites and originally may have been more basic than those analysed (Table III, I and II), there being an addition of silica and of potash at a late stage, which caused sericitization of the felspar and some silicification. A decrease in the amount of magnesia may imply a movement of chlorite-bearing solutions, and the increase of ferric iron relative to ferrous iron further suggests alteration. In the field the pink rock shows an intrusive front against the orthoclase-diorites, and it seems fairly obvious that this is brought about by an invasion of hydrothermal solutions that have not only brought in potash and silica, but have brought about alteration and movement of many of the components of the rock. This possibly took place during the last stage of the cooling history of the granite, and perhaps slightly later than or approximately at the same time as the discrete injections.

This study is not sufficiently detailed to permit further elaboration of these processes, and these suggestions are put forward only as a tentative explanation of the origin of this interesting and complex group of rocks. An attempt is made to indicate their origin schematically below.



References.

Andrews, E. C., 1901. "Report of the Kiandra Lead." *Geol. Surv. N.S.W., Min. Res*, **10**, 17.

Bowen, N. L., 1922*a*. "The Reaction Principle in Petrogenesis." *Journ. Geol.*, **30**, 177–198.

———— 1922*b*. "The Behaviour of Inclusions in Igneous Magmas." *Ibid*, 513–570.

Brown, I. A., 1930. "The Geology of the South Coast of New South Wales, III. The Monzonitic Complex of the Mount Dromedary District." *Proc. Linn. Soc. N.S.W.*, **55**, 692.

Browne, W. R., 1914. "The Geology of the Cooma District I." This Journal, **48**, 172–222.

———— 1944. "The Geology of the Cooma District II." *Ibid*, **77**, 156–172.

———— and Greig, W. A., 1923. "On an Olivine-bearing Quartz-Monzonite from Kiandra." *Ibid*, **56**, 260–277.

Deer, W. A., 1938. "The Composition and Paragenesis of the Hornblendes of the Glen Tilt Complex, Perthshire." *Min. Mag. Lond.*, **25**, 61.

Hall, L. R., and Lloyd, J. C., 1954. "Snowy Mountains Area Progress Report I, Toolong." *Dept. Mines, N.S.W.*, Ann. Report for 1950, 98–99.

Hanlon, F. N., Joplin, G. A., and Noakes, L. C., 1953. "Review of Stratigraphical Nomenclature. 2. Permian Units in the Illawarra District." *Aust. Journ. Sci.* **15** (5), 160–163.

Harker, A., 1919. "Petrology for Students," Cambridge, 46.

Harper, L. F., 1916. "The Adelong Goldfield." *Geol. Surv. N.S.W. Min. Res.*, **21**.

Iddings, J. P., 1913. "Igneous Rocks," Vol. II. New York, 200.

Johannsen, A., 1952. "A Descriptive Petrography of the Igneous Rocks," Vol. III. Chicago, 110, 127, 154, 173, 193.

Joplin, G. A., 1939. " Studies in Metamorphorism and Assimilation in the Cooma District of New South Wales. I. The Amphibolites and their Metasomatism. THIS JOURNAL, **73**, 88–106.

———— 1942. " Petrological Studies in the Ordovician of New South Wales. I. The Cooma Complex." *Proc. Linn. Soc. N.S.W.*, **67**, 156–196.

———— 1943. "*Idem.* II. The Northern Extension of the Cooma Complex." *Ibid,* **68**, 159–183.

———— 1947. "*Idem.* IV. The Northern Extension of the North-east Victorian Complex. *Ibid,* **72**, 87–124.

Nockolds, S. R., 1954. " Average Chemical Composition of Some Igneous Rocks." *Bull. Geol. Soc. Amer.*, **65**, 1007–1032.

Read, H. H., 1931. " The Geology of Central Sutherland." *Mem. Geol. Surv. Scot.* 165–172.

Richey, J. E., and Thomas, H. H., 1930. " The Geology of Ardnamurchan, North-west Mull and Coll." *Mem. Geol. Surv. Scot.*, 86–87.

Shand, S. J., 1949. " Eruptive Rocks." London, 275.

Tyrrell, G. W., 1928. " Principles of Petrology." London.

Vallance, T. G., 1953. " Studies in the Metamorphic and Plutonic Geology of the Wantabadgery-Adelong-Tumbarumba District N.S.W., II. Intermediate-Basic Rocks." *Proc. Linn. Soc. N.S.W.*, **78**, 181–225.

Whitworth, H. F., 1954. "Petrological Determination of Specimens from Toolong Area." Appendix to paper by Hall and Lloyd, *Dept. Mines N.S.W.*, Ann. Report for 1950, 103–104.