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A PRELIMINARY ACCOUNT OF THE PETROLOGY OF THE CLONCURRY MINERAL FIELD.

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(With thirteen Text-figures.)

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CONTENTS.

I. INTRODUCTION.

The Cloncurry mineral field covers an area of approximately 35,000 square miles and occupies a region in north-west Queensland which includes the mining towns of Mount Isa on the west and Cloncurry on the east. A reconnaissance survey of the regional geology of this area is being undertaken by the Commonwealth Bureau of Mineral Resources, Geology and Geophysics, and in order not to anticipate work which will appear shortly in their Bulletin, the present paper is confined to a descriptive account of the main rock-types occurring within the area, and to the different metamorphic agencies affecting them. A brief summary of the tectonic and metamorphic history is included, and it is hoped that certain sections of the work may be studied later in greater detail.

The writer would like to thank Dr. N. H. Fisher, Chief Geologist of the Bureau, for allowing her to do this work in conjunction with the regional survey, and for making available camping and transport facilities. She also gratefully acknowledges the help of a number of the Bureau field officers, in particular that of Messrs. E. K. Carter and K. A. Townley. Mount Isa Mines Ltd. generously supplied information and a number of unpublished partial analyses, which are acknowledged with thanks. Apart from making several complete analyses, which are acknowledged elsewhere, Miss J. K. Burnett has determined several minor constituents in a number of analyses made by the writer and by B. E. Williams.

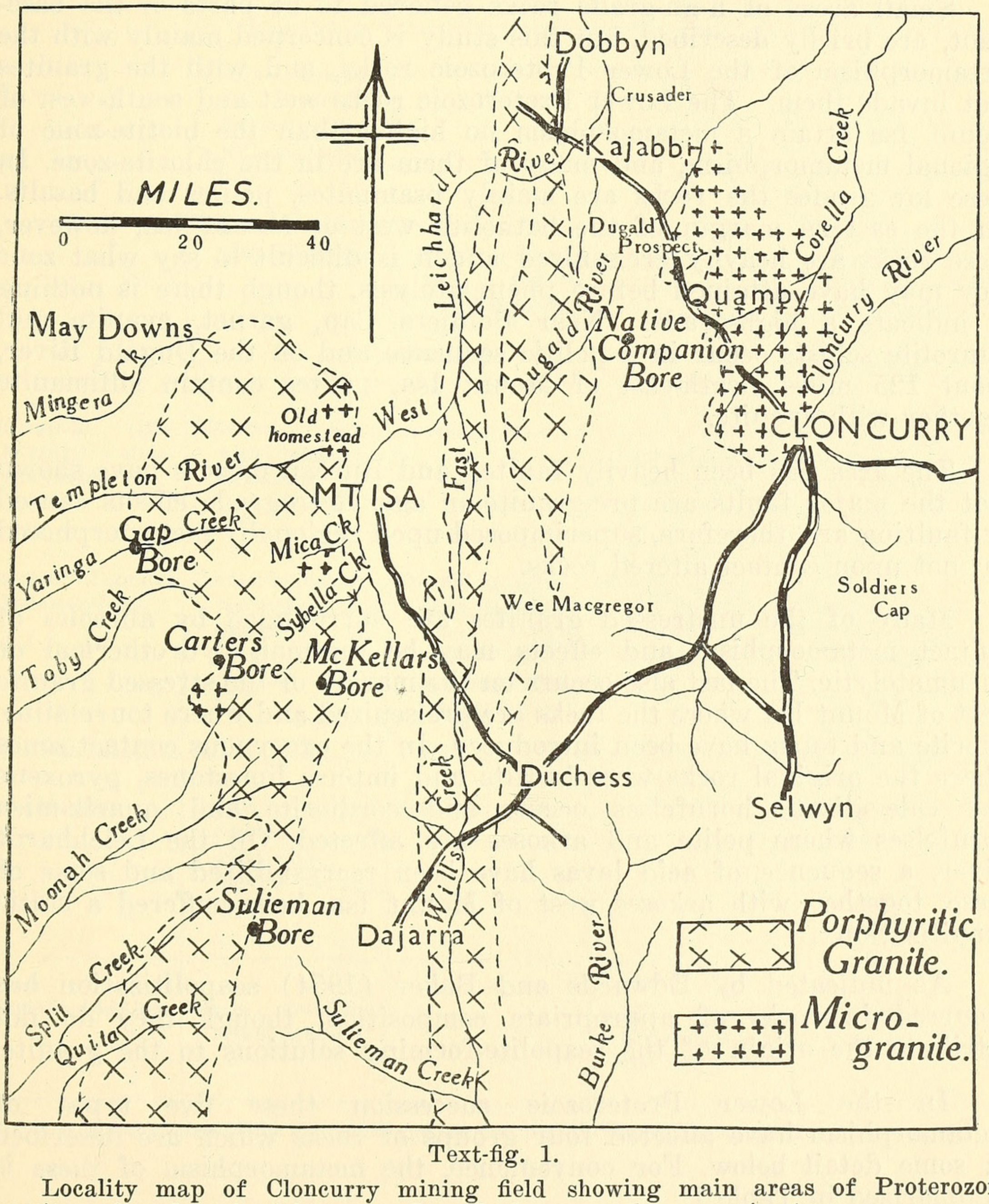
II. DEFINITIONS.

In an earlier paper (Joplin, 1952) it was pointed out that some confusion exists with regard to the use of some petrological terms, and that at times granitization appears to be used synonymously with contamination or with hybridization. In the present paper the term granitization is applied only when a small volume of magmatic fluid has converted a large volume of solid rock into a granite. If, on the other hand, a large quantity of liquid or semi-liquid magma appears to have assimilated a smaller volume of solid rock, then either the term hybridization or contamination is used. Following the original usages of these terms (Harker, 1904; Read, 1923) hybridization is reserved for the process when the incorporated material is of igneous origin, and contamination when it is of sedimentary origin.

In recent publications (Misch, 1949, a, b, c; Goodspeed, 1953) the terms synkinematic and static granitization are employed. Synkinematic granitization refers to a type which accompanies folding, is associated with regional metamorphism and takes place on a regional scale, whereas static granitization is not associated with folding and is not accompanied by regional metamorphism. Misch claims that this also takes place on a regional scale, but to the present writer his descriptions and Goodspeed's figures of replacement breccias, suggest a type of alteration which commonly occurs on the roof and walls of a batholith and passes inwards to a zone crowded with de-orientated xenoliths. This zone, according to the above definition, is a zone of either hybridization or contamination. If this interpretation of Misch's meaning is correct, then it would appear that static granitization is developed only locally about an igneous body, though in places it may appear to be of regional extent where a large body is only partly unroofed and this zone is exposed over a wide area. In the present paper the term static granitization is used in this sense.

III. AGE OF THE GRANITES.

Below it is shown that small masses of granite are associated with high grade rocks which are believed to be part of the basement upon which the Lower Proterozoic succession was laid down. Most of the granites, however, invade the Lower Proterozoic rocks, and among them two types may be recognized—a coarse porphyritic granite and a fairly even-grained microgranite. The porphyritic granite is the predominating type west of the Dugald River, and the microgranite to the east of the river. Small masses of the fine granite invade the coarse porphyritic type and it is obviously the younger, although chemical and mineralogical work suggest that the granites are of one age, the microgranite merely representing a later phase.



Text-fig. 1.

Locality map of Cloncurry mining field showing main areas of Proterozoic granite referred to in this paper. Boundaries are only approximate.

The areas occupied by these Proterozoic granites are roughly delineated in Figure 1. The map is based on previously published work, but some slight modifications have been made by the writer in certain areas with which she is familiar. It will serve as a locality map for the present paper, but it is hoped that soon it will be superseded by the publication of the maps in the Bureau memoir.

IV. TYPES OF METAMORPHISM.

As the country under consideration covers a very wide area, detailed mapping is impossible in a reconnaissance survey. Extensive collections have been made, however, and specimens pin-pointed on aerial-photographs on a scale of $1\frac{1}{3}''$ to a mile. In preparing this paper about 320 microslides have been examined in some detail.

Small areas of high-grade rocks believed to be parts of the basement, are briefly described, but this study is concerned mainly with the metamorphism of the Lower Proterozoic rocks, and with the granites that invade them. The Lower Proterozoic rocks west and south-west of Mount Isa attain a metamorphism no higher than the biotite-zone of regional metamorphism, and many of them are in the chlorite-zone. In these low-grades the rocks are mainly psammites, pelites and basalts. On the eastern margin of the batholith west of Mount Isa, however, these rocks are heavily greisenized and it is difficult to say what zone they may have attained before pneumatolysis, though there is nothing to indicate a high-grade. Near Soldiers Cap, garnet, cyanite and staurolite schists occur in a pelitic sequence and on the Dugald River, about 125 miles north-east of Mount Isa, pelites contain sillimanite together with cyanite.

The area has been heavily faulted and Bureau officers have shown that the major faults are pre-granite in age. Retrograde effects caused by faulting are, therefore, superimposed upon regionally metamorphosed but not upon contact altered rocks.

Many of the unstressed granites are surrounded by aureoles of contact metamorphism and effects may be thermal, hydrothermal or pneumatolytic. The last also occurs on the margin of the stressed granite west of Mount Isa where the rocks are greisenized and where tourmaline, fluorite and topaz have been introduced. In the exogenous contact-zones where the original rocks were basalts and impure limestones, pyroxene and calc-silicate hornfelses occur, and cordierite and quartz-mica hornfelses where pelite and arkoses are affected. On the Leichhardt River, a sequence of acid lavas have been recrystallized and some of these, together with arkoses west of Mount Isa, have suffered a static granitization.

As indicated by Edwards and Baker (1954) scapolitization has occurred in rocks of appropriate composition, though they do not attribute the origin of the scapolite-forming solutions to the granite.

In the Lower Proterozoic succession these five types of metamorphism have affected four groups of rocks which are described in some detail below. For convenience, the metamorphism of these is summarized in Table I.

TABLE I.

Type of Metamorphism.	Aluminous and Siliceous Rocks.	Calcareous Rocks.	Acid Lavas.	Basic Lavas and Intrusives.
Regional Metamorphism	Chlorite- and Quartz-chlorite Schists	Chloritic Marbles	..	Uralitized Gabbro, Blastophitic Dolerite
	Biotite Schists ..	..	Dacites with hornblende pseudomorphed by biotite	Amphibolites and Hornblende-biotite Schists
	Garnet-, Cyanite- and Staurolite-Schists (with or without Andalusite)	..	..	..
	Cyanite - Schists with Sillimanite	Pyroxene-, Hornblende-pyroxene, and Biotite-scapolite Granulites	..	Pyroxene- and Hornblende-pyroxene Schists and Gneisses
Retrograde (Dislocation) Metamorphism	Silicified Slates with cataclastic structures	Tremolite Rock	Lavas with cataclastic structures	Chlorite-amphibolites and Chlorite-Schists
Thermal (Contact) Metamorphism	Cordierite quartz-Hornfelses, and Quartz - muscovite Rocks (Arkose)	Diopside-plagioclase Hornfelses (Class 7) Diopside - garnet-plagioclase Hornfelses (Class 8)	Recrystallized Rhyolites and Dacites	Pyroxene Hornfelses and Recrystallized Dolerites
Metasomatism	Greisenization with addition of tourmaline, fluorite and topaz	Scapolitization*	..	Formation of Biotitites
Magmatic Addition	Static granitization of Arkoses	..	Static granitization of Rhyolites and Dacites	Acidification of basic xenoliths

* The metasomatism of the aluminous and calcareous rocks is not necessarily contemporaneous.

V. THE OLDER METAMORPHIC COMPLEX.

A few yards west of the MountIsa-Dajarra Road, at a distance of 6½ miles north-west of the Sulieman Bore, a knotted, greenish rock is overlain by flat-dipping sandy schists, which show little alteration except at their immediate contact with the porphyritic granite further west. The knotted rocks are cordierite-andalusite-sillimanite gneisses and their origin and stratigraphical position are matters for speculation. In these rocks, xenoblasts of cordierite measure up to 1 cm., and contain numerous inclusions of biotite, quartz, tourmaline, rutile and zircon. The zircons are surrounded by a characteristic yellow halo and the cordierite is altered to sericite and pinite along cracks and cleavage planes. In places subidioblastic columnar crystals (0·6 mm.) of andalusite are intergrown with cordierite. Biotite is pale reddish brown and shows alteration to sillimanite. Brown idioblasts of rutile are numerous and relatively large, and small crystals of a black metallic mineral have not yet been identified.

In the vicinity of Gap Bore another metamorphic unconformity appears. The Lower Proterozoic rocks nearby are in a low grade of regional metamorphism and are invaded by the porphyritic granite, the foliation of which is approximately north-south. Near Yaringa Creek, however, small areas of schist, granitized schist and granite are exposed and these show a marked east-west directional structure. The granite is very variable, some outcrops being even-grained and others slightly porphyritic. Phenocrysts are scarce and very sporadic in their distribution even within a single outcrop. The granite is intimately associated with psammopelites, and *lit-par-lit* injection is present in places. Xenoliths are not common, but in places almost completely granitized shadowy fragments may contain porphyroblasts of felspar up to 25 mm. in length. An aplitic type of granite also occurs, and it is intersected by small dykes and veins of pegmatite. One such vein appears to be folded with the granite. When much contaminated by schist, the granite is dark in colour and in hand specimen resembles a mica diorite.

Some of the related schists are very coarse and almost gneissic with bands of biotite and muscovite alternating with bands rich in cordierite and quartz; others contain augen up to 1.5 mm. which consist of a mosaic of quartz and biotite, and these are set in a finer mosaic of quartz, muscovite and biotite with a false cleavage. Some rocks show seams of iron ores transgressing the schistosity and suggesting an original banding.

Most of the granites contain subidiomorphic phenocrysts of plagioclase (about 4 mm.) with inclusions of microcline, and in some, small phenocrysts of microcline also occur. The groundmass consists of a mosaic of quartz, felspar and biotite and the biotite may be intergrown with iron ore and contain inclusions of apatite. One granite contains a little pinitized cordierite, and a yellow isotropic material which is mantled by epidote, may be allanite.

Further to the north-east, at the head of Mica Creek, a coarse cordierite schist has been greisenized at the margin of the later porphyritic granite. It contains large (6 mm.) ellipsoids of cordierite, crowded with inclusions in a granoblastic mosaic of quartz, biotite, muscovite, and a little sillimanite is present. This area needs further investigation, but it seems likely that this rock antedates the general metamorphism of the Lower Proterozoic succession.

At 13 miles south-east of the old May Downs homestead, a small area of coarse knotted schist appears to occur with others of lower grade, but this also needs further investigation in the field. The rock contains large (12 mm.) porphyroblasts of cordierite thickly studded with inclusions of biotite, sillimanite, muscovite and minute grains of iron ore. These are surrounded by coarser flakes of biotite which are intergrown with a granoblastic groundmass of quartz, biotite and muscovite with bands of fibrous sillimanite.

About 4 miles south-west of Rifle Creek Dam, Mr. E. K. Carter found a well-rounded granite-like boulder in a matrix of schistose rhyolite. This rock contains large porphyroblasts of microcline and plagioclase in a granoblastic base of quartz, biotite, muscovite, sphene and iron ore. The felspars are heavily sericitized, and within some of them large flakes of muscovite are developed. Carbonates are also present. The rock is threaded with quartz veins which are probably related to the rhyolite that engulfed the boulder.

This boulder indicates that granitized rocks were present in the vicinity of Rifle Creek before the outpouring of the rhyolites, and since the main granites of the region post-date the acid lavas, there is reason for assuming an older granite basement. Furthermore, the presence of arkoses west of Mount Isa points to the proximity of an earlier granite, and the metamorphic unconformity and difference in the direction of the foliation also suggest that these small exposures are part of that basement.

Nevertheless, some of these granites are not unlike some of the later porphyritic hybrids described below. Careful comparison, however, will show that there are some differences. First, the younger granite is characteristically porphyritic, whilst granite considered to be older has very rare and sporadic phenocrysts. Second, the smaller quantity of microcline is strikingly different in the older granite compared with the non-porphyritic younger type. Third, the older granite contains far more muscovite than either of the younger types, and, whilst fluorite is ubiquitous in the younger granites, it has not been noted in the older.

VI. THE LOWER PROTEROZOIC SUCCESSION.

1. The Country Rocks and their Metamorphism.

(*a*) Aluminous and Siliceous Rocks.

Pelites, psammopelites, psammites and psammites with a tuffaceous matrix, as well as arkoses are included in this section. Although aluminous and siliceous sediments are not prominent in the Lower Proterozoic succession in this region, they are found in thin seams on many horizons interbedded with the calcareous types and with the acid and basic lavas. As indicated above it has not been possible to draw zones of regional metamorphism, but it can be broadly stated that on the west most of the rocks are either in the chlorite-zone or come just on to the edge of the biotite-zone where there is a development of green mica. Near the Dugald Prospect, carbonaceous rocks are in the biotite-zone. West of the Wee Macgregor Mine in the Ballara Area, and locally in the Soldiers Cap Area, garnet-, staurolite-, and cyanite-bearing schists are developed, but as some of these contain andalusite they are not typical of the garnet, staurolite and cyanite-zones. In the Dugald River Area, cyanite schists contain sillimanite.

About ¾ mile east of Mount Isa a white slate consists of fine grains of quartz and minute flakes of sericite and chlorite with larger patches of leucoxene. A slight schistosity cuts across the sedimentary bands at an angle of about 30°. About 6 miles south of Mount Isa on the Dajarra Road a fine tuffaceous psammite, containing quartz, felspar, chlorite and carbonaceous material, is associated with a basalt (Fig. 7) which has suffered only slight alteration.

Near the Native Bee Copper Mine, 13½ miles south of Mount Isa, fine slate or tuff shows small grains of quartz in a dense matrix of green biotite, and west of the shear-zone on Sybella Creek fine grained quartz-muscovite schists also contain a little green biotite. South of Carters Bore a screen of sediments in a low grade of regional metamorphism is adjacent to the porphyritic granite on the east, and to a small mass of microgranite crowded with sedimentary xenoliths, on the west. At the northern end of the screen a conglomerate contains large stretched pebbles of quartz and quartzite in a schistose matrix of chlorite and pale green mica, quartz and magnetite, the chlorite and mica occurring as streaks and lenses in a mosaic of fine quartz. Adjacent psammopelites contain small porphyroblasts of chlorite in a granoblastic base of quartz and orientated flakes of muscovite with a trace of biotite. Coarse bands and lenses have the same composition with the addition of a little iron ore. Tourmaline occurs sporadically in these rocks, and in some of them original clastic structures are preserved. About 1½ miles south of Carters Bore quartz-sericite schists occur. They are probably in the chlorite-zone, the development of chlorite possibly being inhibited by their composition.

Near the Dugald Prospect, 11 miles north-west of Quamby, the rocks are in the biotite-zone. They are finely banded schists consisting of quartz and brown biotite, with carbonaceous material marking the sedimentary banding. Other types, showing coarser, less carbonaceous bands, contain muscovite.

In parts of the Soldiers Cap area and in the Ballara area, west of Wee Macgregor Mine, some rather anomalous high-grade schists occur. They are described very briefly here as it is hoped that more detailed work can be done after another field season. A number contain staurolite porphyroblasts, up to 10 mm. in length (Fig. 2A). Idioblastic garnets ranging in size from 0.25 mm. to 1.5 mm. also occur, and these with the staurolite are present in a lepidoblastic and granoblastic base of quartz, reddish brown biotite, muscovite and carbonaceous material.

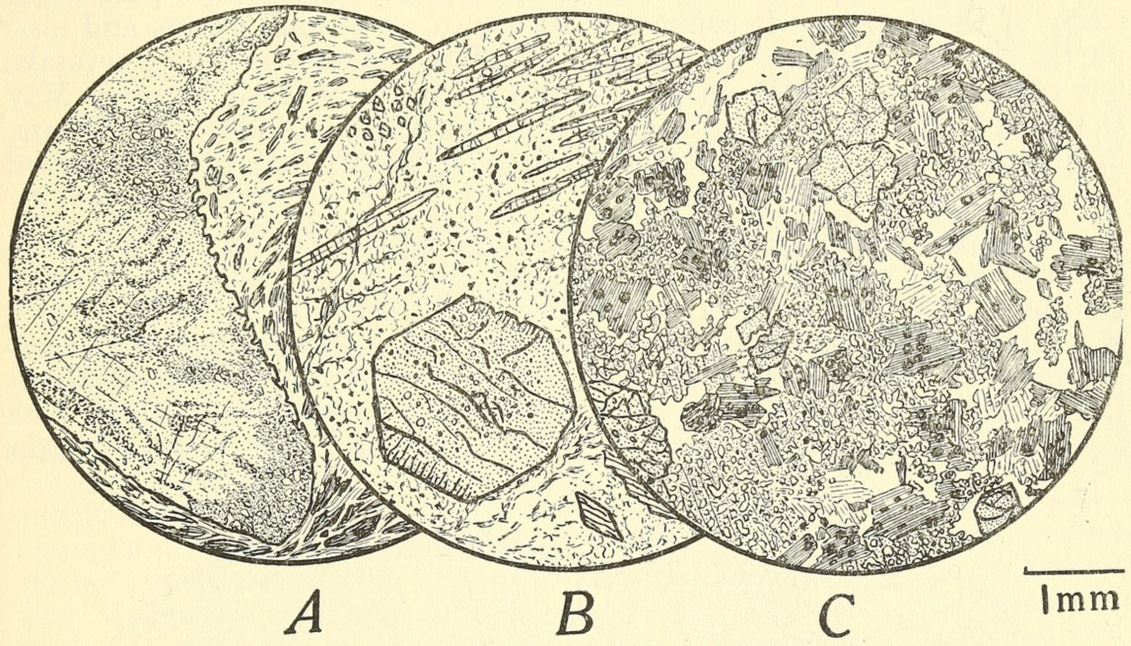
Garnetiferous schists containing radiating bunches of bladed crystals of cyanite also occur in some parts of the district. Both garnet and cyanite are in a fine granoblastic base of quartz, white mica, chlorite and a little iron ore (Fig. 2B).

Other rocks contain large poikiloblastic porphyroblasts of andalusite up to 25 mm. in length. These contain small (0.2 mm.) idioblasts of garnet and are surrounded by a fairly coarse (0.75 mm.) fringe of muscovite which passes out into a finer lepidoblastic base of muscovite and biotite with porphyroblasts (1 mm.) of garnet (Fig. 2C).

In the Dugald River area rare pelites and psammites are associated with calcsilicates. The pelites consist of subidioblastic crystals of cyanite in a coarse (1.5-2 mm.) intergrowth of biotite and muscovite.

Sillimanite forms mats of small needles enclosed in muscovite, and a little iron ore is also present. Associated psammites are coarse biotite-muscovite-quartz-schists. Fluorite and apatite are present in some of these rocks.

With regard to dislocation metamorphism, very few of the aluminous and siliceous rocks have been examined in the shear-zones. A psammite from the Soldiers Cap area shows a relict clastic structure with granulated, banded and undulose patches of quartz surrounded by a fine mylonite-like aggregate of quartz and white mica, and a coarse schist from south of Mount Isa shows the development of plumose mica in a silicified quartz-muscovite-biotite-schist. The quartz shows strain.



Text-fig. 2.

A. Staurolite schist from west of Wee Macgregor Mine, showing part of a twinned porphyroblast with peripheral embayments and patches of inclusions. The base consists of quartz, biotite and muscovite and shows bending around the end of the porphyroblast.

B. Cyanite-garnet schist from Soldiers Cap area showing porphyroblast of garnet and bundle of cyanite crystals in a quartz-mica base. A transverse section of a cyanite bundle is shown on the top left.

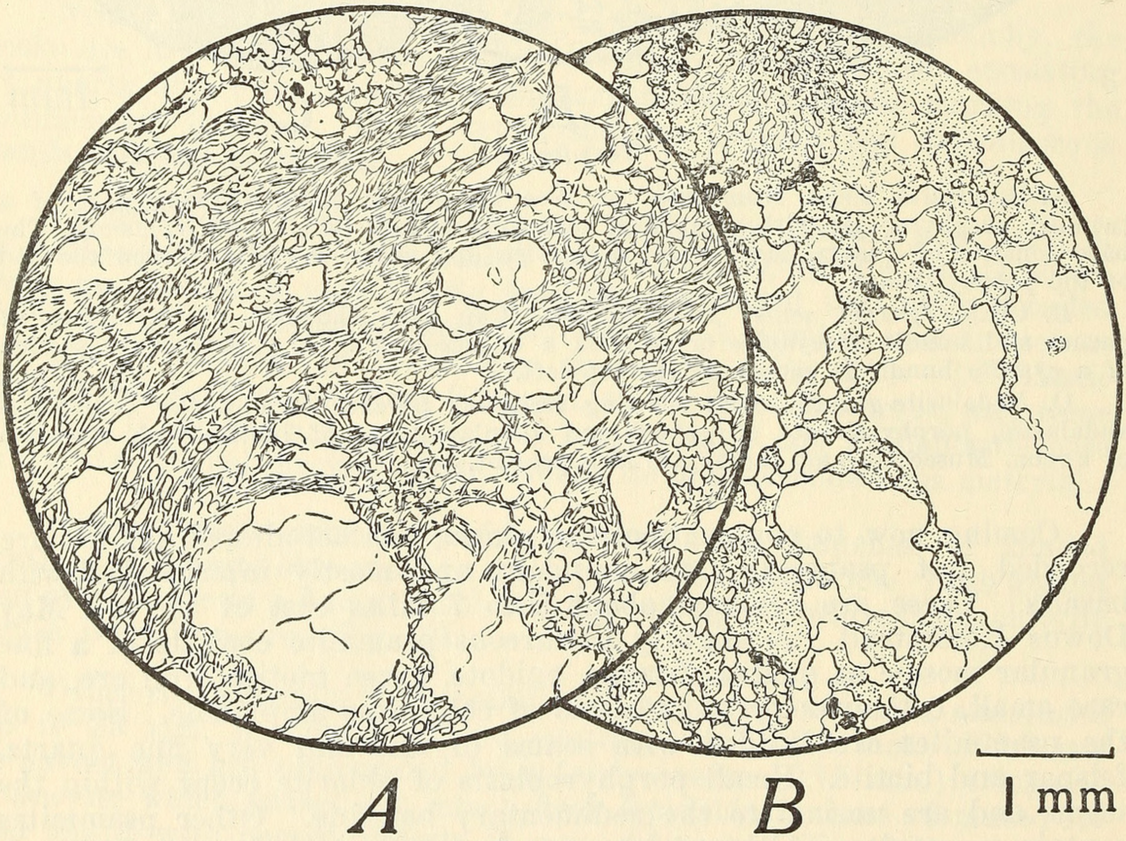
C. Andalusite-garnet schist showing irregular parches of optically continuous andalusite, porphyroblasts of garnet and tabular flakes of biotite with inclusion of zircon. Muscovite and quartz are also present.

Coming now to contact metamorphism, contact-altered pelites are recorded, but psammites are abundant and mostly interbedded with basalts. These are common about 5 to 7 miles east of the old May Downs Homestead. A slightly calcareous psammite consists of a fine granular mosaic of quartz, felspar, epidote, green biotite, iron ore, and rare small, columnar porphyroblasts of colourless amphibole. Some of the psammites are banded with seams of fine and very fine quartz, felspar and biotite. Small porphyroblasts of chlorite occur within the seams and are normal to the sedimentary banding. Other psammites contain muscovite. Although these rocks are completely recrystallized, they have not attained a very high grade of thermal metamorphism.

Granitized psammites are locally developed on the margin of the western batholith, and on Waverley Creek, about 50 miles south-west of Mount Isa a banded siliceous type contains microcline, which appears to have been derived from the granite. A fragment of fractured garnet, partly altered to muscovite, is present in this rock. In many places in the Dugald River area psammites also are granitized. These contain irregular porphyroblasts of microcline (3 mm.) and of quartz (1 mm.) in a fine lepidoblastic base of biotite, quartz, felspar and a trace of sphene. Other rather similar rocks contain apatite, chlorite and muscovite.

On the north-eastern margin of the batholith, west of Mt. Isa the rocks have suffered pneumatolytic alteration and many of the pelites are now represented by a micaceous lepidoblastic schist. The biotite flakes measure about 2 mm., and the muscovite crystals which are slightly larger may cross cut the biotite bands. Fluorite is present in many of these rocks. It commonly occurs in very small grains and may partly replace felspar. Tourmaline is fairly common in small crystals, but schorls may develop in places, and on the back road through May Downs a micaceous schist contains crystals of tourmaline up to 150 mm. in length and 65 mm. in diameter. Near Sybella Creek the greisenized schists contain a little topaz.

The porphyritic granite has invaded arkoses on Mingera Creek, about 28 miles west-north-west of Mount Isa, and exposures of contact-altered arkose may be seen on the back road between the old and new May Downs Homesteads, near Beetle Creek. Arkoses also occur as roof-pendants or screens associated with granite 25 miles north-west of Mount Isa. These masses are both contact-altered and granitized. The rock least altered by addition appears to be an arkose with rounded grains



Text-fig. 3.

A. Contact altered arkose showing recrystallized grains of quartz in a matrix of muscovite and quartz.

B. Granitized arkose showing large grains of quartz in a felspar-quartz matrix. The quartz and felspar are graphically intergrown at the top of the figure.

of milky quartz in a stony base, and a later stage shows the development of large rectangular porphyroblasts of felspar in the arkose. This mass is invaded by the granite and in most places the contact with arkose is sharp.

Contact-altered arkoses show a relict clastic structure with rounded areas of granulated quartz up to about 3 mm. in diameter in a base of fine granular quartz and mats of extremely small flakes of muscovite which may sweep round the larger masses of quartz (Fig. 3A). Some types contain a little biotite and iron ore. Granitized arkoses contain large porphyroblasts of microcline and a good deal of felspar in the groundmass, much of which is graphically intergrown with quartz. The rounded clastic grains of quartz may still be recognized, but otherwise the rock resembles a granite (Fig. 3B).

(*b*) Calcareous and Calcsilicate Rocks.

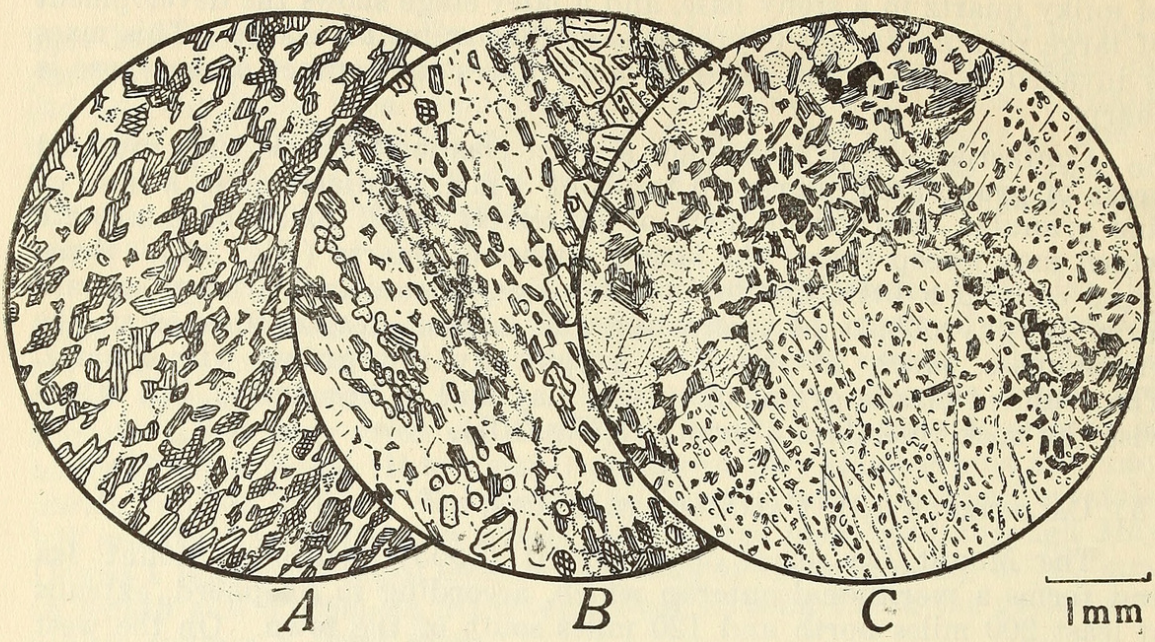
The Mount Isa series of Shepherd (1953) occurs at Mount Isa and forms a meridional outcrop which, according to Shepherd, extends at least 200 miles north and 120 miles south of the town. On the west it is invaded by granite and on the east underlain by basalts. The sequence consists of shales, calcareous and dolomitic shales and some thin beds of limestone and dolomite.

A calcareous sequence with interbedded normal shales in the Duchess area has been described by Edwards and Baker (1954), who also described scapolitized calcareous rocks in the Trekelano and Dugald River areas. This sequence was formerly referred to as the Argylla Series (Honman, 1937; Shepherd, 1953), and Edwards and Baker have suggested the possibility of its being the more highly metamorphosed equivalent of the Mount Isa shale. On petrological grounds, the present writer concurs with this suggestion, and for convenience the calcareous and dolomitic members of both sequences are described together. Although most of the types mentioned below have been fully described by Edwards and Baker (1954), the present summary is included in this regional study for the sake of completeness.

The banded calcareous and dolomitic shales at Mount Isa are in a low grade of metamorphism. An interbedded marble consists of calcite and chlorite and interbedded pelites are in the chlorite-zone. Near the Dugald Prospect, 11 miles north-west of Quamby, very similar types occur and interbedded pelites reveal that they are in the biotite-zone.

In hand specimens the rocks near Mt. Isa appear to have suffered very little alteration apart from local silicification, but under the microscope the arrangement of minute flakes of sericite, chlorite and carbonate minerals indicate a slight schistosity. Dense masses of carbon make difficult the identification of minerals in some of these fine-grained rocks. These low-grade rocks from both localities appear to have escaped scapolitization.

From the Dugald River area, Edwards and Baker described scapolite-pyroxene-granulites, scapolite-marbles, scapolite-biotite-schists and scapolite-albite-hornblende schists. In hand specimens these rocks are very similar to hornfelses from the Duchess area described below. On Cleanskin Creek, a tributary of the Dugald, these granulitic rocks are interbedded with pelites which contain cyanite and sillimanite, and in this case their texture is the result of high-grade regional metamorphism and not contact metamorphism. This is substantiated by the co-existence of calcite and quartz in the same rock.



Text-fig. 4.

A. Hornblende-plagioclase schist showing lineation of hornblende and incipient scapolitization of felspar.

B. Banded granulite showing seams of pyroxene-scapolite-quartz and hornblende-plagioclase.

C. Spotted granulite showing large poikiloblastic porphyroblasts of scapolite in a base of quartz, biotite, calcite and iron ore.

Hornblende-plagioclase rocks show a marked foliation, and when much hornblende is present, they are schists rather than granulites (Fig. 4A). A number of these rocks have been examined from the Mount Burstall area, and it is difficult to decide whether they are impure dolomites or basic igneous intercalations. Plagioclase ranges from andesine to albite and is commonly much sericitized. Incipient scapolitization of the felspar is also present. Near Mount Burstall, scapolite-pyroxene-quartz assemblages, with or without hornblende, alternate with hornblende-plagioclase assemblages (Fig. 4B) and this compositional banding parallels a slight lineation. Some of these rocks contain a little bright orange mica suggestive of titaniferous phlogopite (Prider, 1939).

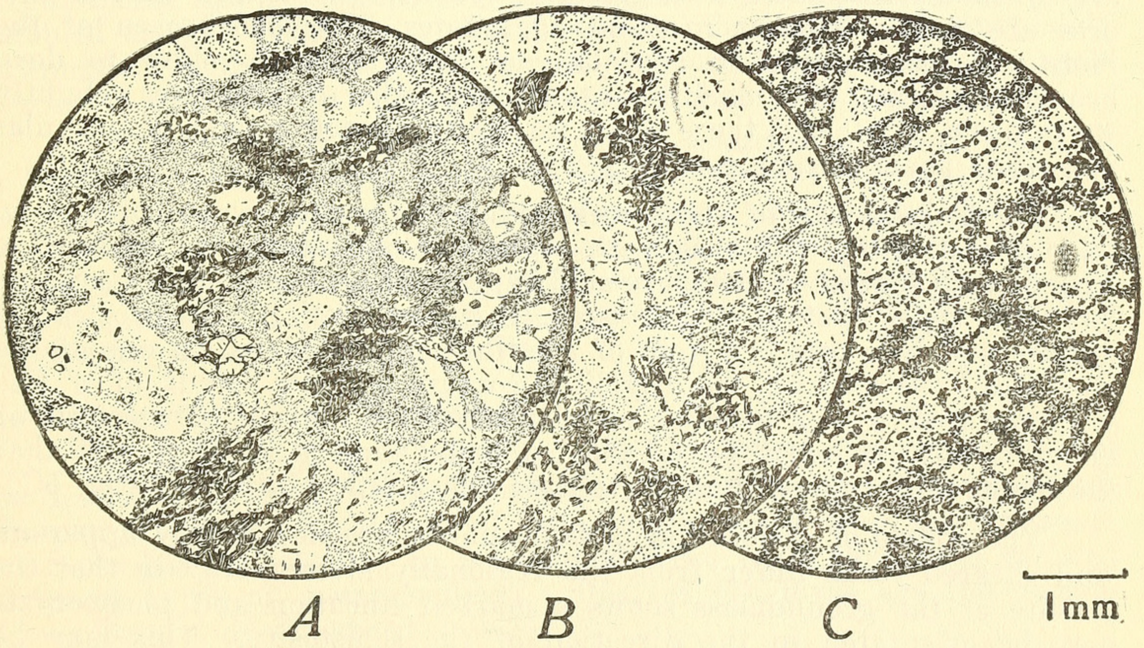
Edwards and Baker also described scapolite-biotite schists in the Dugald River area, and similar types are very widespread between Native Companion Bore and the Dugald River, 14 miles west-south-west of Quamby. In hand specimens, they are spotted grey granulites forming narrow seams that alternate with non-spotted types. The spots are porphyroblasts of scapolite that measure up to 5 mm. (Fig. 4C). They have a marked sieve-structure. Edwards and Baker found that biotite tended to be rejected by the scapolite, but at this locality inclusions of biotitie are numerous, though they are lighter in colour than that of the granoblastic base, and there may be some chemical difference. Quartz and felspar also occur as inclusions in the scapolite and the base contains quartz, biotite, calcite and iron ores; fluorite has been noted in some specimens.

With regard to the dislocation metamorphism, sheared types have not been recorded among the high-grade rocks, but in the lower grades there has been much deposition of silica and dolomites have been converted into tremolite-calcite rocks.

Contact metamorphism is evidenced in places. Near Duchess, the calcareous sequence consists of dense banded granular rocks with light and dark grey and green seams ranging in width from a few to over a hundred millimetres. These rocks are adjacent to granite and appear to be typical hornfelses. The most common type is a diopside-plagioclase assemblage, but some rocks also contain a little brown lime-iron garnet. According to Goldschmidt (1911) these would belong to the hornfels classes 7 and 8. Diopside-hornblende-plagioclase and hornblende-plagioclase assemblages also occur, and these possibly represent either Class 6 hornfelses formed under conditions of wet contact metamorphism (Joplin, 1935) or intercalations of a basic igneous rock. From this area, Edwards and Baker have described scapolite-bearing marbles and scapolite-pyroxene- and scapolite-hornblende-pyroxene-granulites which appear to represent the scapolitized representatives of the above mentioned hornfelses. Edwards and Baker also have described the leached equivalents of these rocks in the Duchess and Dugald River areas, and have shown that certain red rocks have been formed by the removal of magnesia, lime and iron oxides with the re-precipitation of some of the iron oxide as haemetite.

(*c*) Acid Lavas.

A sequence of rhyolites and dacites, with some toscanites, andesites, basalts and tuffs has suffered several different types of metamorphism. As there is a marked similarity in the mineralogical composition of this suite of rocks, except for the basalts described below, they are dealt with together in this section and only differences noted.



Text-fig. 5—Regionally altered Acid Lavas.

A. Dacite with corroded phenocrysts of quartz, tabular phenocrysts of plagioclase and micaceous pseudomorphs of hornblende in a fine groundmass. A slight schistosity is apparent.

B. Rhyolite showing quartz, albite and microcline phenocrysts with patches of criss-cross biotite in a fine crystalline groundmass. The arrangement of mica indicates a slight schistosity.

C. Recrystallized (?) spherulitic obsidian.

All the rocks are highly porphyritic with quartz and felspar phenocrysts and criss-cross patches of biotite, which, in the more basic types, are probably pseudomorphing original hornblende phenocrysts. It seems likely that the regionally altered rocks are mainly in the biotite zone, though there are no interbedded pelites to identify the zone. Quartz phenocrysts are idiomorphic and two sizes of crystals (3 mm. to 0.6 mm.) are commonly present in the same specimen. In the more basic types, quartz phenocrysts are less numerous and smaller (1.5 mm.). In all types they are highly corroded and crowded with pseudo-inclusions (Fig. 5A and Figs. 6A and B). Undulose extinction is common and minute inclusions of mica and chlorite follow curved lines within the crystal suggesting recrystallization along lines of conchoidal fracture.

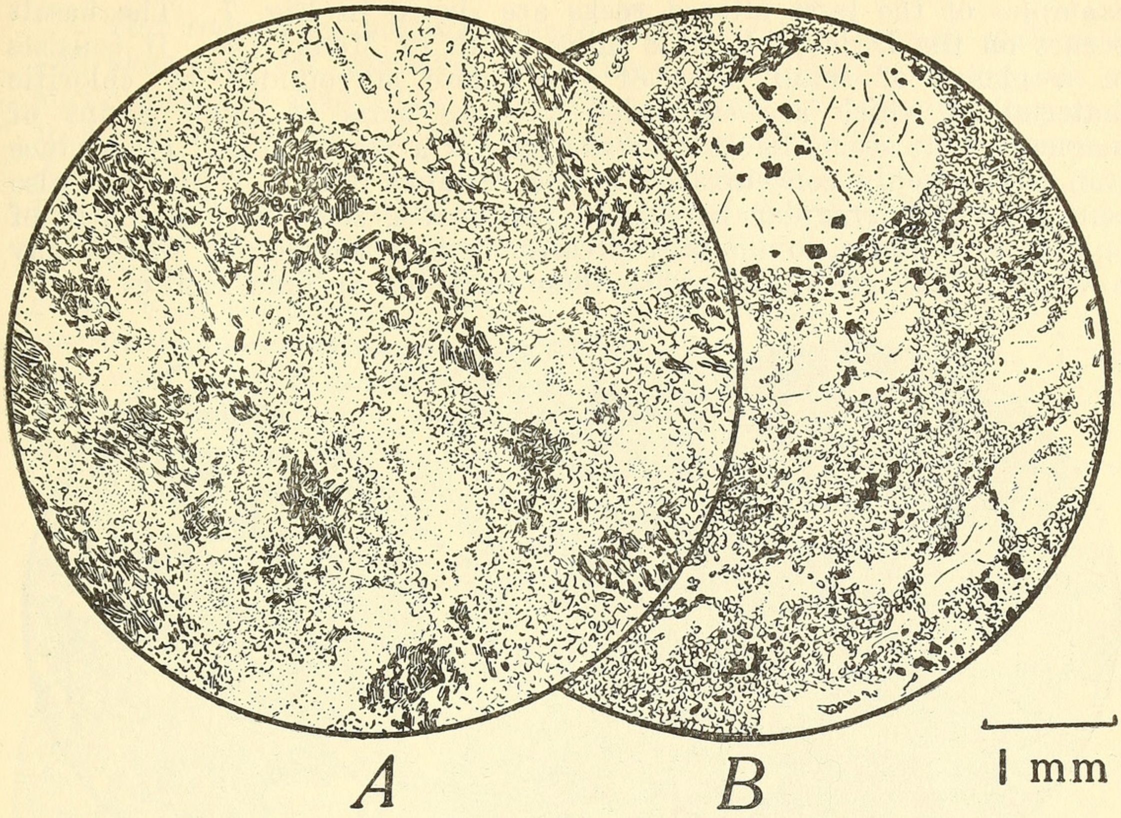
Tabular phenocrysts (1-3 mm.) of plagioclase range from albite in the rhyolites to andesine in the more basic rocks. The albite may show a peculiar twinning similar to the chequer albite of the albitites. It is commonly altered to sericite and the more basic types are heavily saussuritized with granular epidote, clinozoisite, calcite and albite among the flakes of sericite. In some dacites, calcite forms elongate grains replacing felspar. In some more basic types there is a glomeroporphyritic grouping of the plagioclase. One of the rhyolites shows a vein of microcline cutting plagioclase phenocrysts.

Rhyolites contain tabular phenocrysts of microcline (3 mm.) and smaller phenocrysts (about 0.75 mm.) occur in the toscanites. Simple Carlsbad twinning may be present in addition to the typical gridiron grating. Microcline may be albitized, and cut by veins of albite.

Dacites and more basic types contain biotite in small (0.1-0.01 mm.) criss-cross flakes which form clusters measuring up to about 3 mm. in length and appear to be pseudomorphs after hornblende. These are commonly associated with granular sphene, epidote and calcite. Iron ores are rare or absent in these aggregates. The pleochroism of the biotite is from yellow to chocolate or from greenish-yellow to deep brownish-green. One dacite contains xenoliths of a coarser, slightly more basic, type, and there is an interesting reaction-ring of granular magnetite about a xenocryst of pyrite.

The groundmass of these rocks consist of a fine mosaic of quartz, felspar and mica. Staining with sodium cobaltinitrite has revealed a little potash felspar in the more acid types. The mica is mostly sericite, but some types contain a little greenish-brown biotite. Accessories are apatite and iron ores. A vein of fluorite has been noted in one of the rhyolites. Several of the rhyolites contain narrow bands of a fine granular rock with a peculiar cellular structure. Small phenocrysts of quartz occur amongst the cellular material, and it is suggested that the bands may represent recrystallized spherulitic obsidians (Fig. 5C).

The effects of dislocation metamorphism are not readily apparent, and sheared rocks differ from the regionally altered only in that the sericite of the groundmass shows a marked lineation and phenocrysts may be orientated in the direction of the schistosity. This may be accentuated by the development of an augen structure and a coarser crystallization of the groundmass at each end of the phenocrysts. Quartz phenocrysts show undulose extinction, strain banding or complete granulation; the more basic types of plagioclase may be broken down into granular calcite and epidote; and hornblende phenocrysts are represented by trails of biotite in the direction of the schistosity.



Text-fig. 6—Thermally altered Acid Lavas.

A. Dacite showing completely recrystallized groundmass with nibbled margins of phenocrysts.

B. Recrystallized rhyolite showing the same features.

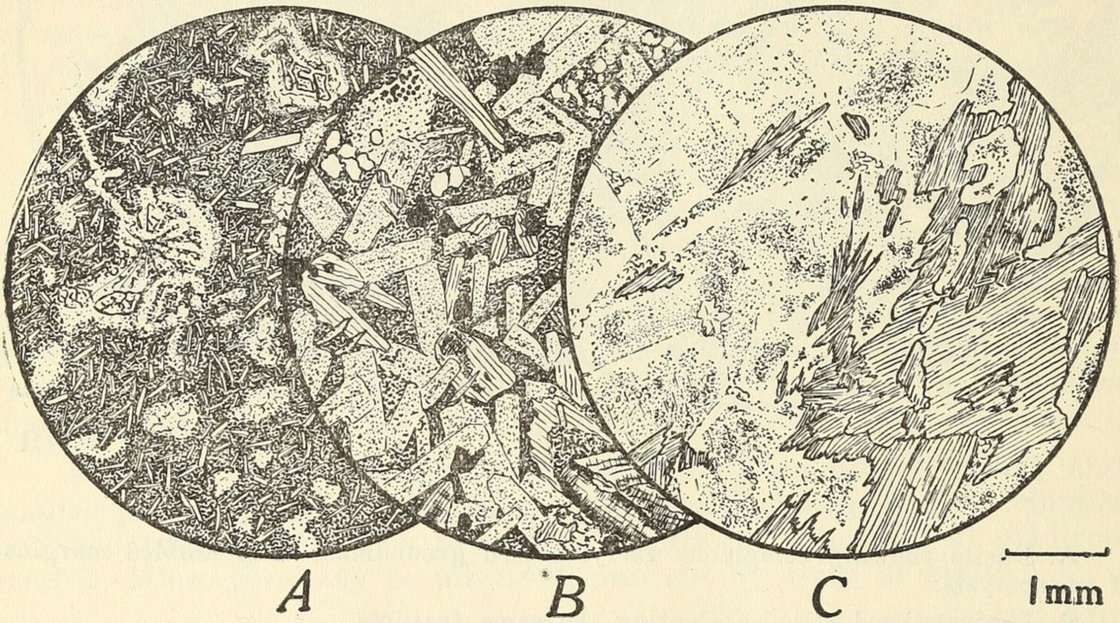
Contact metamorphism is evidenced by a coarser granoblastic groundmass against which the phenocrysts show a characteristically nibbled margin (Figs. 6A and B). Quartz phenocrysts are completely granulated, and in one of the rhyolites, microcline phenocrysts show a zone of quartz blebs with an outer rim of clear untwinned felspar.

On the Leichhardt River this volcanic sequence forms the roof of a batholith which is only partly exposed. Most of the rocks are recrystallized as described above, but in places quartz and microcline phenocrysts show very indefinite outlines and may in fact be porphyroblasts that have grown as the result of static granitization. A fine grained, banded microcline granite appears to represent the complete granitization of a banded rhyolite.

(*d*) Basic Lavas and Intrusives.

A thick succession of basic lavas interbedded with quartzite will be described in the bulletin to be issued shortly by the Commonwealth Bureau of Mineral Resources. In the present paper they are discussed, with the basic intrusives, as a group of basic rocks that have suffered different types of metamorphism. Most of the lavas are the Spring Creek basalts of Shepherd (1953).

Basic dyke swarms invade the acid lavas between Mount Isa and Cloncurry in the region of the East and West Leichhardt Rivers and small bodies of gabbro occur in the noses of a number of folds in the Mount Isa and Cloncurry areas. In most instances original structures have been obliterated, and except for their field occurrence, it would be difficult to identify specimens as either intrusive or extrusive. Three examples of the least altered rocks are shown in Fig. 7. The basalt occurs on the Dajarra Road 6 miles south of Mount Isa. It consists of a plexus of small laths of plagioclase surrounded by chloritic material in which are embedded a dense mass of small grains of magnetite. It seems likely that the base is a recrystallized glass since iron is commonly concentrated in the residual liquid. This rock also contains small irregular patches of carbonates, some with a centre of epidote and these no doubt represent former amygdules which may have originally contained either these minerals or lime zeolites.



Text-fig. 7.

A. Partially altered hypohaline amygdaloidal basalt showing small laths of plagioclase in a fine recrystallized base rich in magnetite. Amygdules are filled with granular calcite and epidote. Dajarra Road, 6 miles south of Mount Isa.

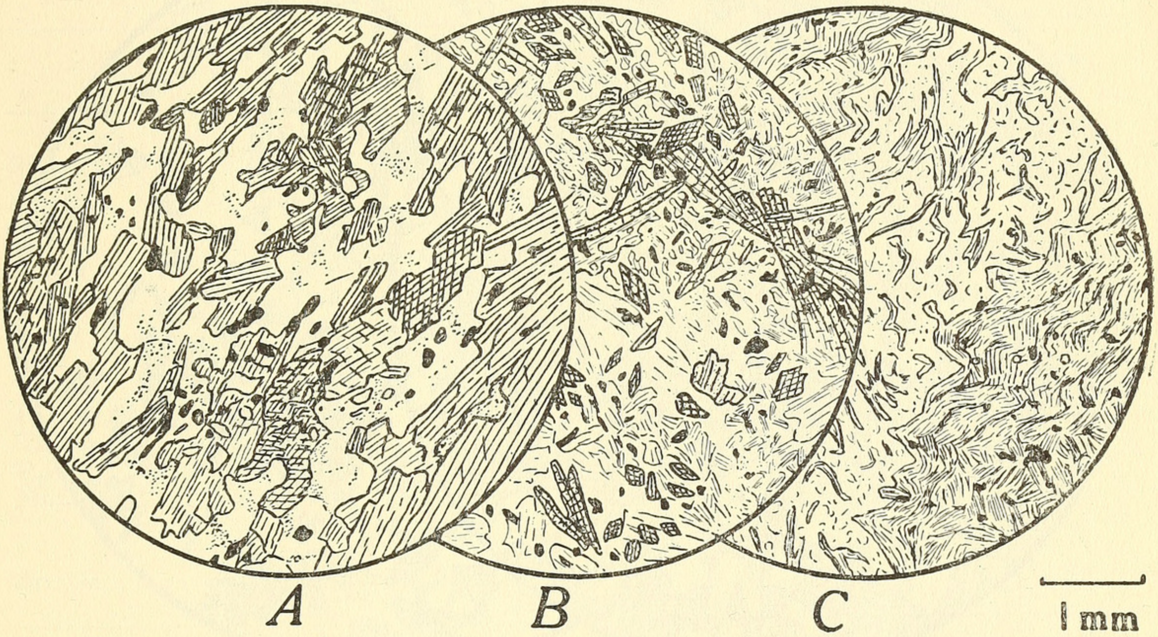
B. Slightly altered dolerite with blastophitic and blastointergranular structure. Interstices are filled with chlorite and magnetite, and small patches of quartz may be partly released quartz. Plagioclase is heavily sericitized and stained by haematite, and most of the augite is altered to green hornblende. Partly altered augite shows a sahlite parting (bottom of figure).

C. Altered gabbro showing saussuritized tabular plagioclase and aggregates of uralitic hornblende. Cloncurry Road, 7 miles east of Mt. Isa.

The least altered of the dolerites occurs to the south of Mount Isa. Its structure is blastophitic and blasto-intersertal. Plagioclase laths measure up to 3 mm. in length and are much altered and stained with haematite. Relict crystals of augite measure up to 2 mm. and are partly enveloped by green hornblende, and small independent crystals of hornblende occur with chlorite in the intersticies where needles of apatite and grains of magnetite are common. Small grains of released quartz are also interstitial, and in places a fine graphic intergrowth of quartz and felspar is present in the mesostasis.

The gabbro (Fig. 7C) occurs on the Cloncurry Road 7 miles east of Mount Isa. The structure is blastogabbroid. Original augite is completely replaced by uralitic hornblende which forms masses of several grains about 6 mm. in diameter. Small flakes of phlogopite are associated with the amphibole. Andesine is subidiomorphic tabular (about 4 mm.) and is heavily saussuritized with some incipient scapolitization.

The regionally metamorphosed basic rocks are very widespread and show a great variation in grainsize. The main constituents are hornblende and plagioclase (Fig. 8A). Hornblende crystals may range in size from 0.2 mm. to 10 mm.; it is a strongly coloured variety with X = light olive green, Y = olive green and Z = dark bluish-green and it shows a well marked parallelism in the direction of the schistosity. Plagioclase is andesine and is commonly sericitized and not well twinned. It forms xenoblasts, sometimes interlocking with quartz, and occurs intergrown with hornblende. In some rocks the felspar occurs in augen or narrow bands and the rock is a hornblende gneiss rather than a schist. Iron ores, usually ilmenite, sphene and apatite are present in all these rocks. Some banded quartz-rich varieties may have been tuffs, and one such rock is exceptionally rich in epidote. Segregations of quartz in some rocks suggest silicification.



Text-fig. 8.

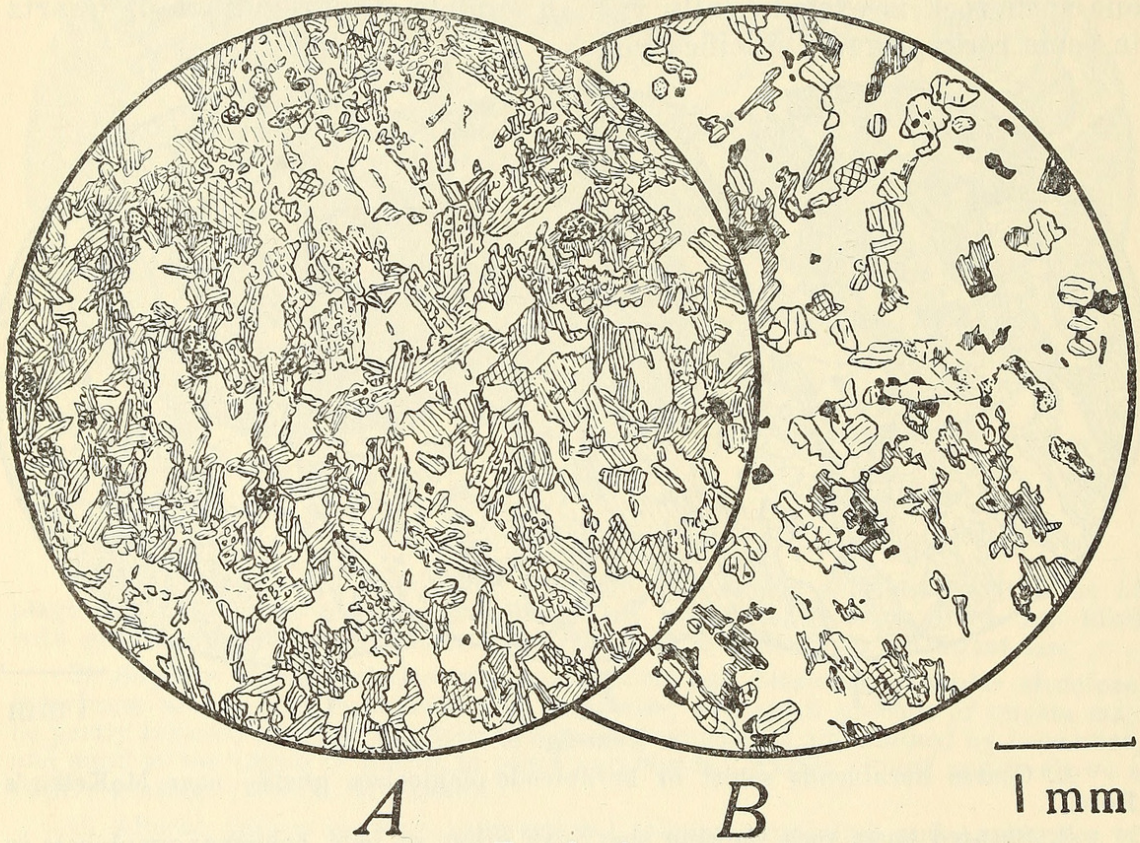
A. Coarse hornblende schist or hornblende-plagioclase gneiss, near McKellar's Bore.

B. Sheared basic rock showing sheaf-like group of pale, columnar amphibole in a base of chlorite, plagioclase, quartz, iron ore and sphene. Gap near Sybella Creek.

C. Strongly sheared basic rock segregation into chlorite-rich and plagioclase-rich bands. Accessory minerals are iron ore and apatite. A well marked plication is developed in the chloritic bands and is only just discernible in the chlorite-poor. Gap near Sybella Creek.

Dislocation metamorphism is evidenced in the shear zones by a more marked schistosity and the schists may be strongly plicated. The least sheared types contain elongated columnar crystals or needles of pale green amphibole, which in one rock appears to be anthophyllite. If abundant, the slender crystals are arranged in sheaf-like or stellate groups (Fig. 8B), and when little amphibole occurs single crystals pierce chlorite or plagioclase. Chlorite is not abundant in types rich in amphibole, and the two minerals are in a roughly inverse relationship. In the most sheared types, chlorite has developed to the exclusion of amphibole. Some rocks contain a little light golden yellow biotite and flakes of both chlorite and mica follow a well marked plication (Fig. 8C.) In the less sheared types these minerals occur in a fine mosaic of plagioclase with accessory quartz, epidote, sphene and iron ore. In the more sheared types felspar and quartz are segregated into lenses or bands and the plication is only just discernible across them (Fig. 8C.) In a few rocks small patches of plagioclase fringed and pierced by needles of amphibole suggest an original phenocryst. Plagioclase commonly shows alteration to clinozoisite and to carbonates.

Thermally altered basic rocks occur as remnants on partly unroofed granites about 12 miles north-west of Mount Isa and on the Leichhardt River to the east. West of Mount Isa they occur as flows interbedded with quartzites, and on the Leichhardt they occur as dykes cutting the acid lavas. The least altered of the dyke rocks have a blastophitic structure and consist mainly of plagioclase and hornblende with accessory sphene, epidote and iron ore. Plagioclase laths are slightly



Text-fig. 9.

A. Dolerite showing early stage of contact metamorphism. A blastophitic structure is still present, but crystalloblastic structures are indicated by the granoblastic intergrowth of plagioclase and hornblende (top right, and bottom) and by early poikiloblastic hornblende. Dyke on Leichhardt.

B. Thermally altered basalt showing pyroxene and clear felspar and biotite enveloping iron ores. A rought parallelism of these minerals indicates an earlier schistosity. East of old homestead, May Downs.

"nibbled", and a faint greyish-brown clouding is indicative of the first stages of contact metamorphism (Macgregor, 1931; Joplin, 1933). Green hornblende forms small columnar crystals with numerous felspar and quartz inclusions indicating an incipient poikiloblastic structure, and in places small xenoblasts of amphibole are intergrown with felspar (Fig. 9A).

In the railway triangle north of the open cut at Duchess. Edwards and Baker (1954) reported basic rocks containing olivine, and though the present writer has not encountered this mineral, specimens from this locality reveal that the rocks are in a low-grade of contact metamorphism comparable to the type figured and described above. Some rocks contain a little scapolite.

In a higher grade of thermal metamorphism, rocks east of Mount Isa consist of a granoblastic mosaic of felspar and pyroxene with some fox-red biotite, iron ore and quartz. Small remnants of amphibole, heavily charged with magnetite dust appear to be passing over to pyroxene. Augite forms stout columnar crystals, which show a rough parallelism and possibly preserve the earlier alignment imposed by regional metamorphism. Biotite tends to envelope and fringe grains of iron ore (Fig. 9B). Plagioclase is extremely clear with a smoky grey clouding in the centre of the crystal, its composition is oligoclase or andesine and the somewhat acid nature suggests that it has contributed lime to the pyroxene. Some of the dykes on the Leichhardt are also in this higher grade. Table II. shows that there is some uniformity in the composition of these rocks despite the different types of metamorphism they have suffered.

TABLE II.

——	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	49·56	48·66	48·8	47·5	48·9	49·1	49·2
Al_2O_3	16·53	17·36	15·1	18·0	12·6	15·3	15·2
Fe_2O_3	1·25	1·96	16·2	15·4	17·7	19·3	14·0
FeO	10·69	8·88					
MgO	7·21	6·88	6·9	5·6	8·4	5·1	7·3
CaO	10·67	9·13	10·1	10·5	8·9	8·4	11·4
Na_2O	3·35	3·28	..	..	..	..	..
K_2O	0·89	1·29	..	..	..	..	..
H_2O +	0·22	0·58	2·2	2·5	2·5	2·0	1·8
H_2O −	0·05	0·06					
TiO_2	n.d.	1·46	..	..	..	..	..
P_2O_5	0·21	n.d.	..	..	..	..	..
MnO	0·06	0·11	..	..	..	..	..
	100·69	99·65					
Sp. Gr.	3·065	3·001	..	..	..	..	..

I. Thermally altered Basalt $3\frac{1}{2}$ miles east of Old Homestead, May Downs, west of Mount Isa. Anal. B. E. Williams.

II. Xenolith in Microgranite. $5\frac{1}{2}$ miles east of Old Homestead, May Downs. Anal. G. A. Joplin.

III. Mean of Four Partial analyses of Greenstones. Spring Creek, Mount Isa By courtesy of Mount Isa Mines Ltd.

IV.-VII. Partial analyses of Greenstones from Spring Creek. By courtesy of Mount Isa Mines Ltd.

Biotitites occur sporadically on the margin of the porphyritic granite west of Mount Isa, and as they are associated with greisenized sediments they are believed to represent basic rocks that have been altered by pneumatolysis. Certain basic rocks have suffered acidification and static granitization, and though most of them are discussed with the granites that they have hybridized, it is fitting that the least altered types should be noted here. Some of the contact altered basic dykes on the Leichhardt show acidification and closely resemble a rock occurring on the eastern bank of the West Leichhardt which appears to be a roof-pendant. This mass is a dense, black granulite threaded with veins of epidote. Porphyroblasts (2 mm.) of plagioclase and ragged grains of green hornblende, in decussate groups, are associated with iron ores, epidote and apatite. Apatite occurs in relatively large crystals.

These minerals are surrounded by a fine granoblastic mosaic of quartz, plagioclase and hornblende. Similar rocks occur near the head of Mica Creek, and on May Downs, 13 miles north-west of Mount Isa. A little biotite is present in some and its origin may be due either to magmatic addition or to an earlier metamorphism.

2. The Intrusive Rocks.

(*a*) Albitites and Soda Granites.

These rocks form small sporadic outcrops in the Soldiers Cap and Dugald River areas as well as west of Mount Isa, and it is probable that detailed mapping would reveal others. The field relations are obscure, though in most places they are close to and are possibly intrusive into the microgranites described below. On the other hand, some masses appear to be related to the earlier basic rocks, and again several are found along fault zones.

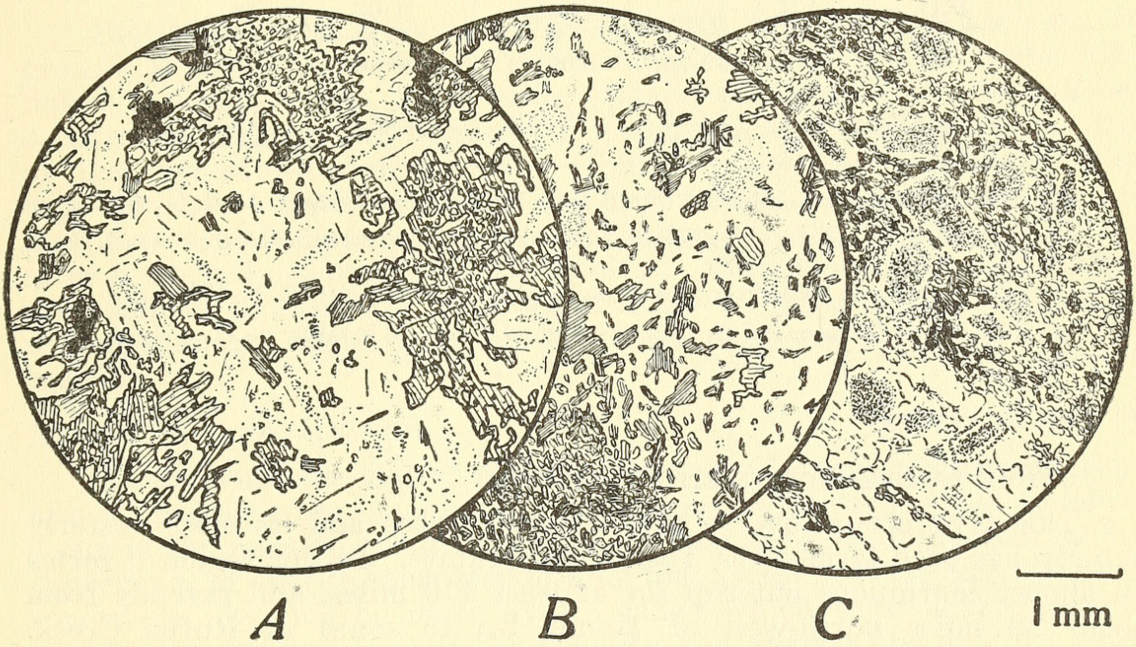
In the Soldiers Cap area they range from albitites with only a trace of quartz to albite granites in which quartz is a prominent mineral. The average grain size ranges from 0.75 mm. to 1.5 mm., but much finer grains of quartz and felspar may be interstitial and suggest a mortar structure. Two miles north-east and 5 miles east of the old homestead on May Downs, the albitites are slightly coarser and grains of albite may measure 3.5 mm. in diameter though finer material is also present. Albite occurs in irregular grains or in subidiomorphic tabular crystals, and drop-like inclusions of quartz may be present. It normally shows a well marked albite twinning, but a peculiar lamination reminiscent of the twinning of microcline is present in some grains. It appears however to be confined to one direction and may be the chequer albite referred to by Browne (1920). A little pale biotite or chlorite occurs in most rocks, and iron ores and sphene are constant accessories. Small grains of tourmaline and a few comparatively large grains of a metallic mineral occur in the albitites from Mount Isa. The metallic mineral was examined in polished section by Mr. W. Roberts of the Bureau of Mineral Resources and identified as ilmenite.

Hybrids.

Near the Volga Mine a fine, white aplitic type containing a little amphibole, cuts a basic rock. East of the old May Downs Homestead the albitite appears to have been injected along a pre-granite fault-zone in which basic rocks have been converted to chlorite schists and chlorite-biotite schists. The shattered basic schists occur as very numerous small xenoliths in the albitite which, on weathered surfaces, has a peculiar nodular appearance. The igneous rock has been slightly hybridized and now consists of a coarse mosaic of albite with scattered irregular flakes of chlorite, pale green mica, and small granules of sphene and iron ore. Some of the chlorite and mica is pyrogenic, but some appear to be mechanically incorporated and to have retained the original plications imposed on these minerals in the fault-zone. An analysis of this hybrid, freed as far as possible from mechanically derived material, is shown in Table III, column II.

A little further east, a dense dark medium-grained rock contains large rounded crystals of hornblende. In hand specimen it resembles a basic diorite, but under the microscope it is obviously a hybrid consisting of a mixture of mechanically incorporated basic material in a coarse base of chemically basified material. In places a slight blastophitic structure is noted and it seems likely that the incorporated rock was not sheared before the incoming of the albitite. The portion which remained solid shows a well marked crystalloblastic structure and consists of poikloblasts of green hornblende, heavily charged with iron ores, in a base of plagioclase, quartz and biotite (Fig. 10A). The plagioclase is andesine and occurs in laths or tabular crystals ranging in size from 1 to 3 mm. as well as in small irregular grains. A slight mottling of some of the larger crystals evidences reaction (Joplin, 1933).

The high soda content of these hybrids shows their parentage with the albitite rather than with the microgranite. In most cases, this is not obvious in the hand specimen, and in the field, the relationship is not clear owing to the fact that the albitite and microgranite are closely associated.



Text-fig. 10.

A. Albitite-basalt hybrid showing large poikilitic porphyroblasts of hornblende in a base of plagioclase laths, quartz and biotite.

B. Basic xenolith in microgranite with adjacent hybrid. The xenolith consists of a plexus of small hornblende crystals and a few large poikiloblasts of biotite with a trace of felspar and quartz. The hybrid is composed of plagioclase, biotite, hornblende, quartz and a trace of sphene.

C. Sedimentary xenolith consisting of porphyroblasts of turbid plagioclase in a fine granoblastic groundmass of quartz, biotite and felspar. The hybridized granite in the lower part of the figure consists of turbid plagioclase, microcline, biotite and abundant quartz.

The basic lavas in this area are interbedded with quartzites, and in places the basified albitite has shattered the sedimentary seams and mechanically incorporated them. In the field, rounded xenoliths of quartzite occur in the diorite-like rocks and under the microscope some specimens show small (0.3 mm.) highly sutured grains of quartz and larger (0.7 mm.) ragged flakes of biotite associated with iron ore in a fine base of plagioclase laths, interstitial quartz and a little epidote and hornblende. Some rocks appear to be albitites with strewn fragments of undigested basic igneous and sedimentary material, others appear to be basified albitites with mechanically incorporated quartzites. It thus seems evident that the basic material is the more susceptible to chemical assimilation.

TABLE III.

——	I.	II.	III.	IV.
SiO_2	67·84	61·95	49·82	76·67
Al_2O_3 ..	20·42	22·02	14·46	13·29
Fe_2O_3	0·01	0·82	4·78	0·42
FeO	0·32	0·51	6·75	0·56
MgO	0·14	3·98	5·42	0·01
CaO	0·67	3·02	9·86	0·17
Na_2O	9·54	6·13	4·98	4·34
K_2O	0·51	0·45	0·44	3·27
H_2O + ..	0·07	0·80	0·81	0·26
H_2O − ..	0·06	0·09	0·05	0·09
TiO_2	0·18	0·51	2·33	1·16
P_2O_5	tr.	n.d.	1·02	tr.
MnO	tr.	0·01	0·14	0·01
	99·76	100·29	100·86	99·95
Sp. Gr. ..	2·595	2·649	2·995	2·639

I. Albitite, 2 miles north-east of old May Downs homestead. Anal. G. A. Joplin.

II. Hybridized albitite, 5½ miles east of old May Downs homestead. Anal. G. A. Joplin.

III. Albitized basic rock from the same locality as II. Anal. B. E. Williams.

IV. Albitite, contaminated by quartzite from the same locality as II. Anal. J. K. Burnett.

(*b*) The Granites.

i. The Coarse Porphyritic Granite.

This type occurs over a very extensive area and its most westerly outcrop has been termed the Templeton Granite. In this region it forms an almost continuous outcrop for at least 110 miles, and extends from about 22 miles north-west of Mount Isa to south of Rufus Creek. Another mass covers a wide area in the region of the East and West Leichhardt Rivers, but here the batholith is only partly unroofed and the outcrops are small and discontinuous. Another large mass occurs on the Dugald River, 15 miles west of Quamby, and extends north of Dobbyn.

The most westerly belt shows a marked foliation at its northern end, and farther south, near McKellars Bore, an augen structure is developed and felspar units measure up to 230 mm. in length. Still farther south, to the west of the Sulieman Bore, the granite is mainly massive and contains numerous de-orientated xenoliths. On the Leichhardt, the granite is mostly massive and in the Dugald area it is a true banded gneiss.

Although the porphyritic granites may be massive, gneissic or schistose in different places and are sometimes much hybridized, it is believed that they are all of the same age and that differences are due mainly to their tectonic environment; this is discussed later. In hand specimen the rock is coarse and porphyritic, with large pink phenocrysts of microcline from about 15 to 65 mm. in length.

Under the microscope the groundmass shows a range in grainsize from 0.5 to 3 mm., and consists of quartz, microcline, biotite and plagioclase, and it can be seen that accessory minerals are hornblende, iron ores, sphene, epidote and fluorite. The microcline may show slight albitization or alteration into myrmekite and scattered grains in the groundmass may show graphic intergrowth with quartz. The plagioclase ranges from oligoclase to andesine, and in the coarser grained rocks forms subidiomorphic laths or tabular crystals with turbid, partly saussuritized cores. The outer margin is clear but there appears to be no change in the composition of the felspar from core to margin, a feature noted by Nockolds (1931). In some rocks twin lamellae show slight bending, and other evidence of strain is shown by undulose extinction, banding and granulation in quartz and by the development of minute inclusions along curved lines which are possibly lines of conchoidal fracture in the quartz. Near McKellars Bore, epidote occurs along joint planes in the granite where slickensiding indicates post-consolidation movement.

Biotite may occur as large independent flakes up to 1.5 mm., in groups of large flakes or, more commonly, in clots of small criss-cross flakes associated with hornblende, sphene and iron ore. The latter occurrence suggests the presence of a xenolith that has reached a state of chemical equilibrium with the granite, but whose mechanical disintegration is not quite complete. The larger flakes may show bending and alteration to chlorite in the stressed granites, and strongly lineated types show a marked orientation of the biotites. Iron ores, sphene and apatite are common inclusions. Analyses of three of these rocks from widely spaced areas are shown in Table IV., where they are compared with two hybrids.

XENOLITHS AND HYBRIDS.

At the southern end of the most westerly belt near Sulieman Bore and in places on the Leichhardt River, numerous de-orientated xenoliths occur in the massive granite. These are mostly basic and consist of fine aggregates of biotite, hornblende and plagioclase. Some xenoliths are surrounded by one or more hybrid rings which show sharp contacts against the granite, against the xenolith and against one another. One interesting xenolith consists of a felted mass of slender carbonate needles and colourless amphibole, possibly representing an original fragment of dolomite. The quartz of the granite is idomorphic against the xenolith.

When the xenolith is of basic material, the hybrid immediately adjacent to it consists mainly of subidiomorphic tabular plagioclase, large grains of quartz and potash felspar in a fine base consisting of the minerals of the xenolith. In this base, biotite is more common than hornblende, and in some hybrids, myrmekite fringes potash felspar which is adjacent to plagioclase. Apatite and sphene are usually very abundant.

In the Duchess area a large mass of coarse, dark granite with phenocrysts of plagioclase invades a calc-silicate sequence in which basic igneous rocks are prominent. Although xenoliths are not common in this mass, on the analogy of the hybrids surrounding xenoliths elsewhere, it is assumed that the Duchess rock is a hybrid of the porphyritic granite. This is supported by a comparison of analyses (Table IV.). In many places along the Mount Isa-Duchess road, the granite has invaded basic schists, and its development seems to be a clear case of static granitization.

This rock is commonly foliated, and its composition and texture change slightly from place to place. In the main, it consists of highly saussuritized subidimorphic crystals of plagioclase, clots of chlorite, epidote and sphene, or of biotite, epidote and sphene, with interstitial quartz and microcline. In some types the potash felspar surrounds the plagioclase to give a monzonitic fabric. Plagioclase is saussuritized andesine which may contain large grains of epidote in the saussurite aggregate. Sphene and apatite are common accessories. These rocks contain more epidote than the hybrid rims around xenoliths in the western granites, and perhaps this may be accounted for by the higher lime content of the calc-silicate rocks which they invade. In the Dugald area, gneisses also are contaminated by calcareous material and their higher CaO content is expressed in a larger quantity of the normative anorthite (fig. 13).

Cataclastic structures are common and are particularly well shown in a rock which outcrops on a small hill west of Bushy Park.

TABLE IV.

——	I.	II.	III.	IV.	V.
SiO_2	72·68	71·26	70·77	70·29	68·63
Al_2O_3	12·83	13·95	14·97	12·59	15·18
Fe_2O_3	0·97	1·08	0·36	0·69	0·78
FeO	2·25	2·58	2·78	2·49	4·04
MgO	0·04	0·10	0·18	0·96	0·07
CaO	1·55	1·84	1·86	2·31	2·71
Na_2O	3·50	2·74	3·23	3·72	2·16
K_2O	5·03	5·65	5·04	4·72	3·71
H_2O +	0·50	0·37	0·39	0·64	0·87
H_2O −	0·02	0·07	0·12	0·08	0·04
TiO_2	0·43	0·26	0·68	0·78	1·35
P_2O_5	0·03	0·41	n.d.	0·38	abs.
MnO	tr.	tr.	tr.	0·02	abs.
CO_2	..	..	..	..	0·13
	99·83	100·20	100·38	99·57	99·67
Sp. Gr.	2·615	2·653	2·702	2·686	2·772

I. Porphyritic Granite. 5½ miles north-west of McKellar's Bore. Anal. G. A. Joplin.

II. Porphyritic Granite. Near head of Mica Creek. Anal. G. A. Joplin.

III. Porphyritic Granite (gneissic). Mountain Paddock, Dugald River, 15½ miles west-south-west of Quamby. Anal. G. A. Joplin.

IV. Porphyritic Granite Hybrid. 5½ miles west of Wills Creek on Duchess-Dajarra road. Anal. B. E. Williams.

V. Contaminated Porphyritic Granite (gneissic). Dugald River, 14½ miles south-west of Quamby. Anal. J. K. Burnett.

ii. The Microgranites.

These rocks form a narrow discontinuous outcrop on the eastern side of the porphyritic granite, west and south-west of Mount Isa, where they appear to occur as sheets and dykes. They also invade the porphyritic granite on the Leichhardt and its most easterly outcrop west of Quamby (Fig. 11). East of Quamby a belt of microgranite extends from south of Cloncurry to the north beyond Dobbyn, and so far as is known, this even finer-grained types is the predominating granite. Apparently related, but slightly more acid types occur in the Soldiers Cap area.

In hand specimen the rocks appear even-grained though different masses may differ in grain size. Under the microscope, however, a slight heterogeneity of grainsize is apparent and certain specimens show a range from 3 mm. to 0.2 mm. The constituent minerals are quartz, microcline, plagioclase and biotite, with apatite and iron ores as accessories. Muscovite, fluorite, sphene and chlorite are also present, and incipient alteration of potash felspar to myrmekite is common. Micrographic intergrowth of quartz and orthoclase is present in some specimens.

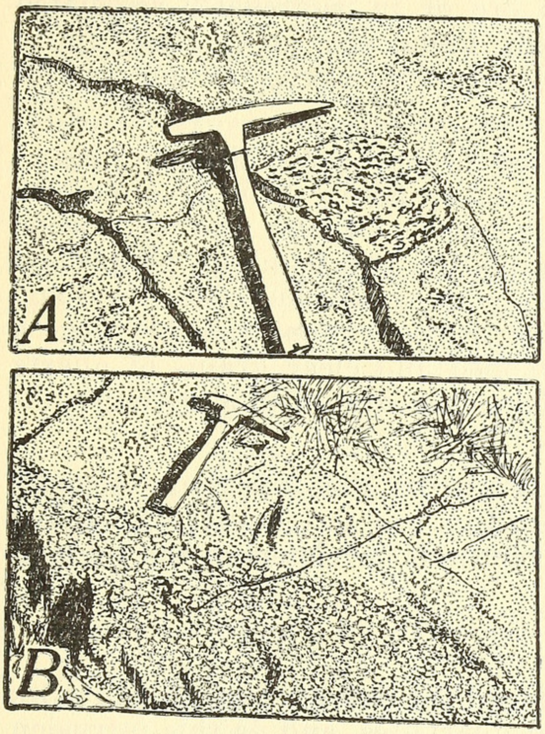


Fig. 11.

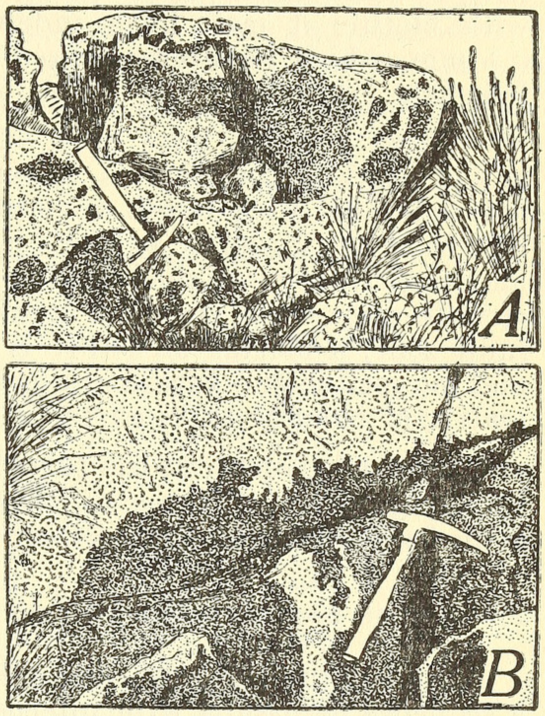


Fig. 12.

Text-fig. 11.

A. Microgranite with inclusion of porphyritic granite.
B. Microgranite showing transgressive relation to porphyritic granite.

Text-fig. 12.

A. Basalt xenoliths in microgranite. East of old May Downs homestead.
B. Basic xenolith with crenellated border and vein of intrusive granite.

The plagioclase ranges from oligoclase to andesine and forms subidiomorphic tabular crystals with turbid cores. The alteration is chiefly to sericite, but saussurite may occur. The turbid cores are commonly rounded and surrounded by a clear rim which shows interlocking with the other minerals forming the granular base. Although the plagioclase crystals are larger than those of the granular mosaic, they can scarcely be classified as phenocrysts.

Quartz occurs as irregular grains in the mosaic, or as interstitial patches between crystals of plagioclase, and in some rocks it forms larger grains resembling small phenocrysts. Undulose extinction is common.

Microcline is abundant and may form large, irregular grains, though normally their size is comparable to others in the mosaic. Myrmekite fringes or replaces microcline when it is adjacent to plagioclase and micrographic intergrowths with quartz have been noted.

Biotite is not abundant and commonly occurs in small equally distributed flakes; in some rocks it is absent. Alteration to chlorite is frequent and sphene is associated. Near the Dugald Fault, on the Cloncurry Road, slight hybridization is evidenced by the presence of clots of chlorite or of biotite and muscovite with associated granular epidote, sphene and iron ores. On the Kajabbi Track, about 7 miles north of Quamby, slight basification is indicated by the presence of a little hornblende.

Sphene may be relatively abundant, and while it commonly occurs in granular masses surrounding iron ore or in aggregates associated with biotite, it may form independent wedge-shaped crystals up to 0.7 mm. which have crystallized late and wrap grains of quartz and felspar.

These granites have been subjected to post-consolidation stresses and a marked lineation is apparent in the field. This is especially noticeable on Mica Creek and near Cloncurry. Under the microscope quartz shows undulose extinction, granulation and banding, plagioclase may show bending of the lamellae, biotite may be bent and chloritized and epidote may occur in small lenses. In extreme cases, possibly near a fault zone, a mortar structure is developed and clear grains of quartz and microcline and turbid grains of plagioclase are set in a mylonite-like matrix of chlorite and quartz.

Near Cloncurry, at the turnoff between the Mount Isa and Quamby Roads, granites of three different textures are developed; one shows chilled margins against the other, and biotite is developed at the contact.

Xenoliths and Hybrids.

East of the old May Downs homestead the fine pink granite invades a sequence of basalts with interbedded quartzites, and as this intrusion is only partly unroofed, xenoliths are very numerous (Fig. 12). The majority of the xenoliths are basic and the granite in their vicinity is basified, but some sedimentary fragments occur and the granite has been slightly acidified by their assimilation. About a mile south of Carters Bore the fine granite is also crowded with xenoliths, and these are mostly of sedimentary origin. Near the head of Mica Creek the granite also contains numerous xenoliths in every stage of disintegration. These measure from about 20 to over 300 mm. in diameter. The granite shows a slight directional structure, but as some of the xenoliths show sedimentary bedding and are de-orientated, the parallel structures in the granite cannot be interpreted as relict bedding. Xenoliths also occur in the fine grained granite of the Cloncurry-Kajabbi mass, but no systematic collecting has been done in this area.

East of May Downs homestead, the xenoliths range in size from a few to many hundreds of millimetres, and they are usually angular. In one place the granite has invaded a schistose basic rock, possibly in a fault zone, and the magma has encroached along the planes of schistosity, with occasional transgressions, and the detached xenoliths have a peculiar crenellated border (Fig. 12B). The junction of the xenolith with the hybrid is commonly quite sharp, and there may be several rings of hybrid material surrounding each xenolith. One such xenolith and inner ring have been analysed and the results are shown in Tables II. and V. This xenolith consists of a fine (0.2 mm.) aggregate of green biotite, epidote, plagioclase, hornblende, sphene and a little quartz. The felspar tends to a lath-shape and the other minerals occur as irregular grains. The plagioclase is very turbid and biotite surrounds granular sphene. The xenolith is surrounded by a clear rim varying in width from 1 to 1.5 mm. consisting of quartz and myrmekite. This is surrounded by an acidified basic rock consisting of large (3 mm.) interlocking grains of quartz, subidiomorphic microcline and plagioclase in a finer base of the same minerals together with much greenish-brown biotite. Further away from the xenolith, a more normal granitic texture is developed and biotite forms large flakes up to 1 mm. across. In this type, plagioclase forms tabular crystals of about 1 mm., and these are surrounded by a mosaic of quartz, plagioclase, biotite and hornblende. Sphene and iron ores are accessory. Some of the plagioclase grains in the groundmass have a sieve-structure, suggesting recrystallization, and it is likely that they have been mechanically incorporated.

TABLE V.

——	I.	II.	III.
SiO_2	73·49	74·76	63·98
Al_2O_3	14·06	14·01	16·75
Fe_2O_3	0·37	0·83	1·95
FeO	1·74	0·71	3·84
MgO	0·01	0·32	1·59
CaO	0·96	0·63	5·10
Na_2O	2·68	2·07	4·05
K_2O	5·63	6·04	1·67
H_2O + ...	0·33	0·35	0·30
H_2O −	0·03	0·01	0·06
TiO_2	0·78	0·37	1·09
P_2O_5	tr.	0·11	0·34
MnO	tr.	tr.	0·11
CO_2	abs.	abs.	0·69
	100·08	100·21	100·52
Sp. Gr.	2·623	2·594	2·763

I. Microgranite. Junction of Mount Isa and Quamby roads, Cloncurry. Anal. J. K. Burnett.

II. Microgranite. East of old homestead, May Downs. Anal. J. K. Burnett and B. E. Williams.

III. Highly basified microgranite from ring around xenolith. (Anal. II., Table III.). Same locality as II. Anal. G. A. Joplin.

Other xenoliths show slight variation of these features, but are essentially similar. One, from the same locality, is a little richer in magnesia, and hornblende predominates, occurring in a fine (less 0.1 mm.) granular assemblage with plagioclase, epidote and biotite. The mica may form poikiloblasts enveloping the other minerals (fig. 10B.). One hybrid from this locality contains an abundance of scapolite. Most of it is fresh, but one or two grains are altered and fibrous and may be remnants from an earlier scapolitized basic rock. A little fluorite is also present. The least basified hybrids contain large (3 mm.) irregular grains of microcline and turbid plagioclase in a granular base of quartz, biotite, felspar and myrmekite.

Sedimentary xenoliths are mainly psammites and psammopelites. Near Carters Bore, a fine grained sedimentary xenolith shows porphyroblasts of turbid plagioclase surrounded by an extremely fine granoblastic mass of quartz, biotite and felspar (fig. 10C.). The marginal granite also contains turbid felspar, quartz, microcline and biotite, and the additional quartz in these rocks indicates acidification by the sediment.

Very similar types occur on May Downs where the granite has assimilated quartzites interbedded with basalts. As noted above, the granites have been basified at this locality, but many xenoliths are studded with rounded and highly sutured grains (about 0.4 mm.) of quartz, suggesting the mechanical disruption of the sediment by a basified magma. In some types, the iron ore occurs in small rods which may show a rough parallelism indicative of a relict bedding.

iii. The Pegmatites.

Large dykes of coarse pegmatite occur sporadically on the eastern margin of the western batholith and consist mainly of quartz, microcline and white mica. The mica has been mined on Mica Creek, and monazite also is recorded from this locality. About 6 miles west-south-west of Mount Isa a pegmatite contains beryl and red garnet. Graphic structures are common.

The pegmatite dykes invade both porphyritic granite and microgranite and some of them show evidence of post-consolidation stress. As these rocks will be the subject of a more detailed study by a member of the staff of Mount Isa Mines Ltd., it is not proposed to treat them in any detail here.

VII. TYPES OF BATHOLITH.

It has long been recognized that large plutonic masses, predominantly of granitic and granodioritic composition, invade the geosynclines at, or shortly after, their compression. Blackwelder and Baddley (1925) studied the relation of batholiths to the schistosity of the country rocks, and their statistical summary indicates that 67% show transgressive relations with the former schistosity entirely obliterated by thermal metamorphism; 10% show schistosity parallel to the periphery of the batholith, indicating recrystallization under compression; and 22% were of lenticular form with all related structures parallel to the regional cleavage. They attribute these differences to different erosion levels.

Closely comparable observations were made by Per Geijer (1916) in Central Sweden where he noted a younger group of Archaean granites, with transgressive relations, associated with folding and faulting; whilst older granites invade the anticlines in closely folded areas and show concordant relations. These he called anticlinal batholiths.

Billings (1928) recognized two types of batholith in the Conway Quadrangle of New Hampshire. The concordant, he believed, were associated with the folding movement and he termed them synchronous batholiths; the transgressive, he considered, were injected after folding, and he termed them subsequent. Following the terminology of Billings, Brown (1931) drew up lists of the characteristics of each type and illustrated them by reference to New South Wales examples. Like Billings, he considered that the differences are due to their relation to the main compressional force, but he pointed out also that in part it may be a function of depth.

Cloos and Chudoba (1931) figured a section of a hypothetical intrusion which showed concordant and transgressive relations related to depth. Goldschmidt (1911, 1920) recognized two types of metamorphism associated with batholiths; thermal metamorphism (Kristiania Type), and injection metamorphism (Stavanger Type). Moreover, these two types of metamorphism are apparent in the Younger and Older Granites of the British Isles.

Hence it is evident that at least two types of batholiths exist, and that the differences have been variously attributed to age, to depth and to their relation to the compression. The present writer believes that there is a third type of batholith which shows some characters intermediate between the other two. Cloos and Chudoba (1931) and Blackwelder and Baddley (1925) have also recognised an intermediate type, the former authors showing them at an intermediate depth. Brown (1931), in discussing examples of the synchronous batholith, has remarked that the Murrumbidgee Batholith is "an intrusion which is of synchronous type, but which lacks some of the characters listed." These intermediate batholiths are concordant, and the plutonic rock commonly shows directional structures parallel to the schistosity of the country rock, but unlike the typical synchronous batholith, they are not associated with high grade regional metamorphism nor with regional granitization. Nevertheless, they are not transgressive nor are they associated with thermal metamorphism. They are associated with low-grade schists upon which has been superimposed a hydrothermal or pneumatolytic alteration. The batholith west of Mount Isa is of this type and it is proposed to call it a quasi-synchronous batholith, because of its close affinity to the synchronous type.

Because the same type of granite is so widespread in the Mount Isa-Cloncurry area, it affords a unique opportunity for the study of batholiths. The porphyritic granite in the Dugald River area is concordant and strongly gneissic, and the country rocks are in the sillimanite-zone. There is only very slight evidence of granitization, but this may be inhibited by the composition of the country rocks, which are mainly calcsilicates. This batholith therefore may be regarded as a synchronous example.

On the Leichhardt River and at Duchess, the porphyritic granite is slightly transgressive, it is associated with thermal metamorphism and static granitization, and at Duchess it is markedly hybridized. Thus it would seem that these masses are of the subsequent type.

All consist of the porphyritic granite, and reference to Table V. will show that their composition is fairly uniform and there is nothing to suggest any difference in their age.

The synchronous batholith of the Dugald River invades calcsilicates which are believed to be on the same horizon as the calcsilicate hornfelses of the Duchess Area, and possibly these may be correlated with the Mount Isa Shale which is invaded by the quasi-synchronous batholith. When the Bureau Bulletin is published it will be shown that the acid lavas, invaded by the subsequent batholith on the Leichhardt, underlie the calcsilicates. Therefore, it would seem that depth of burial is not responsible for the differences between these batholiths, and their relation to compression will now be considered.

It is noteworthy that the strongly compressed synchronous batholith of the Dugald River area is near the centre of this Proterozoic geosyncline, and not only was it subjected to lateral pressure, but no doubt it was under a heavy load. The Leichhardt mass also is near the centre of the mobile belt, and conditions might be expected to be the same, yet it is of the subsequent type. The Dugald Batholith invades incompetent and highly folded calcareous rocks, whilst the Leichhardt mass invades resistant acid lava. Thus it would seem that the physical properties of the country rocks were the controlling factors. In this event, the terms synchronous and subsequent do not apply.

The origin of the so-called quasi-synchronous batholiths needs further investigation. There is a suggestion that they have been subjected to an intermittent compression, and this might be possible on the edge of the geosyncline near a zone of thrusting. The batholith west of Mount Isa occurs in such a position where the load would be less than that of the centre and where some protection would be afforded by the borderland of older rocks. In this case therefore the position of the batholith within the geosyncline may be significant. There is no field evidence of thrusting in the immediate vicinity of the granite in the Mount Isa region, but there is reason to believe that the intrusion was emplaced in the old basement rocks under a comparatively shallow cover of the Lower Proterozoic strata.

It is therefore concluded that the different types of batholiths are related to their position within the geosyncline at the time of injection, and that the degree of competence of the country rock plays an important role.

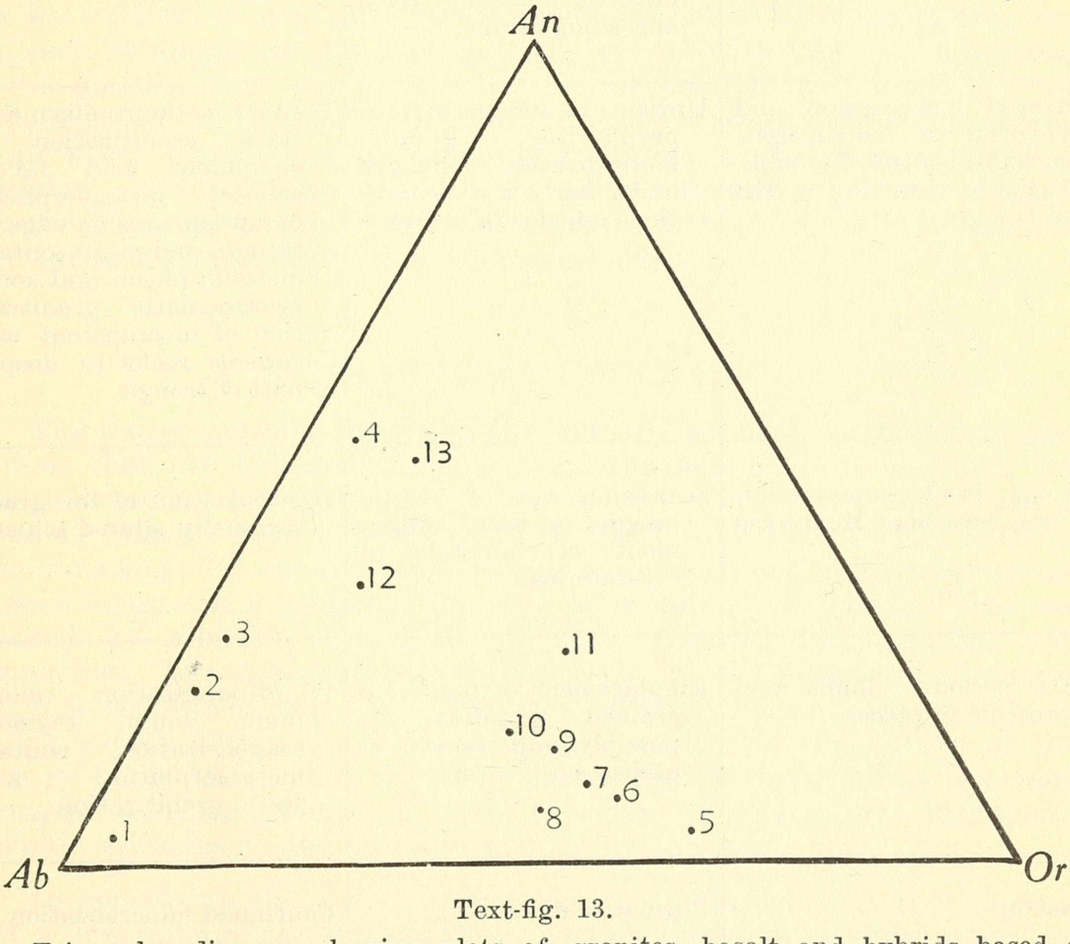
VIII. ORIGIN OF THE GRANITES.

It has been held by many that the granites of the Mount Isa-Cloncurry area have been formed as the result of granitization, but with this view the present writer does not concur. It is true that an examination of the aerial photographs reveals trend lines in the granite which appear to be continuous with the surrounding sedimentary structures; that many of the granite masses are concordant; that many of the granites are porphyritic; and that the contacts are indistinct in many places. These facts, however, do not prove granitization, though they are worthy of careful field and laboratory examination.

In the company of Mr. E. K. Carter, a trip was made into the rough granite country on the May Downs property north-west of Mount Isa, where strong structural lines showed on the aerial photographs. These proved to be remnants of arkose, highly contact altered and partly granitized. In most places the contact with the granite was sharp and the masses appear to be either roof-pendants or screens. Detailed mapping has been impossible, but it seems likely that the western batholith was emplaced by a number of concordant injections, possibly separated by screens of the country rock, or of earlier phases of the igneous rock. Undoubtedly some static granitization has taken place, particularly in such susceptible rocks as arkose or dacite, but these form a very small part of the sequence invaded by the western batholith. Actually the country rocks in this part of the area are mainly basalts and quartzites, and it is difficult to assume that such rocks could be granitized to form granites with the composition shown in Table IV. Undoubtedly some of the granites have been strongly basified and more analyses would probably show a wider range of composition, but the three analysed rocks were chosen from amongst the least basified types, and as they are many miles apart, there seems some justification for assuming that they represent one magma. They preserve marked uniformity, even though the country rocks on the Dugald River are mainly calcsilicates.

Where it can be shown that reaction has taken place between basalts and granite magma, it is significant that intermediate hybrids are developed. In fig. 13, an attempt is made to show the relationship of these granites and hybrids to one of the basalts. Obviously none of these types can be represented by a single point, and when more analyses are available, it is likely that the basalts, granites and their hybrids will occupy overlapping fields. At point 11, although the Ab :Or is comparable to the other granites, it is displaced towards An indicating assimilation of calcerous material. In the absence of further chemical work this diagram is included as a possible pointer towards the origin of the porphyritic granites and their hybrids. Furthermore, the diagram clearly indicates that the albitite is the parent of some of the hybrids.

Near Duchess there is much evidence to show that the granite has been hybridized by the basic country rock, and that xenoliths of the country rock have been acidified to give a complex series of hybrids. Some of these are undoubtedly the result of static granitization, where but little acid magma has been added to the solid basic rock. Other hybrids



Text-fig. 13.

Triangular diagram showing plots of granites, basalt and hybrids based on normative albite, orthoclase and anorthite. 1. Albitite; 2. Hybridized albitite; 3. Albitized basic rock; 4. Basalt; 5. Microgranite (May Downs); 6. Microgranite (Cloncurry); 7. Porphyritic granite (Mica Creek); 8. Porphyritic granite (near McKellar's Bore); 9. Porphyritic granite (Dugald River); 10. Hybridized porphyritic granite (Wills Creek); 11. Contaminated porphyritic granite (Dugald Area); 12. Hybridized granite surrounding basic xenolith; 13. Basic xenolith.

TABLE VI.

Tectonic.	Magmatic.	Metamorphic.
Sinking Trough	Outpouring of Acid Lavas	
Partial stabilization ..	Outpouring of basic lavas. Dykes and sills cutting acid lavas	..
Compression of varying intensity in different parts of geosyncline	..	Regional metamorphism. Chlorite and biotite zones on west. Staurolite and garnet schists locally near Soldiers Cap and west of Wee MacGregor Mine
Thrusting from east ..	..	Retrograde metamorphism superimposed on regional along shears
Relief of compression ..	Small bosses of gabbro injected in noses of folds and along faults	..
Renewed compression and yielding of incompetent rocks in centre of trough. Relief by thrusting on edge of trough	Uprising of magma to form porphyritic granite. Hybridization of magma under fairly static conditions on edge of trough	Contact metamorphism and static granitization of competent acid lavas; contact metamorphism of calcsilicates on edge of trough, and piezo-contact metamorphism and some synkinematic granitization of incompetent calcareous rocks in deeper part of trough
Strong local compression from west near Mount Isa	Squeezing out of partial magma on east. Alignment of minerals in crystal mush	Greisenization of low-grade regionally altered schists
Static period. Slight compression in places	Emplacement of fine even-grained granites (?) possibly emplacement of albitites	(?) Mineralization along fault zones, regional scapolitization, contact metamorphism and static granitization
Tension	Pegmatite dykes	Continued mineralization
Slight local compression ..	..	Directional structure in pegmatites and slight shearing of some even-grained granites

have formed as the result of crystallization of a basified magma. An examination of certain xenoliths indicates that static granitization has been brought about mainly by the mechanical forcing apart of the xenolith by porphyroblasts of microcline or plagioclase, and by the intergranular deposition of quartz and myrmekite.

Reference to fig. 13 shows that all the analysed porphyritic granites indicate some slight hybridization, but their uniformity suggests that this may have taken place at greater depth, where in fact the magma may have arisen as a result of granitization of pelitic sediments (Joplin, 1952). It seems certain, however, that the granite was injected as a magma at the present level of erosion in this region and this is further supported by the presence of de-orientated xenoliths on the southern end of the western batholith in the region of the Sulieman Bore. The fine pink granite injects the porphyritic as veins and sheets, and in many places it is crowded with de-orientated xenoliths; its magmatic origin, therefore, seems beyond question.

IX. TECTONIC, MAGMATIC AND METAMORPHIC HISTORY.

Although much detailed work needs to be done before these histories can be written, a bold attempt is made in Table VI. to correlate the sequence of magmatic and metamorphic events with the possible phases of the diastrophism. At present it is not possible to date either the scapolitization or the mineralization with any certainty, and the placing of all other events is only an interpretation of the data at present available. Nevertheless, such a Table serves a useful purpose in assembling the data and possibly suggesting future lines of investigation which may throw further light on dating these events.

X. SUMMARY AND CONCLUSIONS.

The paper contains brief descriptions of a group of ortho- and para-gneissis that are believed to be part of the basement upon which the Lower Proterozoic succession was deposited. Four chemically distinct types of country rock are described in the Lower Proterozoic, namely, aluminous and siliceous rocks, calcareous and calcsilicate rocks, a sequence of acid lavas and a sequence of basic lavas and intrusives. These are invaded by albitites, coarse porphyritic granite, microgranites and pegmatites. The types of batholith present in the areas are discussed and it is concluded that the differences between them are due partly to their position within the geosyncline and partly to the nature of the country rocks which they invade. The origin of the granites is briefly discussed and an attempt is made to relate the magmatic and metamorphic episodes to the tectonic history of the area.

In conclusion the writer would like to emphasize that this work is only a preliminary account, and that certain ideas may require modification or correction when more detailed studies are undertaken. It is hoped that detailed work on the tectonic history, on the older complex, on the albitites, on the basic rocks and on the pegmatites may be carried out in the near future.

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——————— (b) Idem, Pt. II. Static Granitization in Sheku Area, N.W. Yunnan (China). *Ibid.*, **247**, 372-406.

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