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The Metamorphism of the Cambrian Basic Volcanic Rocks of Tasmania and its Relationship to the Geosynclinal Environment

By

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(With 4 Plates and 2 Text Figures)

ABSTRACT

A spilitic suite comprising picrite basalts, spilites, keratophyres, albite dolerites and associated pyroclastics of Middle and Upper Cambrian age, outcrops on the North-West and West Coast of Tasmania. The spilites and keratophyres are considered to have been normal basalts which later suffered soda metasomatism as a result of geosynclinal deposition and orogeny. Hydrothermal alteration of the volcanics has also given rise to a variety of other rock types which includes porphyries, variolite, spherulitic quartz rock and jasper.

INTRODUCTION

While the author was resident in Tasmania, a detailed petrographic study was made of the Cambrian volcanic rocks of the State and the results were submitted to the University of Tasmania as a thesis for the degree of Doctor of Philosophy in 1952. Several papers have already been published on this work (Scott, 1952), but after leaving Tasmania it was thought necessary to publish a general summary of the whole study even though the interpretations may not be conclusive.

Much confusion exists in the literature dealing with the volcanics of the West Coast of Tasmania. The igneous rocks have been referred to as porphyroids, keratophyres, quartz and feldspar porphyries, andesites, melaphyres and syenites. The present author believes that the greater part of the volcanics was essentially basic in composition, probably basalts and porphyritic basalts, with or without amygdales, and their corresponding pyroclastics. The rocks which are seen to-day are the metamorphic products of these. The varying nature and extent of the metamorphism have yielded a great diversity of rock types. It was probably because of an incomplete understanding of the metamorphic processes which were operative that the confusion in terminology arose.

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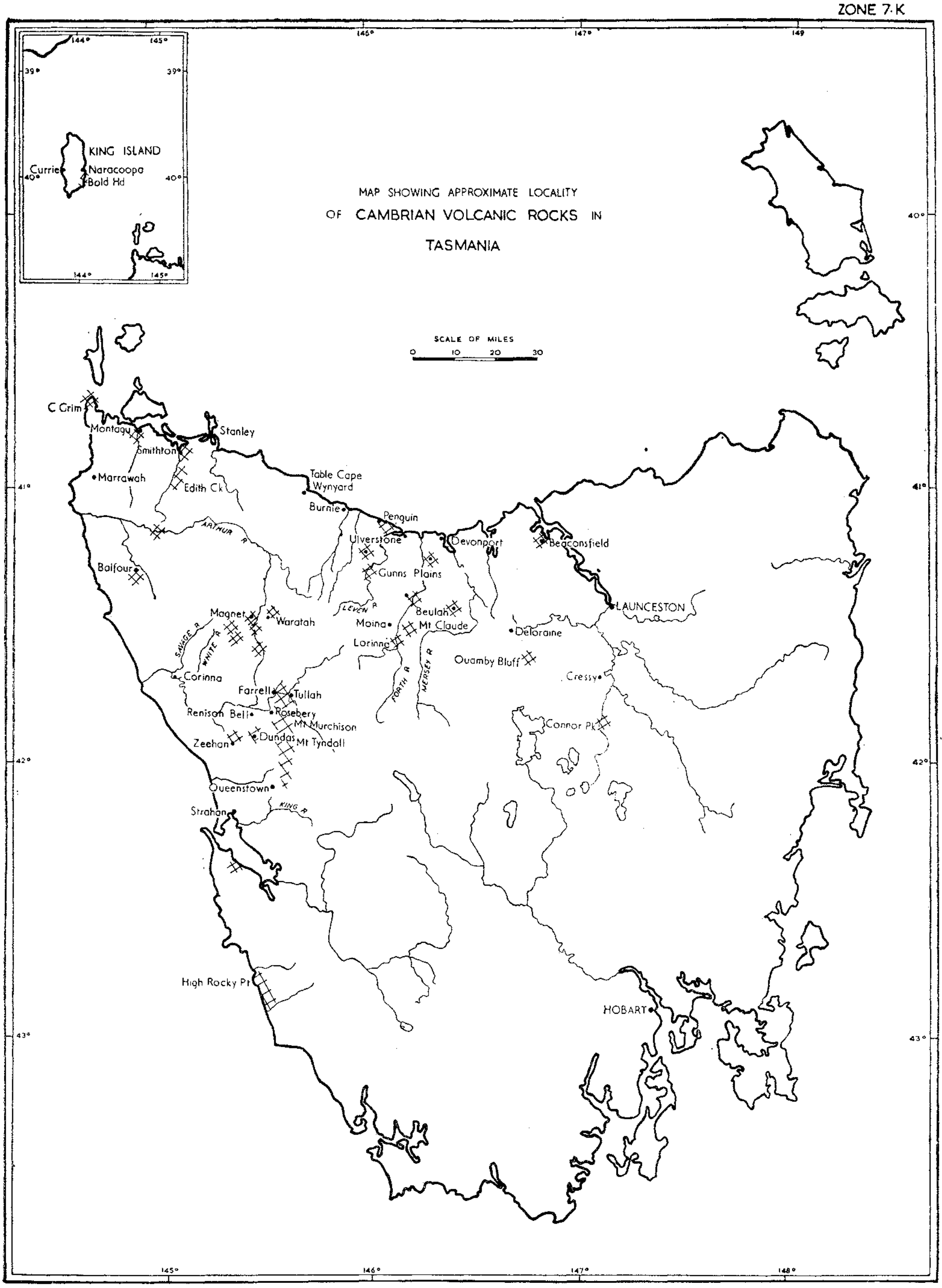

Figure 1

FIGURE 1.—Map showing approximate locality of Cambrian Volcanic Rocks in Tasmania.

Distribution of the Volcanic Rocks

As indicated in figure I these ancient volcanic rocks outcrop intermittently along a belt some 30 to 40 miles in width. This trends in a northerly direction for about 100 miles from High Rocky Point on the south-west coast, through Double Cove on the southern shore of Macquarie Harbour, the Jukes-Darwin District south of Queenstown, Zeehan, Dundas, Rosebery, Mt. Farrell, Tullah and Waratah, thence trending north-east to the Dial Range, Penguin on the north coast and the Leven Gorge. From here it begins to swing south-east, the outer boundary being in the vicinity of Beaconsfield and the inner in the vicinity of Quamby Brook. About Cressy the group is concealed by overlying younger rocks. It seems that this broad band of volcanics trends around the stable Tyennan Block of Pre-Cambrian rocks.

About 30 miles west of Waratah is a narrower band of volcanic rocks. Its width would be in the order of two miles. It extends approximately in a northerly direction through Balfour to Smithton on the north-west coast of Tasmania. Most probably the volcanics of the south-east of King Island, which outcrop from Naracoopa in the north to the Grassy River in the south, belong to this belt. Very little is known about the country in between these bands. Petrologically the rocks in both are similar.

Closely allied with the volcanics are intrusions of basic and ultrabasic rocks which have been serpentinized to varying degrees.

Age and Thickness

The age most commonly given these rocks in the older literature is Cambro-Ordovician, although ages ranging from Cambrian to Devonian have been imposed. It now seems from the fossil evidence of Thomas and Henderson (1945) and Opik (1951), that the volcanics are of Middle Cambrian age.

Elliston's unpublished work on the Dundas District indicates that volcanic material of over 9000 feet in thickness makes up the Dundas Group (Middle Cambrian) in which the Curtin Davis Lavas of approximately 1000 feet in thickness occur. The author believes that most of these tuffs are not true pyroclastics but sedimentary rocks composed of a great deal of transported igneous material and belong to the greywacke suite, as defined by Pettijohn (1949).

Petrography

It is often difficult to determine the original nature of the rocks because of abundant silicification and chloritisation which have affected them. From examination of the least altered specimens, however, it seems that the following types are present.

LAVAS:

Picrite Basalt: At Beaconsfield are lavas which are similar to the picrite basalts of King Island (Scott, 1951). A slide of a specimen, labelled " Western Tasmanian Copper Mine at Beaconsfield " shows phenocrysts of olivine now pseudomorphed by calcite and iron ore. The olivine can be recognised by its crystal outline and irregular cracks along which occurs iron ore. The olivine pseudomorphs show irregularly developed glomeroporphyritic texture. The groundmass is fine grained and contains tremolite needles. Veins containing quartz and calcite traverse the rock.

Porphyritic Pyroxene Basalt: Along Lynch Creek, south of Queenstown, are to be found two fairly thick beds of volcanics. The lower flow is akin to the amygdaloidal Montana Melaphyre or Spilite while the upper flow with its associated breccia is quite different. Even in the greenish-grey coloured hand specimen large idiomorphic phenocrysts of pyroxene can be seen. Under the microscope these phenocrysts exhibit multiple twinning and good cleavage. Sometimes smaller crystals are grouped together to give a glomeroporphyritic effect. The pyroxene is colourless, has an extinction angle of 50° (γ; c), double refraction of 0·030 and an optic axial angle, determined by means of the universal stage, of 52°. Its optical properties indicate a diopsidic augite. The chemical analysis given in Table I confirms the variety of diopside as a salite. Phenocrysts of albite up to 1 mm. in size are also present and show a combination of both multiple and simple twinning. Some of the albite shows alteration to sericite and some to chlorite. The groundmass is composed of laths of feldspar and granules of augite. Amygdales are rare but when present are lined with chlorite and quartz and filled with radiating prehnite or radiating albite with a little quartz.

Basalt: This is the most common type amongst the lavas. It is represented in the Zeehan district by the Montana Melaphyre or Spilite; at Groom's Slip near Penguin and in the Smithton district by a rock very similar to the massive lava of King Island (Scott, 1952). Blake (1936) states: " There is a general similarity between the dolerites of this district (i.e., district between the Mainwaring and Wanderer Rivers) and those found near Smithton in the north-west of the State, even to the inclusion of small flakes of native copper and patches of epidote.". Hence, it may be assumed that the Mainwaring River is another area in which the basalts are found. According to evidence gained from the study of slides it seems that similar rocks are also to be found at Magnet near Waratah, Heazlewood, Penguin, Leven Gorge, Mt. Claude, Mt. Ramsay, north of Mt. Chester, King River, Dundas and Double Cove. Most probably the basalt occurs elsewhere but generally what are found to-day are its silicified equivalents.

Microscopically the Montana Melaphyre is light-grey in colour and contains numerous ovate amygdales containing dark-green to black chlorite. These amygdales range in size from less than 1 mm. to almost 10 mm. in length while the average is about 2 mm. Traces of silicification are evident.

TABLE I—ANALYSES AND OPTICAL PROPERTIES OF PYROXENES

	a	b	c	d
SiO_2	48·53	50·23	45·86	48·77
Al_2O_3	7·10	5·29	8·30	4·18
Fe_2O_3	0·70	1·16	2·08	2·03
FeO	5·71	4·48	7·03	9·34
MgO	15·99	14·74	12·65	12·48
CaO	21·24	20·50	20·23	20·49
Na_2O	n.dt.	0·70	0·68	0·51
K_2O	n.dt.	0·10	0·11	0·02
H_2O+	n.dt.	0·66	0·54	0·98 (H₂O+ and H₂O—)
$H_2O—$	n.dt.	0·03	0·02	
TiO_2	0·85	0·92	2·34	1·59
P_2O_5	n.dt.	0·05	0·05	nil
MnO	n.dt.	0·25	0·17	0·11
CO_2	n.dt.	0·68	0·20	—
	100·12	99·79	100·26	100·50
Optical Data—				
α	1·69 (dt. graph)	1·685	1·707	1·699
β	n.dt.	1·690	1·714	1·706
γ	1·72 (dt. graph)	1·706	1·727	1·722
$\gamma—\alpha$	0·030	0·021	0·020	0·023
2V(+)	51°	49°	38°	52°
γ; c	50°	53°	55°	44°
Sp. Gr.	3·307	—	—	—
Atomic %—				
Ca	46·7	47·5	48·3	46·8
Mg	42·3	43·4	36·6	34·2
Fe	11·0	9·1	15·1	19·0

a. Pyroxene from Lynch Creek Lava, South Queenstown, Tasmania. Anal. B. Scott.
b. Pyroxene from olivine basalt (Lower Carb.) from Old Pallas area, Co. Limerick. Ashby (1946), p. 196.
c. Pyroxene from olivine basalt (Lower Carb.) from Old Pallas area, Co. Limerick. Ashby (1946), p. 196.
d. Pyroxene from trachybasalt (Lower Carb.) from Old Pallas area, Co. Limerick. Ashby (1946), p. 196.

TABLE II—FORMULA OF PYROXENE

Z	Si	1·785
	Al	0·215
Y	Al	0·094
	Ti	0·022
	Fe‴	0·018
	Fe″	0·174
	Mg	0·883
X	Ca	0·839

i.e., Z = 2·00, XY = 2·030

or

$$Ca_{0\cdot839}\ (Al, Ti, Fe''', Fe'', Mg)_{1\cdot191}\ (Si, Al)_2O_6$$

Similar rocks occur at Beulah, Beaconsfield and Mackintosh River. Perhaps the augite porphyrite at Smithton described by Nye, Finucane and Blake (1934) would also belong to this group.

Microscopically the rock consists of numerous lath shaped crystals of feldspar up to 0·5 mm. long which have been stained brown. The remainder of the rock is composed of small patches of carbonate, chlorite, quartz and fine acicular crystals and tiny grains of iron ore. No primary ferromagnesian mineral is present and it appears to have been replaced by the carbonate and quartz. Under very high power tiny pseudomorphs of chlorite after olivine were observed, the identification of olivine being based on crystal outline only. The feldspar is now albite and generally shows no twinning. It is partly altered to carbonate, chlorite and quartz and sometimes is surrounded by very small granules of iron ore. The amygdales are usually filled with chlorite, often with a concentric arrangement, or calcite. In some cases the amygdales are lined with chlorite and then filled with calcite, while the two minerals may occur together, concentrically arranged. Quartz, too, is known to occur with these minerals in the amygdales. Related rocks differ from this general description by the presence of abundant chlorite with a little quartz and/or calcite filling the interspaces between the feldspar laths. Granules of sphene and ilmenite are quite common. Sometimes the pyroxene has been replaced by green pleochroic hornblende with some chlorite while in rocks from localities such as King Island, Smithton and Penguin fresh pyroxene still remains. When altered, it has been attacked around the edges and along the cleavage and changed to a brown unidentified material and green chlorite.

Porphyritic Basalt: This appears to be a common rock type in the Magnet district and resembles the melaphyre to some extent. It is often amygdaloidal and contains large tabular phenocrysts of albite up to 3 mm. in length which are now partly sericitized.

The Curtin Davis Lavas which are well exposed near the Montezuma Falls near Dundas belong to this group. As well as being porphyritic they are amygdaloidal. The phenocrysts of feldspar which are idiomorphic to subidiomorphic have been replaced by chlorite, carbonate and quartz while the groundmass which once perhaps consisted of laths of plagioclase and granules of augite, now has its minerals replaced by chlorite, quartz and carbonate in different proportions. When the rock has been slightly sheared and more silicified and chloritized it is difficult to distinguish the phenocrysts from the groundmass under crossed nicols.

Glassy Basalt: Evidence of the existence of glassy lavas is revealed throughout the West Coast. The breccias and tuffs commonly contain fragments of devitrified glass.

In the Leven Gorge there are flow rocks which were once glassy. They contain a few laths and skeletal phenocrysts of feldspar up to 8 mm. in length. In some specimens the feldspar has been silicified while in others it is sericitized. The groundmass is extremely fine grained and its constituents are almost irresolvable but seem to be chlorite, feldspar and iron ore. In one specimen the devitrification has caused the appearance of spherulitic structure.

Feldspathic Basalt: Occurring in the Smithton District and Leven Gorge are very feldspathic basalts consisting of laths of albite (Ab_{95}) up to 0·5 mm. in length. The albite shows good multiple twinning and some crystals show interpenetration twins. The edges of the laths have a nibbled appearance. Between the feldspar is a little quartz and chlorite. A few granules of sphene and ilmenite are present. Sometimes the rock is slightly porphyritic when some of the larger crystals of albite form phenocrysts.

With an increase in chlorite and iron ore this rock passes into the normal basalts and all gradations between the feldspathic basalt and true basalt exist. It may be that the Montana Melaphyre is more closely related to this group than the more basic basalts.

PYROCLASTIC ROCKS:

Extensive developments of tuffs and breccias from localities throughout the West Coast have been described in the bulletins of the Geological Survey of Tasmania. However, in light of recent detailed work on the rocks in this district which has revealed great quantities of greywackes, it may be that most of the tuffs and breccias described by the earlier workers should be classed as greywackes.

Wherever the lavas were examined in the field, the author found evidence of pyroclastic rocks in the form of tuffs and breccias. These have been described from King Island (Scott, 1951), and volcanic breccias and bombs have been described from Smithton (Carey and Scott, 1952).

Breccias occur along Lynch Creek, South Queenstown, and along the Trial Harbour Road at Zeehan. In the former locality the breccia is composed of numerous fragments of volcanic rock, up to three inches in size, which have been caught up in the lava. The fragments contain idiomorphic phenocrysts of feldspar, now pseudomorphed by sericite, together with a fresh pyroxene set in a devitrified glassy groundmass. Amygdales are filled with quartz, chlorite and a little sericite. The fragments appear to be the glassy equivalents of the lavas and represent portions of a quickly chilled upper surface of the lava flow which were caught up in the body of the lava after the chilled crust had been fractured by pressure from the flowing lava. At Zeehan a somewhat similar rock occurs. Associated with flows of the very amygdaloidal melaphyre is a breccia which is composed of fragments of melaphyre within melaphyre. In spite of their brecciated appearance the term breccia is not strictly applicable to these rocks as they are really lavas containing numerous cognate xenoliths.

Most of the breccias and tuffs examined by the author consist of fragments of quartz, plagioclase (which, wherever determined proved to be albite), and basic lava, some of which has been glassy, set in a fine grained matrix which is generally feldspathic and siliceous showing patches of carbonate and chlorite and grains of iron ore, either magnetite or ilmenite.

Nye, Finucane and Blake (1934) describe a tuff from Duck Bay, Smithton. Nye (1923) describes two varieties in the Waratah district; a feldspathic breccia without mica and a micaceous breccia interbedded with slate. Nye, Finucane and Blake (1934) record the occurrence of similar breccias in the Smithton district but state that instead of these two distinctive types being present there are gradations between the two.

DYKE ROCKS:

Earlier writers such as Twelvetrees (1900), Nye (1923) and (1931), and Nye, Finucane and Blake (1934) regarded large occurrences of the volcanic suite as dolerite dykes.

The work of Nye, Finucane and Blake on the Smithton dyke has been reinterpreted by Carey and Scott (1952) who now regard the dyke as a suite of extrusive volcanic rocks including pillow lavas and volcanic breccias. Likewise in a recent publication by Scott (1952), the dolerite of Lower Palaeozoic age reported by Nye (1931) from Groom's Slip near Penguin has been reinterpreted as portion of the volcanic suite on the basis of the occurrence of pillow lavas and their association with tillite (?) and finely laminated shales.

Twelvetrees (1900) and later Nye (1923) described the Magnet Dyke which outcrops for about five miles in a north easterly-south westerly direction a few miles west of Waratah. The dyke, according to the writers, has an average thickness of about 200 feet and is very complex. It consists of " websterite porphyrite " which has been dolomitized towards the eastern margin, then " diabase porphyrite " which contains bands of " variolite " followed by " spherulitic websterite porphyrite ". Inclusions of slates and quartzites belonging to the " Bischoff Series " have been described by Nye (1923) as occurring in the dyke between the " websterite " on the east and the " diabase porphyrite ". This dyke was a problem to the writers as they were puzzled about the relationship of the " diabase porphyrite " to the " websterite porphyrite ". The conclusion reached was that the " variolite " was probably a magmatic variation of the " diabase porphyrite ", which was intruded along a fault plane in the earlier intruded " websterite porphyrite ".

After reading the literature and examining many slides of the rocks from the Magnet Dyke in the collections of the Mines Department and University, the author doubts the validity of the interpretation of the diabase porphyrite as a dyke for the following reasons:—

1. The outcrop of the alleged dyke lies in the general belt of known volcanic rocks of the West Coast.
2. There is general petrographical similarity with known volcanic rocks (e.g., Montana Melaphyre, King Island lavas, &c.) based on the—
    - (i) general fine grained basaltic appearance as well as the existence of coarser varieties, as elsewhere.
    - (ii) abundance of amygdales which seems too great to be consistent with an interpretation as a dyke rock.
    - (iii) hydrothermal alteration similar to the Montana Melaphyre, even to the formation of spherulitic quartz rock.
3. The presence of volcanic breccia.

Twelvetrees (1900) reports " Subsequent to the middle Silurian, basic and ultrabasic eruptions or intrusions took place, penetrating and displacing the buried sedimentary strata, and forming subterranean masses and dykes of gabbro, peridotite and pyroxenite. There is no evidence that these deep seated eruptions ever reached the surface, for we see no ancient basalts in this area, unless the diabase porphyrite at the Magnet Mine is regarded as a lava sheet." The diagram in this report shows the diabase porphyrite is concordant with the associated sediments.

Dense secondary growth of vegetation now renders the area almost impenetrable and obscures the outcrops and although most of the rock types recorded by the earlier writers were found by the author, it was impossible to establish their relationship with each other. It must be remembered that the slides examined by the present author were cut from rocks brought out from the workings during mining operations. Most of the information stated by Twelvetrees and later reproduced by Nye was gained from the observations in the adits.

During an examination of the area the author found no conclusive evidence but the petrological evidence indicates that the dyke is a portion of the volcanic suite.

Associated with the volcanic rocks in most areas where they outcrop is what older writers have termed diabase. To use modern nomenclature, this dolerite is probably the hypabyssal equivalent of the basalts and occurs as cognate dykes and sills. As in the volcanic rocks the plagioclase has been greatly altered to albite, chlorite and sericite. The augite is often fresh but when altered the alteration product is usually chlorite and very occasionally hornblende as in the Leven Gorge dolerites.

Hydrothermal Alteration

The outstanding feature of these old Cambrian volcanic rocks is their hydrothermal alteration which has given rise to a variety of rock types, some of which are quite unusual and are described below. The chief types of alteration seem to have been albitization, silicification and chloritization.

Albitized Basalt.

This is the simplest rock type developed. As on King Island, at Smithton and Penguin it is quite common to find the pyroxene practically unaltered. The only major form of alteration is the albitization of the plagioclase which may also show partial alteration to sericite and chlorite.

Albitized and Chloritized Basalt.

In this basalt the plagioclase has been converted to albite and the pyroxene to green chlorite which now occupies the spaces between the albite laths. The albite often shows further alteration to sericite and chlorite while the chlorite is often accompanied by granules of sphene. Sometimes quartz with needles of tremolite may be observed in association.

Silicified, Carbonated and Chloritized Basalt.

A very amygdaloidal basalt from Magnet has been completely changed to a rock containing quartz, carbonate and chlorite while the circular amygdales have been filled with chlorite. Not one of the original constituents remains.

Siliceous Spherulitic Rock.

Siliceous spherulitic rocks are known from the Montana area at Zeehan. Boulders have also been found in the Castray River, a tributary of the Pieman, and in the Arthur River where it is crossed by the Magnet " dyke ", indicating that the same rock may also crop out some 30 miles north of Zeehan. Twelvetrees and Ward (1910) gave a description of the occurrence on Montana Flat. The author does not wish to redescribe the rock but to put forward a view as to the possible formation of the spherules. This view arises from the observation of a sequence of stages in the development of the spherules by examining a suite of closely related rocks in the vicinity.

A less silicified specimen found a few feet from the spherulitic rock in the same trench on the Montana Flat is very dark greyish green in colour with light coloured spherules, averaging about 5 mm. in diameter, scattered through it. In a thin section it is seen that small laths of feldspar are partially replaced by quartz and chlorite. Quartz is developed between the laths and seems to have taken on a feathery form and a tendency to spherulitic texture as illustrated in figure 1, plate I. Always accompanying the quartz is chlorite, probably pennine, which is also developed together with iron ore, sphene and quartz between the embryo spherules. Often iron ore outlines the pseudomorphs after the feldspar amongst the chlorite.

A similar rock, incorrectly named a chloritized actinolite schist from the Lucy River and also the variolite associated with the diabase porphyrite described by Twelvetrees (1900) in dealing with the so-called Magnet Dyke, were similar alteration products of the diabase porphyrite.

On pp. 83-85 of Bulletin 33 of the Geological Survey of Tasmania in a description of the ore body of the Old Jasper Mine, there is a reference to a "pseudo-amygdaloidal" variety of hypersthenite. No doubt the slide from the Mines Department labelled "Amygdaloidal pyroxenite" from No. 3 Adit of the Old Jasper Mine is an alteration of the old lavas. The white patches have taken on a form as in the spherulitic rock but the material in between is still mainly chlorite with some carbonate, quartz and albite. Some of the white nodular patches are of radiating albite which shows slight alteration to kaolin, good cleavage and multiple twinning.

Nye (1923) included in his report a detailed description of a microscope slide of the variolite by Professor Rosenbusch which was originally recorded by Twelvetrees in his report of 1900, hence redescription here seems unwarranted.

At Zeehan and Magnet this so-called variolite and the spherulitic rock are intimately related to the Montana Melaphyre and diabase porphyrite respectively, i.e., with old basalts, both amygdaloidal and porphyritic. The following is an outline of the suggested formation of the spherules:—

1. The spherulitic rock is probably derived from a more basic lava such as the Montana Melaphyre in which the first stage is the development of quartz, chlorite and sometimes carbonate between the feldspar laths, i.e., a break-down of the pyroxene.
2. The quartz takes on a feathery form with spherulitic tendency (figure 1, plate I) while the chlorite is pushed out to between the embryo spherules.

3. With the addition of more silica, complete spherules are developed with fringes of radiating quartz and with fine granular quartzitic material between. This is illustrated in figure 2, plate I.
4. The radiating fringes grow outwards from the spherules at the expense of the fine granular material which they incorporate. These fringes continue to grow until all the granular material has been consumed and a perfect spherule is developed in the area formerly occupied by the minute grains of quartz. Figure 1, plate II, illustrates this phenomenon.
5. In some cases the fine grained material increases in grain size and finally unites and at the same time the radiating fringes grow out. It has been noted, as indicated by figure 1, plate III, that at the junction of the two a crack develops.
6. Figure 2, plate III, illustrates the final development of the spherulitic rock which is the stage when all the spherules are close together with no granular material between them.

The formation of the secondary spherules represents an interesting case of silica metasomatism. Below are analyses (Table III) of rocks from different areas representing the various stages of alteration. It is assumed that the original lava was somewhat similar in composition to the least altered lavas of King Island. This is illustrated by the variation diagram (figure 2).

TABLE III

	I	II	III	IV
SiO_2	50·01	60·00	73·00	99·11
Al_2O_3	15·38	11·97	9·95	nil
Fe_2O_3	4·86	7·68	5·29	0·75
FeO	9·21	0·39	0·39	Tr.
MgO	5·85	6·50	3·84	nil
CaO	6·53	4·35	2·30	nil
CO_2	0·13	8·90	5·90	nil
FeS_2	—	0·24	0·57	nil
	—	100·03	101·24	99·86

I. Spilite (basaltic type), King Island, Tasmania. Anal. B. Scott.
II. & III. Variolite from Magnet Mine, Tasmania (different portions of same specimen). Anal. Geol. Surv. Lab. (Bulletin No. 33.)
IV. Spherulitic quartz rock, Montana Flat, Tasmania. Anal. B. Scott.

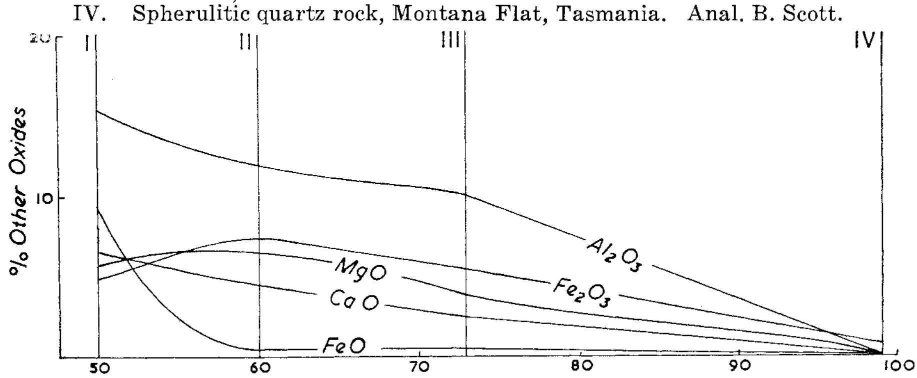

FIGURE 2.—Variation diagram showing development of secondary spherules in basic rocks.

Porphyries.

In numerous localities in the West Coast area are quartz, quartz feldspar, syenite and granite porphyries. They have been classified by various writers as being intrusive or metasomatic (i.e., metasomatically altered sediments and volcanic rocks). The author does not wish to deal with the formation of the porphyries in detail as this is being done by a colleague, Mr. J. Bradley, formerly of the Geology Department, University of Tasmania. She is only interested in them in so far as they are related to the volcanics.

There is undoubted evidence that some of the volcanic rocks, both lavas and associated pyroclastics, have given rise to the development of "porphyritic" (i.e., porphyroblastic) rocks. This, however, does not mean that all the porphyries were originally volcanic. In fact there is evidence of sediments being "porphyritized" too. The region of greatest development of these rocks is at Queenstown (Mt. Lyell) and Read-Rosebery district along the crest of the Porphyroid Anticlinorium.

The alteration begins by a replacement of the original rock by quartz and albite to form a very finely granular quartz albite mosaic rock. With further silicification some of the quartz grains seem to coalesce and eventually take on the appearance of a quartz "phenocryst" even to the extent of the development of well defined crystal faces (see figure 2, plate IV). It is not uncommon to find such idioblasts surrounded by very fine (finer than the groundmass material) granules of quartz as though the quartz had to be as fine as possible before it could be absorbed or "digested". Likewise, as soda metasomatism advances albite "phenocrysts" are developed from the minute granules of the groundmass.

Not only idioblastic quartz and albite but also hornblende seems to grow into well shaped porphyroblasts by a similar process. Specimens of rocks collected by Banks along the Tyndall Track near Lake Margaret were examined. According to Banks, the rock in the field shows evidence of flow structure in the alignment of hornblende "phenocrysts" and contains many cognate inclusions.

In the hand specimen the rock consists of idioblastic crystals of fresh hornblende up to half an inch in length, and smaller crystals of feldspar in a grey stony groundmass. On first appearance it could be classed as a hornblende andesite. In thin section the rock consists of these large idioblasts of green hornblende which show good cleavage, strong pleochroism and both simple and multiple twinning, abundant "phenocrysts" of plagioclase and a few of quartz and orthoclase in a fine grained groundmass. Observation of a number of slides indicates that the groundmass varies. Sometimes it is composed of tiny laths of feldspar with chlorite, carbonate and granules of sphene, in others it is predominantly feldspathic with some quartz while in still others it is predominantly quartzitic with some feldspar. With an increase in quartz in the groundmass there is an increase in quartz "phenocrysts". These quartz "phenocrysts" seem to be secondary and always show the "replacement borders". (See figure 1, plate IV.) The plagioclase is albite (approximately Ab_{95}) and shows slight alteration to sericite. Just how much of the plagioclase originally belonged to the lava and how much is secondary is impossible to say. The porphyritic lavas which are fairly common on the West Coast contain phenocrysts of both augite and plagioclase but there is evidence that some of the "phenocrysts" of albite are secondary. They too show the replacement border.

There is evidence to suggest that this rock did not originally crystallize as a hornblende andesite but as a porphyritic basic pyroxene lava (cf. Lynch Creek type) which has since been greatly altered. This evidence is given by the presence of augite which is in various stages of alteration. The first change appears to be in the formation of chlorite around the edge and along the cleavage planes and cracks of the augite. As alteration proceeds tiny granules of sphene, epidote and even a little iron ore are developed. A later stage is the complete pseudomorphism after the idiomorphic augite by chlorite and sphene. In the end stage hornblende is born out of these alteration products. The power of crystallization is apparently great because soon afterwards idioblastic crystals are developed. Sometimes patches of the unincorporated alteration products are left as inclusions or "embayments" in the hornblende and inclusions of idiomorphic albite crystals are quite numerous. It seems that the hornblende originated as tiny needles which gradually coalesced to give a plate of the mineral. Fringes of the hornblende which have a similar optical orientation to that of the idioblasts may be traced. In some cases hornblende is the direct alteration product of the augite and in ordinary transmitted light it is often difficult to distinguish it from chlorite with which it is closely associated. In fact, one mineral seems to merge imperceptibly into the other.

The mode of origin of this rock is very controversial. According to Hatch, Wells and Wells (1949), the hornblende of hornblende andesites is usually the brown "basaltic" variety and generally shows that it is not in equilibrium with the magma because all degrees of magmatic resorption are displayed. They say "At an early stage this may amount to no more than a slight 'peppering' with magnetite granules, but at a later stage of alteration the hornblende is progressively replaced by an aggregate chiefly consisting of granules of nearly colourless clinopyroxene and octohedra of magnetite". After critically examining thin sections of this rock the author is of the opinion that the reverse is true. The clinopyroxene, a stable diopside augite, is in keeping with the variety suggested as being typical of andesites.

The alignment of the hornblende "phenocrysts" is suggestive of a primary origin but the petrographical evidence is against this. The pyroxene which is usually stable shows more alteration than the usually less stable hornblende. The needles of hornblende, optically oriented similarly to the rest of the hornblende, cut across what some authorities would regard as the alteration products of the hornblende. If the hornblende is secondary after pyroxene then the pyroxene originally was oriented in the direction of flow. Only in a few places is the hornblende directly replacing pyroxene; more commonly it is formed by the metamorphism of alteration products of pyroxene (chlorite, epidote, &c.). If the pyroxene had been originally oriented, then the hornblende would have grown with the same direction, yet in most cases none of the original mineral was left to control the direction of growth of the new mineral.

Another suggestion is that the orientation of the hornblende crystals may be a metamorphic effect but the rocks in general do not exhibit structures indicative of dynamic metamorphism. According to Banks the direction of alignment is at an angle to the cleavage. If, as the author thinks, this rock is not a true hornblende andesite the orientation of the hornblende remains unexplained.

In the Mines Department is a slide, cut from a rock from the Que River, labelled " Feldspar Quartz Porphyry ". It is an interesting rock, because in the groundmass are remnants of the fine grained basaltic lava. Phenocrysts of both augite, some showing slight alteration to chlorite and epidote, and albite are present in a groundmass containing quartz, feldspar, chlorite and granules of sphene. A similar rock, which is amygdaloidal, occurs at Farrell Siding. In this case the pyroxene has been pseudomorphed by a carbonate or quartz and carbonate.

The author does not wish to be dogmatic and state that all the porphyries and porphyrites of the West Coast of Tasmania are of secondary origin. She does suggest, however, that those so-called " porphyroids " and augite porphyrites which contain phenocrysts of augite of the salite variety and albite with or without quartz in a feldspathic groundmass are to be suspected of having a secondary origin. Earlier workers have regarded rocks having albite and augite (both considered primary) as occurring in minor intrusions and representing the acid differentiate of the basic and ultrabasic rocks.

Keratophyres.

The terms porphyry, porphyroid, keratophyre and felsite have been indiscriminately applied in the past. Similar rocks have been given any of the above names. After examining many specimens and microscope slides of these rocks the author is at a loss to determine the criteria on which these distinctions were based. If the term porphyroid is used as it was originally meant then some of these rocks could correctly be referred to as porphyroids because many are sheared and some of the phenocrysts even have a " rolled out " appearance.

Twelvetrees and Petterd (1899) describe some of the felsites and associated rocks of the Mt. Read district. They considered the rocks to be lavas which were contemporaneous with the argillaceous sediments which are now converted to schists. These authors sent specimens to Professor Rosenbusch for confirmation of naming. The following description was returned " Undoubtedly we have here strongly dynamically altered forms of the acid eruptive rocks. The typical porphyritic structure, the nature of the phenocrysts, the still recognisable fluidal structure, the nearly entire absence of dark constituents, the occasional spherulitic forms still recognisable in their replacement products (quartz, albite) all point with certainty to members of the quartz porphyry family, and with great probability, not to quartz porphyry in the narrower sense, but to quartz keratophyre and keratophyre."

Ever since then similar rocks and even dissimilar associated rocks have been classed as one of the rock types mentioned above, without any other reason.

In summarizing their descriptions they say, " The rocks have a compact quartz-feldspathic (felsitic) groundmass, with quartz and orthoclase and albite phenocrysts, sometimes distributed sparingly, at other times so crowded as almost to lose the porphyritic stamp. In the typically porphyritic varieties are altered spherulites and signs of flow structure.".

In all the specimens examined by the author she failed to note spherulites (excluding the spherulitic quartz rock) or true flow structure. Actually the apparent flow structure is a pseudo flow effect and is very misleading. It is really a schistose structure as indicated by the direction of the sericite streaks. Often these streaks curve between the " phenocrysts " which, being brittle, commonly exhibit fracture although some of the feldspars have been " rolled-out ". In the field, the weathering of the schistose structure resembles flow structure but when sections of the rock are examined the schistose nature is readily recognised.

Diopside augite has been observed in some of the so-called keratophyres. Mawson and Dallwitz (1944) correlate similar rocks from south-eastern South Australia, in which pyroxene is present, with the Tasmanian porphyroids. To the author, the presence of such a pyroxene, and especially one of identical composition to that which is prevalent in the associated basaltic rocks, is anomalous. One would not expect to find such a pyroxene in keratophyres if they are soda rich trachytes.

The formation of these keratophyres seems to be similar to that of the porphyries outlined in the previous section. Some original acid volcanic rocks may have existed. If they did, it is now impossible to distinguish them from the highly metasomatized basaltic rocks. However, it is interesting to note that on King Island, at Smithton and Groom's Slip, near Penguin, where the least altered basaltic rocks occur, no acid eruptives comparable with a keratophyre have been found. Also, the keratophyres seem to be restricted to the zone of structural weakness where metasomatism has probably been at its maximum. It seems reasonable to suggest that if true acid volcanic differentiates existed, a trace of them would have been found with the freshest basaltic rocks.

Jasper.

Jasper bands are commonly associated with the lavas in most localities where they outcrop and have been recorded in the literature.

At Groom's Slip, just east of Penguin, where the lavas outcrop strongly along the coast, they are associated with regularly shaped blocks, bands and irregularly shaped patches of red jasper. Some of the bands are up to about eight feet in length and about one to two feet wide. The jasper is the usual red colour and is very finely crystalline. Sometimes it carries a considerable amount of pyrite and in places is associated with green epidote. Thureau (1881) noted the presence of " hornstone " and jasper at Penguin and Twelvetrees (1903) reports the occurrence of jasper from a shaft in the Heazlewood district.

As well as bands of jasper, abundant veins of quartz cut irregularly across the lavas in all localities.

The occurrence of jasper with basic lavas is not restricted to Tasmania. Skeats (1908) records the association of jasperoid material with the Heathcotian rocks in Victoria. In fact, the association of jasperoid rocks is reported from many localities in the world from which spilitic rocks are recorded.

The origin of these jasper rocks is not known. Skeats (1908) regards them as one of the forms of silicified "diabase". Because of the evidence of the formation of the spherulitic quartz rock, which is perhaps a modification of the jasper, the author is in agreement with Skeats and regards them as being the silicified equivalents of the old lavas, especially as they are associated with each other so intimately. In contrast to a number of writers who regard these thick extensive beds of chert with which spilitic lavas so frequently are associated as being precipitated from silica expelled from the lavas, the author believes that the lavas under discussion have gained silica from an extraneous source.

Nature and Origin of the Chemically Active Solutions.

In the paper on the volcanic rocks of King Island, the author dealt with the facts of the hydrothermal solutions as they presented themselves and drew conclusions from these. However, the study has been confined to a small area and later work which has been done on a broader area now indicates that the conclusions drawn from the King Island study do not hold in general for the Cambrian volcanic rocks of Tasmania.

As mentioned earlier, the predominant types of alteration are albitization, silicification and chloritization, and imply the addition of soda, silica and alumina. Many theories have been put forward to explain the origin of albite in spilitic rocks. The possible processes may be classed as primary, deuteric or secondary. For the albite to be of either primary or deuteric origin one must postulate a soda rich magma as in either case the soda belongs to the magma, whether it crystallized early in the form of a primary sodic plagioclase, or later, when in the form of a soda rich solution it affected the earlier plagioclase and converted it to albite. However, on the West Coast of Tasmania not only the lavas but their associated rocks appear to have been albitized so one must look further afield than the lavas for the source of soda. This fact is also borne out when the relative time of alteration is considered. Albite is the only plagioclase present in the lavas which are associated with a suite of greywackes also containing albite. In view of the mode of formation of greywackes, i.e., rapid erosion and deposition in a geosyncline, the albitization must have taken place either before the formation of the greywackes, in which case the albite was derived as such from the lavas, or after their deposition. Chlorite and other secondary minerals associated with the albite are abundant in the greywackes as in the lavas indicating that albitization followed deposition. It seems then that a secondary origin for the albite is assured.

Carey (pers. comm.) suggested to the author that the soda rich lavas on the West Coast of Tasmania (possibly spilites in general, the world over) were not derived from a soda rich magma but were normal basalts which were later albitized, the albitization being due to burial in a geosyncline. Other factors in the suggested alteration were the thickness of geosynclinal sediments underneath the original basalts, the temperature reached by the base of the sedimentary prism and the permeability distribution in the geosyncline, the temperature being considered the most important of all. It was also suggested that it was unnecessary to go beyond the geosynclinal rocks for an adequate supply of soda and silica. A redistribution of the normal content of these constituents in the sediments is sufficient. In the pre-eugeosynclinal phase of most geosynclines there may be appreciable thicknesses of orthoquartzites and other highly siliceous rocks which yield their surplus silica to subsequent migrant fluids. The soda content of the initial connate water seems sufficient to account for the albitization while the alumina could be an excess constituent from some of the pelitic sediments.

After careful consideration of the many possibilities as to the origin of the hydrothermal alteration, the author agrees that the soda metasomatism which has affected the basaltic rock is due to a geosynclinal environment. Although depth of burial may be an important factor, it does not entirely control the proportion of alteration. In the miogeosyncline of South Australia where the basalts of a somewhat similar age are associated with 40,000-50,000 feet of sediments they have only spilitic tendencies, yet in the eugeosyncline of Tasmania where the lavas are associated with 10,000 to 20,000 feet of sediments they have been completely albitized.

The solution could not have been above its critical temperature and pressure because of the assemblage of minerals produced. The assemblage of minerals—albite, chlorite, carbonate, quartz, &c.—developed as a result of metasomatism is not indicative of high temperature formation. It could be formed readily at temperatures below 300° C.

The formation of hydrogrossular, which is rather restricted, requires a higher temperature (see Scott, 1951) but on King Island where it is developed, the intrusion of granite of Middle Devonian age could perhaps account for the higher local conditions of temperature. The formation of hornblende in the porphyries and the lavas also possibly requires a slightly higher temperature. Petrographical evidence indicates that hornblende developed after the low temperature alteration so it may have been formed during the rising crescendo of the Tyennan (late Cambrian) Orogeny or, since it is developed most strongly in rocks along the structural weakness, any rise in the temperature below (possibly during the Tabberabberan Orogeny) could be transmitted readily to the rocks above.

Relationship of the Metasomatism to Geosynclinal Deposition and Orogeny

The group of sediments with which the volcanic rocks are associated is typical of eugeosynclinal deposition. The sediments were deposited in the Dundas Geosyncline which is peripheral to the Tyennan Block composed of Pre-Cambrian rocks (Carey, 1953, p. 1115). This geosyncline contains about 11,000 feet of Cambrian cherts, slates, conglomerates, volcanics and greywackes, the latter being derived for the most part by rapid erosion and deposition from the basic volcanic rocks. In addition to the Cambrian, there are, in the geosyncline, several thousand feet of Ordovician, Silurian and Lower Devonian strata.

The Tyennan uplift which commenced in the early Middle Cambrian and continued throughout the Upper Cambrian was coeval with the Dundas sedimentation, according to Carey (1953). It was probably during this orogeny, particularly in its latest stages when the accumulation of sediments was greatest, that metasomatism took place. The metasomatic alteration resulted in widespread albitization and silicification accompanied by other changes such as chloritization and epidotization which required additional alumina, no doubt provided from pelitic sediments. This metasomatic alteration was responsible for the formation of the spilitic rocks and porphyroids. The alteration was differential because the rocks are altered to various degrees. In places it has been so advanced as to give rise to the formation of granites (e.g., Darwin granite) and syenite such as in the Murchison Gorge south of Mt. Farrell. The greatest development of the " porphyroid " group is approximately along the crest of the West Coast Range anticlinorium which was rising during the last phases of the orogeny.

If a very general picture of the structure is considered, there appears to be a kind of zonal arrangement in the metasomatism of the lavas. These zones are as follows:

1. A zone along the Porphyroid Anticlinorium where soda metasomatism was predominant together with silicification resulting in the formation of the porphyries and keratophyres.
2. West of the zone, through Zeehan, Magnet and Leven Gorge is a zone where silica metasomatism predominated.
3. Further west still, through High Rocky Point, Smithton and King Island is a zone of very little alteration apart from albitization.

Evidence that this phase of metasomatism was completed before the deposition of the basal beds of the Junee Group (Lower Ordovician) is revealed by the presence of boulders of Darwin granite (reported by Hills, 1914) and " porphyroid " (verbal communication by Banks) in the West Coast Range Conglomerate.

However, there was another more violent period of orogeny, the Tabberabberan, of Middle Devonian age, which was also accompanied by a period of hydrothermal alteration. This period of alteration was responsible for the widespread silicification of the West Coast Range Conglomerate.

During the Tabberabberan Orogeny an important very deep shear, which in places has its surface expression in a fracture and elsewhere as a zone of overturned attenuated strata was developed, according to Carey (1953). This overturned and attenuated zone is associated with local sericitization and with numerous hydrothermal ore bodies.

The so-called hornblende andesite from the Tyndall Range near Lake Margaret is very close to this shear zone. It is possible that the development of the hornblende which, as indicated in a previous section, probably needed a slightly higher temperature of formation and followed the low temperature alteration, may belong to this second period of metasomatism.

Most probably the earlier formed porphyroids suffered further alteration and shearing. Two periods of alteration are suggested by petrographic evidence and it is interesting to note that the second period gave rise to the development of more quartz than albite.

Carey (1953) is inclined to believe that the silicification of the lavas in the Zeehan-Magnet district took place during the Tabberabberan Orogeny. Certainly, this and the silicification of the lavas to jaspers near Penguin (found since the writing of Carey's paper), fit into his structural pattern, but apart from this the author has no definite evidence to indicate to which orogeny it belongs. Since silicification is a common phenomenon associated with spilites elsewhere in the world she is inclined to think it may belong to the Tyennan Orogeny, thus completing the "spilitization" in the one period.

Summary and Conclusions

An attempt has been made to elucidate the nature and metamorphism of the Cambrian volcanic rocks of Tasmania which outcrop predominantly over a wide area on the West Coast of Tasmania and along the south-east coast of King Island.

The most important points to be drawn from the study are as follows:

1. The volcanics comprise a spilitic suite consisting of picrite basalts, spilites, keratophyres, albite dolerites and associated pyroclastics which were erupted into the Dundas Eugeosyncline during the Middle Cambrian.
2. The magma, when erupted, was not soda rich. The association of greywackes, porphyries and keratophyres (developed from sedimentary and volcanic rocks) containing albite, points to a secondary origin for the albite.
3. Hydrothermal alteration is prevalent with albitization, silicification and chloritization indicating an enrichment in soda, silica and alumina. The mineral assemblage developed indicates low temperature conditions, although the formation of hydrogrossular and possibly hornblende indicate locally higher temperatures.
4. Silicification is revealed by the abundance of secondary quartz in the lavas, together with the formation of jasper and spherulitic quartz rock.
5. Soda and silica metasomatism of the lavas along a major geanticlinal structure has given rise to the formation of a variety of porphyries and possibly keratophyres.
6. The chemically active solutions which caused the hydrothermal alteration were activated by heat and movement during the Tyennan Orogeny (Late Cambrian) giving rise to metasomatism which affected the lavas. The Tabberabberan Orogeny (Middle Devonian) was responsible for further alteration of the "porphyroids" and possibly the development of the hydrogrossular on King Island and hornblende on the Tyndall Range.

7. The formation of the spilitic suite was from normal basic lavas and was due to the geosynclinal environment. It was activated primarily by heat and crustal movement.
8. The necessary supply of soda, silica and alumina came from a redistribution of the normal content of these constituents in the sediments of the geosyncline.

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LOCALITY INDEX

Locality	*Quadrangle*	*Latitude S*	*Longitude E*
Arthur River	Magnet 35	41° 28′	145° 27′
Balfour	Balfour 34	41° 16′	144° 55′
Beaconsfield	Beaconsfield 30	41° 11′	146° 45′
Beulah	Sheffield 37	41° 26′	146° 24′
Castray River	Corinna 43	41° 32′	145° 20′
Comstock	Lyell 58	42° 02′	145° 39′
Cradle Mt.	Mackintosh 44	41° 40′	145° 57′
Cressy	Longford 47	41° 40′	147° 08′
Dial Range	Devonport 29	41° 11′	146° 01′
Double Cove	Macquarie Hbr. 64	42° 20′	145° 20′
Duck Bay	Smithton 21	40° 50′	145° 04′
Dundas	Zeehan 50	41° 53′	145° 28′
Grassy River	S.E. King Island 1	40° 02′	144° 04′
Groom's Slip	Devonport 29	41° 07′	146° 06′
Heazlewood	Magnet 35	41° 30′	145° 18′
High Rocky Point	Mongomery 78	42° 46′	145° 23′
King Island	———	40° 00′	144° 00′
King River	Strahan 57	42° 10′	145° 30′
Lake Margaret	Murchison 51	42° 01′	145° 37′
Leven Gorge	Devonport 29	41° 15′	146° 10′
Lucy River	Corinna 43	41° 37′	145° 07′
Lynch Creek	Lyell 58	42° 07′	145° 33′
Mackintosh River	Mackintosh 44	41° 43′	145° 37′
Macquarie Harbour	Macquarie Hbr. 64	42° 15′	145° 25′
Magnet	Magnet 35	41° 28′	145° 26′
Mainwaring River	Rocky Point 79	42° 49′	145° 32′
Montana	Zeehan 50	41° 51′	145° 17′
Montezuma Falls	Zeehan 50	41° 51′	145° 27′
Mt. Chester	Mackintosh 44	41° 42′	145° 32′
Mt. Claude	Sheffield 37	41° 30′	146° 12′
Mt. Darwin	Lyell 58	42° 16′	145° 36′
Mt. Farrell	Mackintosh 44	41° 44′	145° 34′
Mt. Jukes	Lyell 58	42° 11′	145° 36′
Mt. Lyell	Lyell 58	42° 03′	145° 37′
Mt. Ramsay	Corinna 43	41° 36′	145° 27′
Mt. Read	Murchison 51	41° 53′	145° 33′
Murchison River	Murchison 51	41° 51′	145° 42′
Naracoopa	Sea Elephant 6	39° 54′	144° 06′
Penguin	Devonport 29	41° 07′	146° 06′
Port Davey	Davey 91	43° 20′	145° 55′
Quamby Brook	Quamby 46	41° 33′	146° 47′
Que River	Mackintosh 44	41° 36′	145° 31′
Queenstown	Lyell 58	42° 05′	145° 33′
Red Hills	Murchison 51	41° 00′	145° 33′
Rosebery	Murchison 51	41° 47′	145° 33′
Smithton	Smithton 21	40° 41′	145° 06′
Tullah	Mackintosh 44	41° 43′	145° 38′
Tyndall Range	Murchison 51	41° 56′	145° 38′
Wanderer River	Point Hibbs 71	42° 43′	145° 25′
Waratah	Valentines Peak 36	41° 26′	145° 31′
Zeehan	Zeehan 50	41° 53′	145° 21′

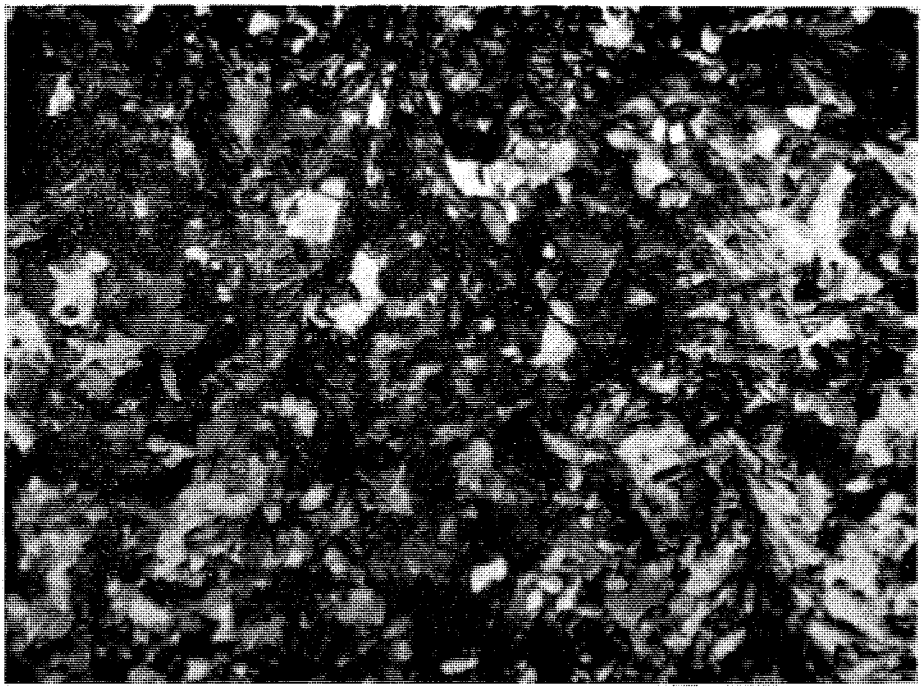

PLATE I.—This and the following plates illustrate the various stages in the development of the secondary spherules of quartz:

FIGURE 1.—Illustrates one of the first stages in the development of the spherules. The quartz is beginning to take on a feathery form. The bulk of the mineral grains in this figure is of quartz with a few altered feldspar laths and some chlorite.

FIGURE 2.—The space between the spherules is filled with very fine granular quartz. Note the narrow radial fringe of quartz around the margins of the spherules.

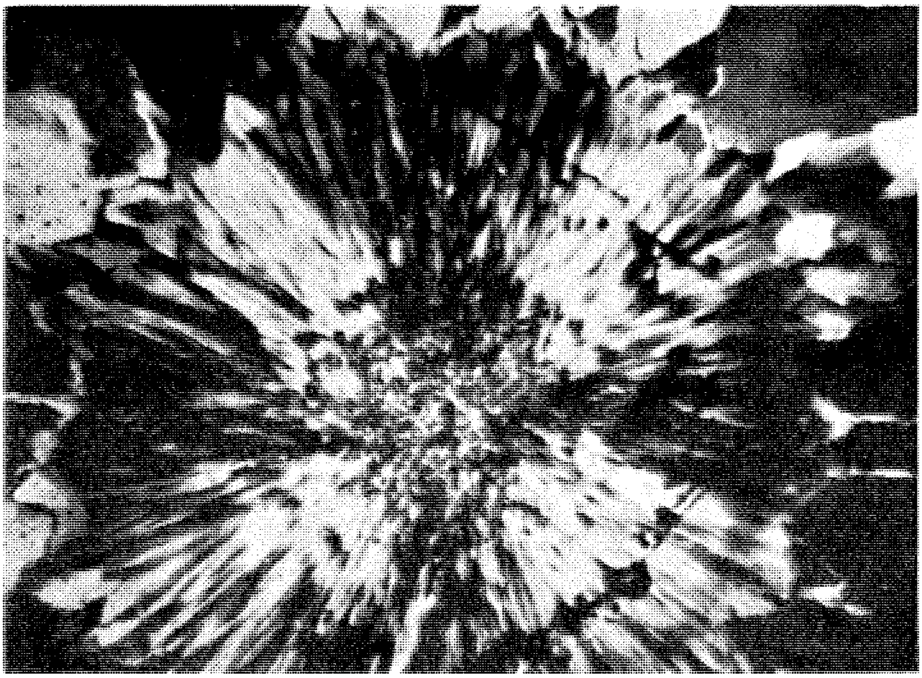

FIGURE 1.—Shows the development of the radial fringes of quartz (see figure 2) at the expense of the fine granular material, some of which is still to be seen in the centre of the newly developed spherule.

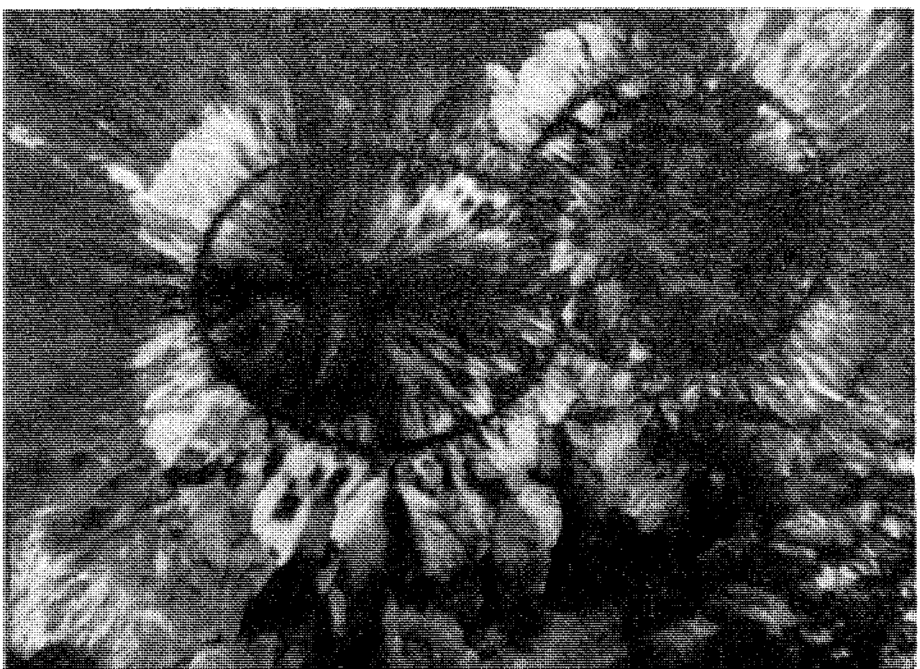

FIGURE 2.—In this case the fine grained material increased in grain size and at the same time the radiating fringes grew out. At the junction of the two a circular crack developed.

PLATE III

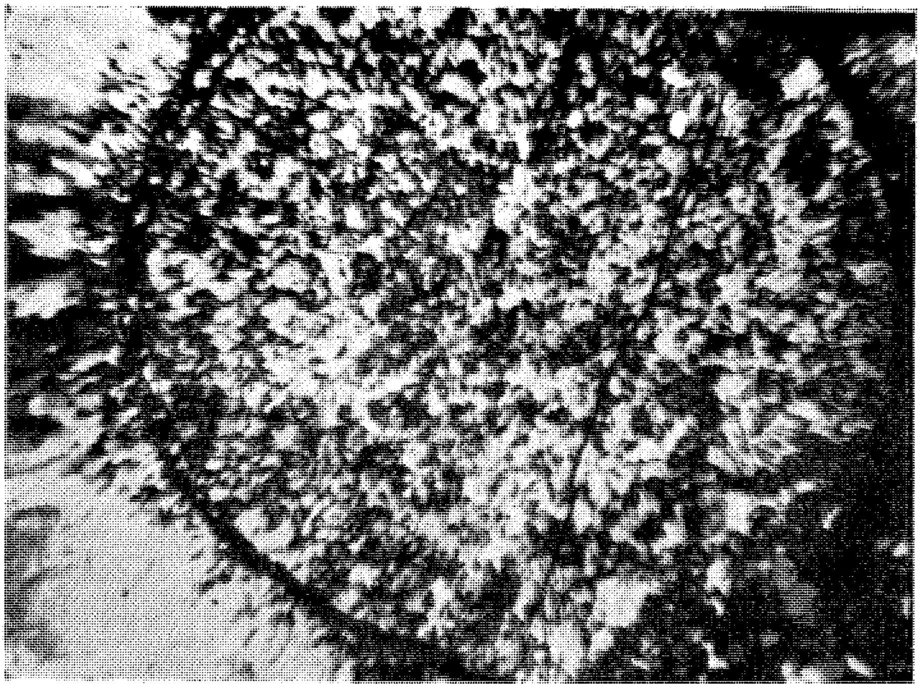

FIGURE 1.—Illustrates the formation of two spherules which began to grow from the inside as well as the outside resulting in the formation of a crack where the two met.

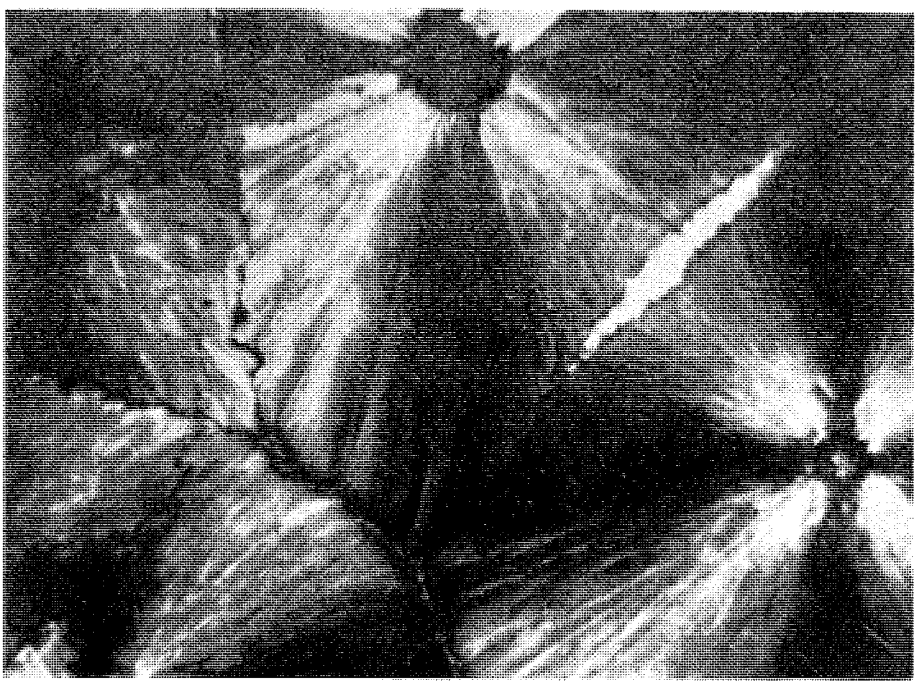

FIGURE 2.—Illustrates the final stage when the whole rock has been converted to a mass of spherules with very little or no granular material between them.

Plate IV

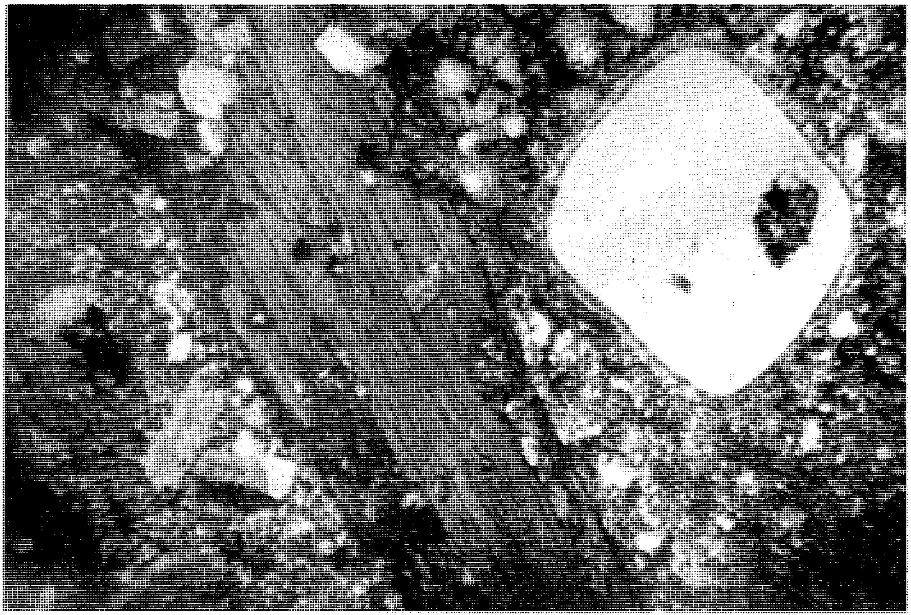

Figure 1.—Idioblast of quartz in the hornblende andesite (?) showing the fine grained "replacement border" and inclusions of the groundmass.

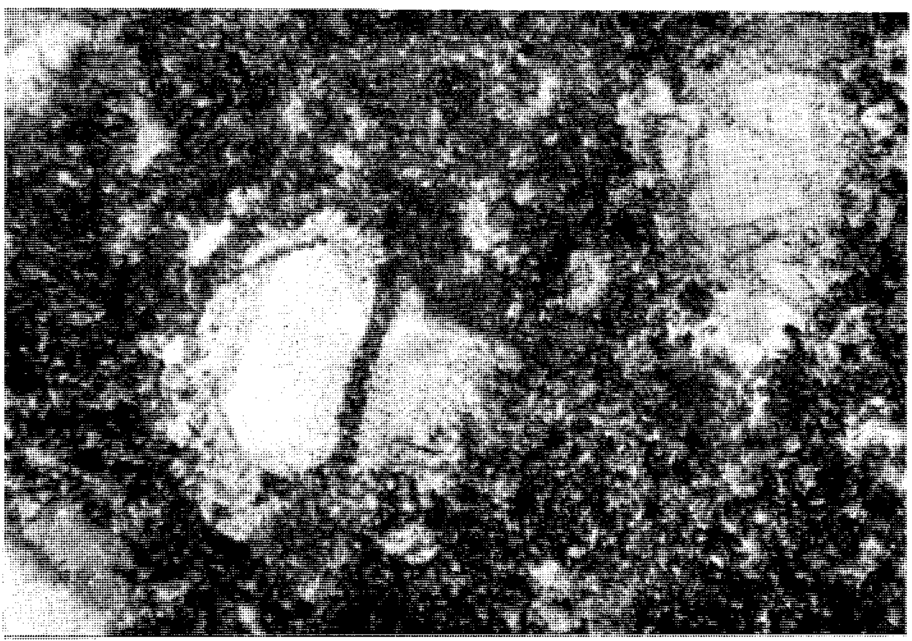

Figure 2.—Idioblasts of quartz growing out of patches of quartz in the groundmass of a porphyroid from Dundas.