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THE GEOLOGY OF THE MT. BISCHOFF DISTRICT

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(With two plates and seven text figures)

ABSTRACT

The basement rocks of the area are the Upper Precambrian (?) Bischoff quartzites and slates, which comprise a 2000 ft. succession of quartzites and sheared mudstones with a bed of dolomite in the upper part of the succession. These sediments have undergone considerable deformation during the pre-Cambrian and/or early Cambrian but show apparent conformity with the overlying mudstones, sandstones, greywackes, volcanic breccias and spilitic lavas of Cambrian (?) age. Late in the Cambrian, ultrabasic and basic dykes were intruded.

The Precambrian (?) and Cambrian (?) rocks were folded into a westerly plunging anticlinorium, with smaller subparallel folds on the limbs. These are distorted by small ENE folds and NNW faults. A granitic body underlies the area and radiating quartz porphyry dykes probably associated with a local, narrow cupola intrude the core of the anticlinorium at Mt. Bischoff. Greisenization of the porphyries is extreme, with the formation of topaz, tourmaline, muscovite, and cassiterite pseudomorphing primary feldspar. Mineralisation associated with igneous activity has resulted in selective replacement of the dolomite bed at Mt. Bischoff by iron sulphides, talc, quartz, carbonate and cassiterite, and the filling of tension fissures throughout the area. A zonation of mineral deposition around Mt. Bischoff is suggested by a nucleus of tin mineralisation with an outer rim of lead-zinc mineralisation. By analogy with other areas in Tasmania the folding, granitic intrusion and associated mineralisation are considered to have occurred during the Tabberabberan Orogeny (Middle Devonian).

Tertiary terrestrial sediments and basalts unconformably overlie older rocks and form a widespread plateau.

PHYSIOGRAPHY

The dominant topographic feature of the Waratah area is an extensive dissected plateau lying at an altitude of 2000 to 2100 feet. This gently undulating plateau is underlain by flat-lying, non-marine, Tertiary sediments and basalt to a depth not exceeding 150 feet, indicating an original Tertiary land surface at an elevation of about 1900 to 2000 feet. The plateau extends down to an altitude of about 1800 feet to the west of the Mt. Cleveland Range and rises to 2200 feet in the north-eastern and central section of the Mackintosh area. Inland from there, a series of accordant summits lie between 3000 and 3500 feet, this level corresponding in elevation to the Lower Plateau Surface of Davies (1959).

Rising above this plateau area are several residual mountains including Mt. Bischoff (2598 feet), Mt. Cleveland (3200 feet), Mt. Meredith (2500 feet), Mt. Ramsay (3890 feet), St. Valentine Peak (3640 feet) and Mt. Pearse (3000 feet). These mountains owe their prominence and shape to the rock types of which they are composed; for example the shape of Mt. Bischoff is conditioned by the distribution of the porphyry dykes, Mt. Cleveland has a resistant backbone of Cambrian chert, and the arcuate form of Mt. Pearse reflects a plunging syncline in Owen Conglomerate.

Two main drainage systems have developed since the uplift of the land surface that followed pre-basalt peneplanation; these are the Pieman and Arthur River systems. The Pieman follows a westerly course some 30 miles to the south of Waratah while the Arthur rises in the Waratah District, flows northerly for 35 miles and then westerly, emerging at the coast about 50 miles north of the Pieman River. The Magnet Range forms the watershed between the tributaries of these two rivers, the Whyte River flowing westerly to the Pieman while Magnet Creek and its tributaries join the Arthur River to the east (Fig. 1). The streams generally meander slowly to the margins of the plateau, from which they fall in a series of rapids and small waterfalls to the valley floors some 800 to 900 feet below. Some structural control is suggested for the course of the Waratah River, the river trending just east of north and then swinging sharply to just north of west (Fig. 2); these directions may represent Tertiary structural lines.

In general, the Waratah area can be described topographically as comprising an extensive, deeply dissected plateau area, with sporadic monadnocks rising some 1000 feet above plateau level.

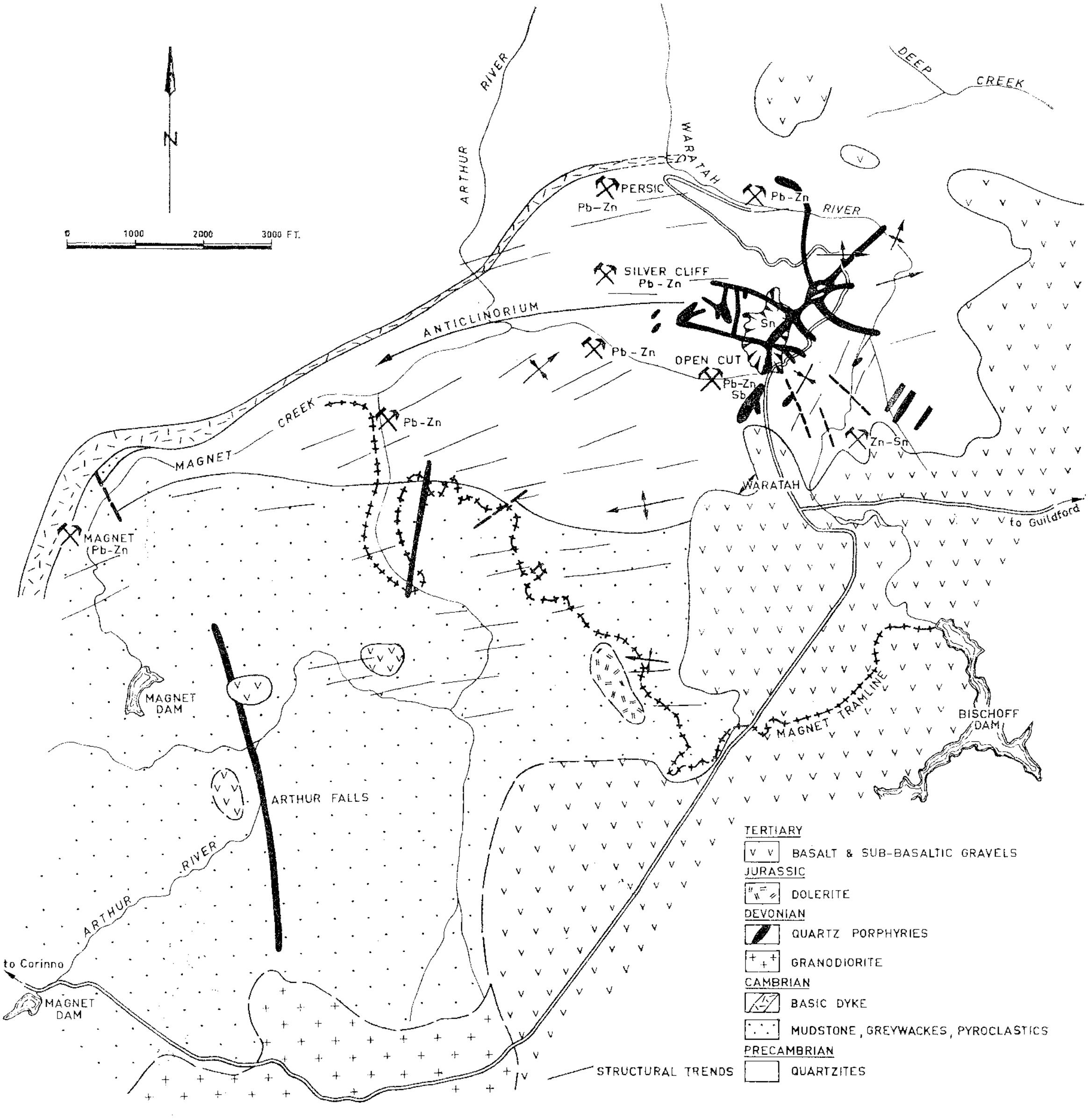

FIG. 1.—Sketch map of the Mt. Bischoff district.

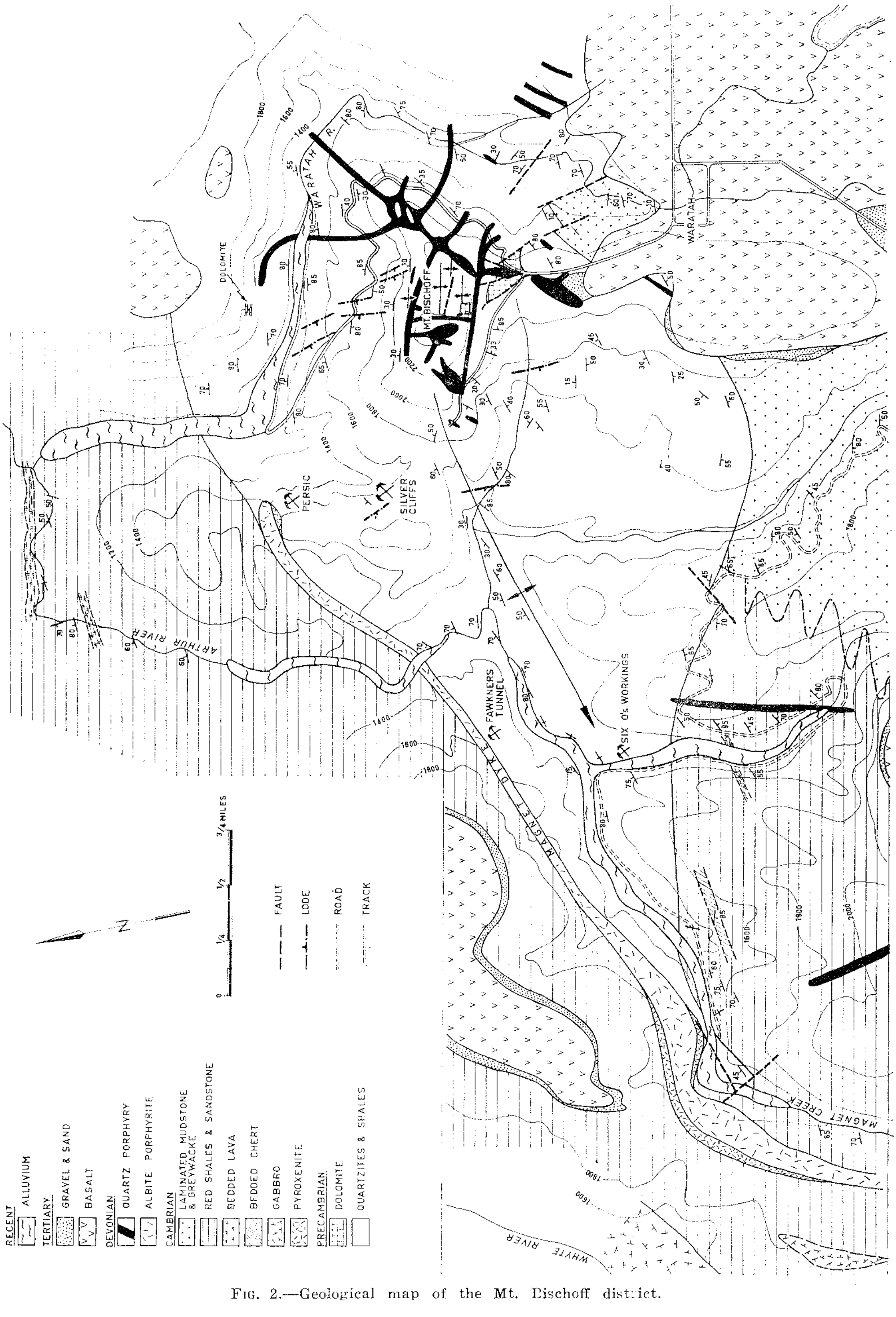

FIG. 2.—Geological map of the Mt. Bischoff district.

STRATIGRAPHY

The basal sedimentary rocks in the area are Upper Precambrian (?) quartzites, sheared shales and dolomite which were previously called the Mt. Bischoff Series by Reid (1923) and are here called the Bischoff quartzites and slates. Overlying these rocks is a thick sequence of shales, mudstones, greywackes, subgreywackes, cherts and altered lavas which were previously called the Dundas Series and are here called Cambrian (?) sediments as their correlation is somewhat obscure. These sediments show apparent structural conformity with the Bischoff quartzites and shales. Unconformably overlying these sediments are conglomerates, sandstones and lignites of Tertiary age, which are generally covered by basalt (Fig. 2).

The succession is summarised below:—

Quaternary—
River gravels and alluvium.
Tertiary—
Gravels, conglomerates, siltstones and lignite: 50-100 ft.
—Unconformity—
Cambrian (?)—
Cambrian (?) argillites, greywackes, breccias, cherts and altered laves: +10,000 ft.
—Disconformity—
Precambrian (?)—
Bischoff quartzites, slates and dolomite: +2,000 ft.

PRECAMBRIAN

Bischoff quartzites and slates

These crop out in a relatively narrow, E-W trending inlier that extends from the head of Deep Creek (east of Mt. Bischoff) to the Magnet Mine. They consists of alternating quartzites and sheared shales and siltstones, with a bed of dolomite and associated dolomitic shales. The sequence shows strong lithological similarities to the Rocky Cape Group on the North West Coast of Tasmania (Spry, 1957) and the Oonah Quartzite and Slate in the Zeehan area (Blissett, 1962), both of which are considered as Upper Precambrian. A correlation of these rocks with similar sediments of Upper Precambrian age was also suggested by Carey (1953) and Knight (1953), the sequence previously being regarded as Ordovician.

The succession in the vicinity of Mt. Bischoff is:—

Hangingwall Shales and Quartzites:	+1000 ft.
Dolomite, including dolomitic shales:	0-200 ft.
Footwall shales:	0-30 ft.
Footwall quartzites, shales and siltstones:	+1000 ft.

This succession differs from that given by Knight (1953), mainly in the addition of the Hangingwall sediments.

The Footwall quartzites and shales are dominantly thinly bedded although massive sequences of 15 feet in a single rock type have been observed. The quartzites contain a high proportion of quartz which has been quite strongly sheared, and thus gives no indication of original angularity and sphericity of grains. The quartz grains exhibit sub-parallel grain and optical elongation and marked undulose extinction, and are in places crushed. The grains vary from 0.1 mm. to 0.5 mm. in diameter. Muscovite occurs in most sections and is quite abundant in several, generally occurring as elongate flakes, 0.1 mm. to 0.4 mm. in length, which are aligned parallel to the elongate quartz grains. Quartz and muscovite comprise the only large grains present, these being set in a matrix of fine sericite and chlorite with sporadic occurrences of interstitial microquartz cement. Minor accessory minerals include well rounded grains of rutile, zircon and tourmaline with graphitic bands and flecks of limonite. Hypogene pyrite is common throughout these sediments.

The sheared shales or mudstones are well laminated and extremely fine grained (0.01 to 0.02 mm. diameter), and consist of quartz, muscovite, sericite and microquartz as in the quartzites. The laminations appear to be produced by variations in the proportion of muscovite which is also found abundantly on the bedding planes. An anlysis of a shale from the mine area at Mt. Bischoff (Table 1) indicates that the sheared shales at Mt. Bischoff are apparently more mature than the average shale, having a higher K_2O to Na_2O ratio, and are more siliceous. However, they do not contain as much silica as the siliceous shale and are probably an intermediate type.

Some thirty thin sections of quartzite and sheared shales from throughout the exposed sequence were examined, and it was found that the sediments in the upper portion of the sequence contained up to 70% quartz grains while the sediments exposed in the Waratah River contained only 50 to 60% quartz. It is also apparent that the sediments become distinctly 'cleaner' towards the upper beds, microquartz cement dominating the normal sericitic matrix. Statistical examination of fairly continuous sections of these sediments in the Mt. Bischoff area and in the Waratah River east of Mt. Bischoff (see Fig. 4) revealed that the Mt. Bischoff section comprised 58% quartzites and 42% shales while the Waratah River section comprised 72.5% quartzites and 27.5% shales. Thus there appears to be an increase in shales towards the top of the sequence, accompanied by an increase in the silica content of the sediments.

Table 1

Analysis of shale from Mt. Bischoff compared with other shales.

	I	II	III
SiO_2	77.18	58.10	84.14
TiO_2	0.59	0.65	0.22
Al_2O_3	11.96	15.40	5.79
Fe_2O_3	1.70	4.02	1.21
FeO	0.38	2.45	—
MnO	trace	—	—
MgO	0.99	2.44	0.41
CaO	0.20	3.11	0.31
Na_2O	0.12	1.30	0.99
K_2O	3.27	3.24	0.50
H_2O-	2.21	5.00	5.56
H_2O+	2.20		
FeS_2	0.13	—	—
CO_2	0.63	2.63	—
	99.56	98.34	100.03

I.—From Mt. Bischoff. Analyst: Department of Mines, Assay Laboratories, Tasmania. 1962.
II.—Average shale (Pettijohn, 1956).
III.—Siliceous shale (Pettijohn, 1956).

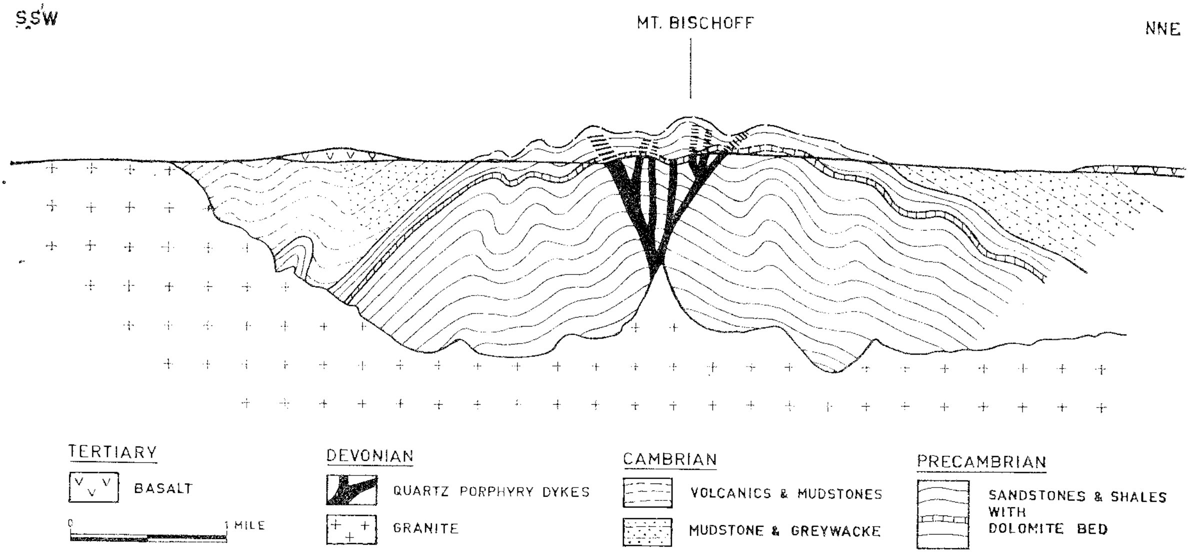

FIG. 3.—Generalised section across Mt. Bischoff.

The Footwall shales are dark grey in colour, lenticular, and represent a local transition to dolomite.

The dolomite is creamy or pale grey when fresh and weathers to pale brown or fawn. Thin sections of the dolomite (30649, 30649 (a)[1], and 36.R.2 of the Mines Department indicate a fine-grained rock consisting almost exclusively of crystalline dolomite with minor interstitial quartz grains. Irregular patches of coarsely crystalline carbonate were developed during recrystallization related to mineralisation. The dolomite also exhibits a fine macroscopic banding which may represent bedding.

Analyses of the dolomite (Table 2) indicate that it is composed of almost pure dolomite mineral, Knight (1953) also indicating the presence of less than 1% MnO in the dolomite. The thin banding (bedding ?) and fine grained texture of the dolomite, and its concordant relations to contiguous rocks, indicate a sedimentary origin (see also Knight, 1953). Thin bedded dolomitic shales occur within the dolomite at the Greisen Face and at the portal of the Main Tunnel.

Table 2

Analyses of Dolomite from Mt. Bischoff

	I	II
Weight %—		
$CaCO_3$	54.6	53.9
$MgCO_3$	43.5	44.1
Mole %—		
$CaCO_3$	50.4	49.7
$MgCO_3$	47.8	48.3

I.—Hangingwall of Greisen Lode, Mt. Bischoff. Analyst: Department of Mines Assay Laboratories, 1959.
II.—50 feet from portal, Main Tunnel, Mt. Bischoff. Analyst: Department of Mines Assay Laboratories, 1959.

The dolomite reaches a maximum thickness of 250 ft. at Mt. Bischoff but is only about 100 ft. thick two miles to the north of the mountain. It has not been found elsewhere, either because it is lenticular or has poor outcrops.

The sediments above the dolomite, the Hangingwall quartzites and shales, are similar to those below, and are dominantly sheared shales.

Pre-consolidation structures occur within both the Footwall and Hangingwall sediments. Somewhat deformed flow casts are exposed on a bedding surface on the North Valley Road, Mt. Bischoff and deformed examples occur in the Waratah River, ½ mile below the mill (Plate I, Fig. 1). As the structure is difficult to determine in these areas no attempt has been made to determine current directions.

Small-scale cross-bedding is visible in some of the coarse siltstones and quartzites but no graded bedding has been observed.

The most widespread feature is the crumpling and brecciation of the sediments; contortion may be confied to a layer a few inches thick between undisturbed material, or may involve several tens of feet of sediments. Plate I, Fig. 2, illustrates a type in which the sand matrix has been liquefied and has incorporated fragments of adjacent mud layers, which retained a shearing strength during the deformation.

The sandstones (Hanging Wall ?) above the Greisen Face (Mt. Bischoff) are almost entirely very contorted and/or brecciated, so that the orientation of the rock is obscure. The deformation has a pre-consolidation appearance and involves fine-grained sandstones with little or no shale; in this case several tens of feet of sandy material appear to have been disturbed.

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[1] Specimen numbers refer to a collection in the Geology Department, University of Tasmania unless stated otherwise.

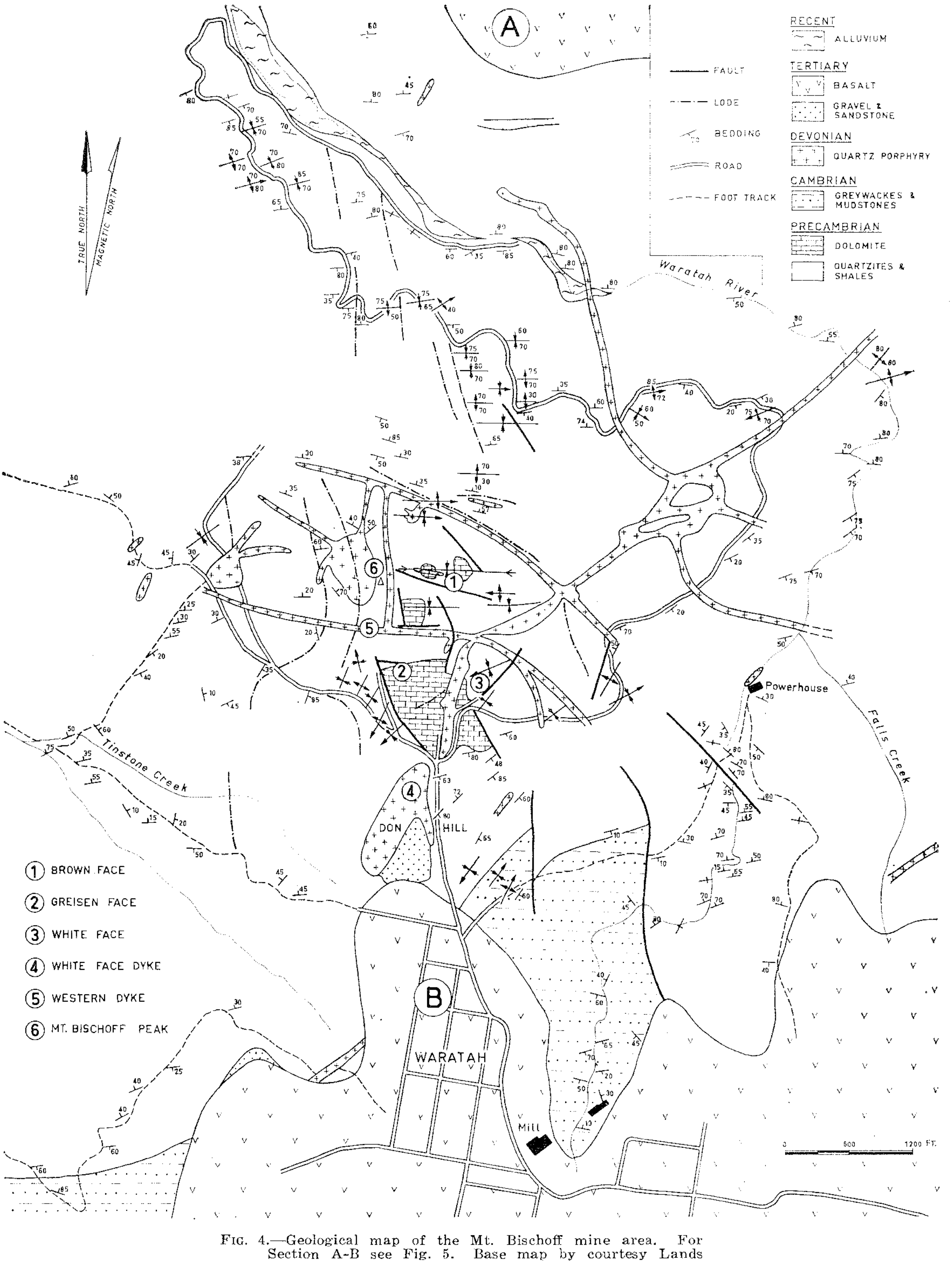

FIG. 4.—Geological map of the Mt. Bischoff mine area. For Section A-B see Fig. 5. Base map by courtesy Lands and Surveys Dept.

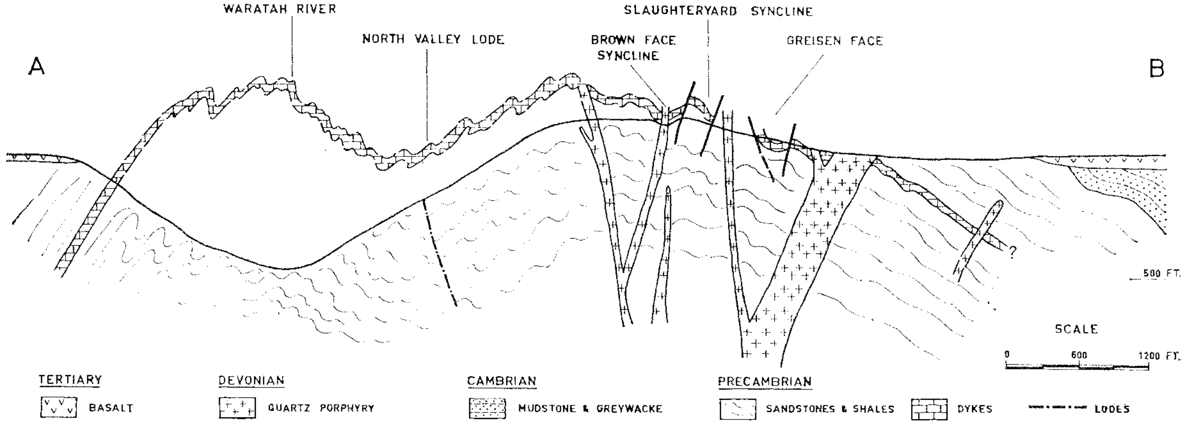

FIG. 5.—Section A B across Mt. Bischoff—see Fig. 4.

Another type exhibits bands of crumpled and brecciated sandstone within a dark shale matrix; the sandstone bands vary from a few mm. to 1½ cm. thick and the shale matrix is generally the dominant lithology. The mechanism in this type is probably the "quickening" of clays containing plastic sandy layers.

CAMBRIAN

Cambrian (?) sediments

These sediments occupy the major portion of the Waratah area and are mainly chocolate-coloured, finely laminated to massive mudstones with minor yellow-brown to grey mudstones, greywackes, subgreywackes, cherts, chert breccias, sandstones and altered lavas. The boundary between these beds and the Bischoff quartzites and slates is not exposed although to the south of Don Hill and on the Magnet Tram they crop out within several feet of each other. At these localities they appear conformable, although the change in lithology from siliceous shale to greywacke is abrupt and the Bischoff quartzites and slates are much more severely deformed than the overlying sediments.

Chocolate coloured mudstones are the dominant sediments in the area. These are extremely fine grained rocks in which even in thin section the constituent minerals are unrecognizable. Haematite and limonite are abundant, producing the red colouration, and thin carbonate veins are also present. In the Waratah River section these mudstones are rare and the finer sediments are grey, black and yellow-brown laminated mudstones which consist of extremely small, angular fragments of quartz, plagioclase, sericite, and calcite. The laminations are apparently caused by thin bands of limonite and graphitic material. The predominant rock types exposed in the Waratah River are subgreywackes, which also occur sparsely throughout the remainder of the area. The rocks are poorly sorted with an open framework and consist dominantly of angular quartz grains, several of which are elongate and exhibit undulose extinction. Other clastic grains include rounded albite, hornblende, augite, chlorite, magnetite and rare rock fragments. They range in grain size from 0.2 to 0.8 mm. diameter and generally the grains are not quite in contact. The matrix consists of chlorite, iron ores and small fragments of other minerals.

Specimen 30659, from the old Magnet tram-line, consists mainly of isolated grains, up to 0.2 mm. diameter, of angular to sub-angular quartz and rounded feldspar, chlorite and magnetite (in order of abundance). The feldspars are interesting in that while a few grains of fairly fresh albite are present, the majority appear to be similar to microcline. Most of these show a very fine, spindle like normal albite twinning and some show pericline cross-twinning; they are optically negative and 2V measurements range from 79° to 87°. Several contain blebs and irregular patches of clear quartz and some crystals appear to be almost entirely replaced by quartz. The significance of these feldspars will be discussed in the section on igneous activity. Somewhat deformed amygdule-like bodies filled with a fine quartz aggregate are also present, with a few flakes of muscovite and small fragments of fine grained basaltic lava.

Other rocks are similar (30655, 30657, 30658, 30660) but vary in quartz (up to 40%) and iron oxide content. Specimen 30657b is unusual in that the matrix has several percent of small (0.05 mm. diameter) hornblende crystals, apparently as a detrital component.

Coarser grained sediments (mainly fine to coarse breccias) are common throughout the area. Many of these rocks contain a high percentage of albite laths and angular volcanic rock fragments with or without clastic muscovite. Fragments of shale are also common, occurring with minor quartz, biotite, carbonate and limonite in a fine matrix of chlorite, albite and a little quartz. Some of the breccias have a much lower volcanic component, e.g., the breccia outcropping in the Waratah River, ¼ mile below the Bischoff mill, which has indistinct bedding and is composed dominantly of angular rock fragments of the Bischoff quartzites and slates and Cambrian (?) sediments; several lava fragments are also present. The fragments are several inches in diameter (to a maximum of 9 inches) and angular to subangular.

Some of these rocks may be volcanic but the presence of quartz and sedimentary rock fragments in quantity suggests they are not tuffs and may be the result of weathering of volcanic and Pre-Cambrian rocks.

Nye (1923) classified these greywackes and breccias as micaceous or feldspathic "breccias" but the number of sediments in which mica was an important constituent proved to be very small while almost all of them contained feldspar.

Lavas and pyroclastics are rare in the Mt. Bischoff area but become more common towards the Magnet Mine where they are associated with a massive bed of banded chert and chert breccia. The volcanic rocks are described in detail in a later section.

An interesting member of the Cambrian (?) sediments in the Arthur River to the north of Waratah is a thin bed of limestone interbedded with yellow-brown laminated mudstones. The limestone is dark grey in colour, fine grained and contains small bands of coarsely crystalline calcite. The thickness of the bed is unknown due to limited exposure.

The Cambrian (?) sediments are apparently unfossiliferous throughout the area although Chapman (1929) records annelid remains (described as arthropod tracks—*Tasmanadia twelvetreesi*—by Glaessner, 1957) in slates on the Arthur River a few miles north-west of Waratah.

On the grounds of lithologic similarity, the Cambrian (?) sediments in the Waratah district have been carrelated with the Dundas Group of Middle to Upper Cambrian age (e.g., Knight, 1953) and also beds lower in the Cambrian (Banks, 1962).

At the present time no direct correlation with other sequences is possible and attention can only be drawn to the similarities of the Waratah rocks to those of the Huskisson River and Dundas areas.

TERTIARY

The beds belonging to the Tertiary System consist of conglomerates, gravels, siltstones, sandy clays and lignites, forming a sequence generally some 50 feet in thickness and reaching 100 feet in places.

The basal members consist of conglomerates and gravels containing boulders up to 12 inches in diameter. Small quantities of cassiterite and gold have been found in these basal beds. Above these are fine grained, poorly sorted siltstones with water worn pebbles and unevenly distributed boulders that distort the bedding. The boulders have been locally derived, consisting of quartz, quartzite, shale, greywacke, breccia, quartz porphyry and granodiorite. Boulders of Permian mudstones have also been found (Nye, 1923). Small outcrops of lignite and ligneous clays occur in the vicinity of Waratah and contain numerous leaf impressions which have been described by Johnston (1888) as belonging to the genera *Eucalyptus, Quercus, Laurus, Cycadites* and *Ulmus*. This and the lithology indicate a terrestrial origin for these sediments and they are thought to have been deposited in streams and small lakes. At Don Hill (Fig. 4) Tertiary sands may be seen deposited against low bedrock cliffs. Differential compaction of the younger sediments has produced folds and high dip angles near these cliffs (Plate I, Fig. 3).

IGNEOUS ACTIVITY

Five major periods of igneous activity are represented within the Waratah area:

(a) Volcanic emission during deposition of the Cambrian (?) sediments, with the production of dominantly basaltic lavas.
(b) Intrusion of ultrabasic and basic igneous rocks, probably soon after cessation of deposition of the Cambrian (?).
(c) Intrusion of acidic rocks including granodiorites and quartz-feldspar porphyries into the Bischoff Series and Cambrian (?) sediments during the Devonian.
(d) Intrusion of dolerite during the Jurassic.
(e) Extrusion of basalt over a vast area during the Tertiary.

(a) CAMBRIAN VOLCANIC ACTIVITY

Lavas are generally rare in the Cambrian (?) sediments but become more prolific towards the Magnet Mine. Individual flows appear to have covered considerable areas, an example in the Arthur River (near the confluence with the Waratah River) outcropping at fairly close intervals over about ½ mile; the maximum exposed thickness is 100 feet. The lavas examined are mainly spilitic (e.g. 636, 642, 30658a, 30662a and 35G5, 35G9 of the Mines Department). Many are porphyritic, with phenocrysts of albite, augite and chlorite in a felted ground mass of albite laths, chlorite, calcite, epidote, magnetite and ilmenite. Some have intersertal texture and consist of an interlocking aggregate of albite, augite and chlorite with interstitial chlorite, calcite, &c. The albite phenocrysts are almost invariably clouded by sericite and in some appear to be completely altered to a fairly coarse interwoven aggregate of sericite plates and sheaves. They reach a maximum size of about 2 x 0.5 mm. As in the spilites elsewhere in Tasmania the albite displays low-temperature optics and varies in composition between Ab_{90} and Ab_{95}. Augite occurs in only a few of the rocks, and is altered to varying degrees to chlorite, or a very fine grained dusty aggregate of chlorite and possibly sericite (e.g. 30662a). The augite is similar to that described by Scott (1954) in the Lynch Creek basalts at Queenstown; this proved to be a diopsidic variety. Chlorite may be primary but in some rocks it is clearly pseudomorphing earlier minerals, probably augite (e.g. 642) and in some cases possibly olivine (e.g. 30662b). Most of the chlorite shows anomalous "Berlin Blue" interference colours and is very pale green in colour and non-pleochroic. Refractive index measurements gave β=1.615 and 1.633.

The ground mass is very variable; it may have a typical basaltic form dominated by thin albite laths or it may be granular. Chlorite occurs interstitially to the feldspar laths, along with calcite, epidote, magnetite and ilmenite.

Some of the rocks are amygdaloidal, the amygdules being of ovoid shape and usually filled with combinations of chlorite, calcite and quartz. In slide No. 642, an amygdule nearly 1 cm. in diameter is filled with quartz, calcite and iron oxide, and rimmed by epidote crystals arranged radially. Calcite and chlorite veinlets are common and prehnite occurs rarely.

A specimen from a lava on the Magnet tram (30662b) consists entirely of euhedral chlorite pseudomorphs up to 2 x 2 mm., in a matrix of chlorite and quartz spherulites up to 0.2 mm. diameter. The chlorite appears to be pseudomorphing pyroxene and/or olivine crystals. Amygdule-like bodies in the ground mass are composed of aggregates of fine quartz spherulites (Plate II, Figs. 1 and 2). One of the "phenocrysts" which has a rim of quartz spherulites consists of chlorite and a fine grained quartz aggregate which appears to be partially replaced by a single skeletal quartz crystal.

Chlorite-quartz spherulite rocks occur in the Magnet Dyke and quartz spherulites line the rims of amygdules consisting of chlorite with cores of calcite in a basalt (636) from the West Magnet Mine. Rather similar spherulitic quartz rocks at Zeehan are assumed by Scott (1954) to be the result of silicification of basalt but the quartz-chlorite development appears to be related to a late stage of lava solidification rather than the regional metasomatism suggested by Scott (1954).

In all specimens collected in the field, albite is the only feldspar present, an observation similar to that made by Scott. However, slide No. 636 from the West Magnet Mine, has a coarse doleritic texture with almost unaltered labradorite (An 58) laths up to 2 mm. long, interstitial areas being occupied by pale green chlorite, calcite and magnetite (?). As already described, the rock is prominently amygdaloidal with chlorite, calcite and quartz spherulites. It appears to be a basalt, or a shallow intrusive, has many textural and mineralogical features in common with the spilites, and is unlike any Tertiary basalt. If it is Cambrian it gives an indication of a parental, more calcic feldspar.

Keratophyric lavas occur about 4½ miles from Waratah on the Corinna Road (639, 640). They are porphyritic, with phenocrysts of albite laths up to 1 x 2 mm. and rare, somewhate smaller, quartz crystals. The ground mass is feldspathic and varies from basaltic to almost variolitic in texture. Rare phenocrysts of augite up to 0.4 x 0.1 mm. occur in specimen 640, along with pale green chlorite in lath pseudomorphs. Rather rounded grains of magnetite (?) up to 0.2 mm. diameter are scattered throughout. The quartz phenocrysts are rounded, euhedral, or shard-like in form, and commonly embayed in identical fashion to crystals in the keratophyres of the Mt. Read Volcanics.

Volcanic rocks with fragmental texture are not common, though some of those described as sandstones and breccias may in fact be pyroclastic. An interesting rock occurs near the head of the Arthur River (646). It consists largely of feldspar crystals, quartz spherulites rock, and basaltic fragments in a variable matrix of chlorite, iron oxides, and calcite. Part of the matrix consists of irregular veins and concretionary forms of a pale reddish-brown, isotropic mineral that is probably hydrogrossular. Scott (1951a, 1954) has described a similar mineral in the King Island spilites, in which it appears to be due to hydrothermal alteration. This rock is of uncertain origin but may be the fine-grained equivalent of an autoclastic breccia (Wright and Bowes, 1963), formed by gas explosions within lava during solidification.

The dominance of K-feldspar in the greywackes interbedded with spilites is surprising in view of the lack of any feldspar other than albite in the spilites or the keratophyres. The reason is not known but it is suggested that the microcline in the sediments is derived from potassic rhyolite or quartz keratophyre flows and necks that have been largely disintegrated by explosive activity during eruption.

(b) CAMBRIAN INTRUSIVES

Basics and Ultrabasics

Peridotites, pyroxenites and serpentinites occur extensively in a wide belt to the southwest of the Waratah District and small masses of these rocks are also present in the Waratah District. Numerous boulders of weathered ultrabasic rocks occur north and south of the Arthur River Dam on the Waratah-Corinna Road, and two small masses occur at Mt. Bischoff. These rocks are similar to other ultrabasic masses in Tasmania, e.g., at Adamsfield, Anderson Creek and Argent Tunnel, and probably belong to the same tectonic phase. With the spilites and albite gabbros they form a typical ophiolite association.

A number of gabbroic bodies intrude the Cambrian sediments west of the Magnet Mine. A typical example crops out ¼ mile east of the Whyte River bridge on the Corinna Road. It is composed almost entirely of plagioclase, hornblende and chlorite (in order of abundance) in an even grained granitic texture, the average diameter being 0.5 mm. The feldspar is loaded with inclusions (?) of yellowish-brown chlorite and sericite (?) and many of the laths possess a thin clear rim in optical continuity with the cloudy core. The plagioclase is albite or albite-oligoclase. The hornblende is somewhat fibrous and the crystals tend to be ragged. It appears to replace both augite (?) and yellowish chlorite. Its optical properties are $\alpha = 1.643$, $\delta = 1.660$, $2V = 71 +$ve.

Nye (1923) refers to similar rocks west of the Whyte River some of which contain augite. Specimen 586 shows pyroxene (diopside ?) in all stages of alteration to hornblende and pale green chlorite.

Magnet Dyke

A long, narrow strip of igneous rock occurs on the contact of the Bischoff and Cambrian (?) sediments from west of the Magnet Mine to the

Persic Mine, a total distance of some 5 miles. This mass of igneous rock has occasioned some controversy, Twelvetrees (1900) and Nye (1923) considering it to be a complex dyke, and Scott (1954) suggesting on petrological evidence that it represents a strip of volcanic rocks.

The " Dyke " is generally some 200 to 300 feet in width, reaching its maximum thickness at the Magnet Mine where it is some 1000 feet wide. At the mine it has a west dip and is more or less conformable. It consists over most of its length of a single, rather variable rock type which has been previously named a diabase porphyrite. At the Magnet Mine, however, the section is more complex, Twelvetrees (1900) describing the " Dyke " from east to west as websterite porphyrite, diabase prophyrite, and orbicular or spheroidal websterite (Fig. 6).

The diabase porphyrite, which extends for the whole length of the " Dyke ", is extremely variable, with albite, pyroxene, chlorite, siderite, quartz, hornblende, pyrite and ilmenite occurring in varying proportions. Commonly the rock is porphyritic with phenocrysts of altered albite, and also chlorite completely or partially pseudomorphing pyroxene. Albite porphyrite is probably a more apt term than diabase porphyrite. The albite, which occurs as multiply twinned and untwinned crystals, has been extensively sericitized. The ground mass is generally very fine and consists dominantly of albite laths and chlorite with irregular masses of quartz and carbonate, the latter also commonly occurring as veins throughout the rock. Quartz occurs rarely as large anhedral crystals associated with chlorite. Small crystals of ilmenite, sphene, columnar epidote and cubes of pyrite also occur throughout the ground mass. Circular masses of carbonate, chlorite and quartz spherulites are also common in some sections, and are similar to amygdule fillings of the Cambrian (?) basalts. The circular bodies also show similar zonation to those in the basalts, with a carbonate nucleus lined by sheaves of chlorite, and quartz spherulites forming an outer margin.

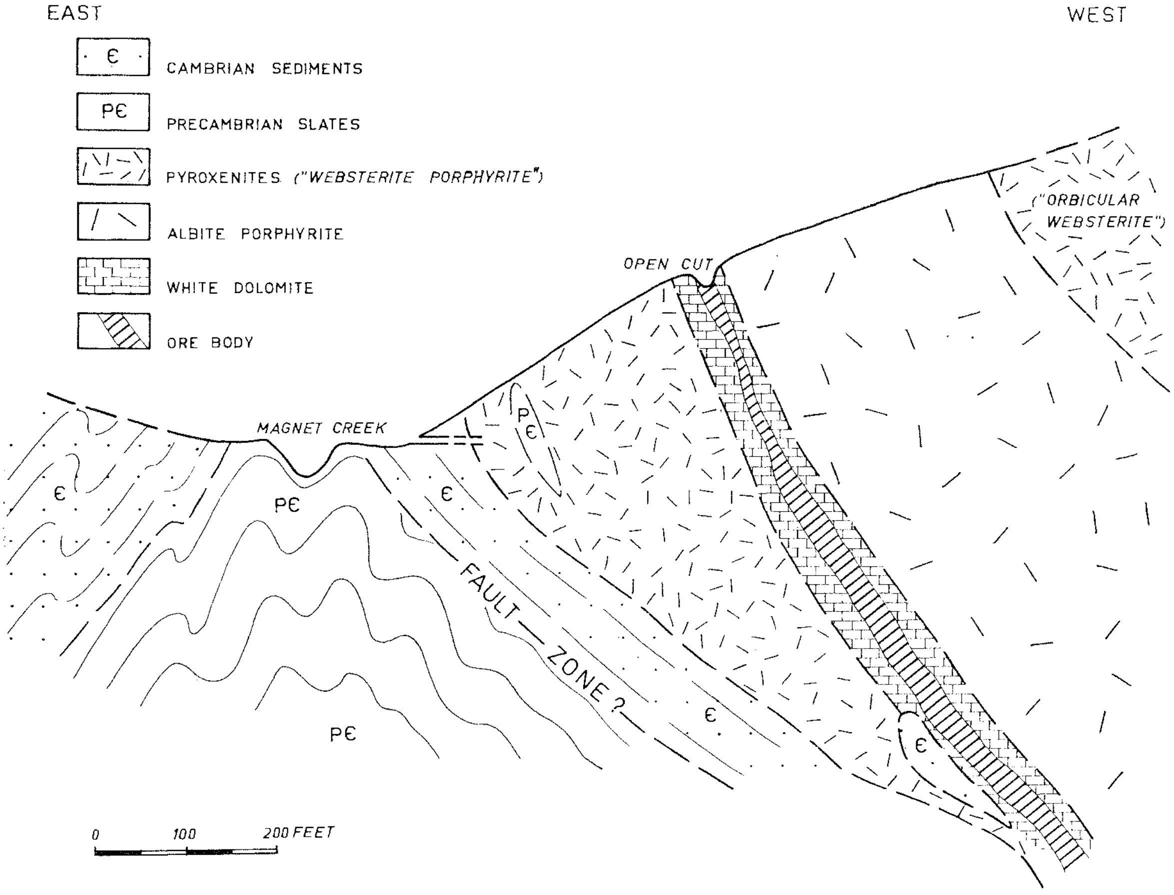

FIG. 6.—Section across the Magnet Dyke at the Magnet Mine (after Nye, 1923).

Although the albite porphyrite is dominantly porphyritic, some sections exhibit a doleritic texture. Specimen 35 N 14 (Mines Department), from the Waratah-Pieman Track, consists of interlocking laths of albite and augite with a very minor proportion of ground mass, and appears to be an altered dolerite. Specimen 712 has a similar texture and composition but also contains some hornblende and actinolite. Several of the albite crystals show myrmekitic texture.

In places the albite porphyrite consists entirely of quartz and chlorite, e.g., 708 and 35 F 11 (Mines Department). This rock consists of large spherulitic masses of quartz with interstitial sheaves of chlorite, and has been called a silicified variolite (Rosenbusch in Nye, 1923). Analyses of these " variolites " are given in Nye (1923) and quoted by Scott (1954) as intermediate phases of the silicification of spilite, the end product being a spherulitic quartz rock (99.1% SiO_2). It is suggested here that the siliceous rock is a primary, or deuteric, feature confined to lenses and channels in the spilitic body.

The pyroxenite on the east of the " Dyke " at the Magnet Mine is reported to occur as a lenticular body with a maximum width of 360 feet and thinning out to the north and south. The rock is extremely weathered, but resembles a decomposed basic rock with large pyroxene phenocrysts. A section of this rock described by Nye (1923) contained dominantly serpentine with a little chlorite. The name websterite porphyrite was applied by Rosenbusch who considered that in its unaltered state, the rock would contain phenocrysts of bronzite or enstatite in a ground mass of pyroxenes. Specimen 637 from North Magnet contains large phenocrysts of enstatite that is largely altered to talc (?); the ground mass is composed of talc (?), sericite, quartz and chlorite. A similar rock (2183—alleged to be from the northern slopes of Mt. Bischoff) consists of enstatite crystals surrounded and in part pseudomorphed by talc (?). Fine anhedral quartz crystals and small fibres of chlorite are also present. This specimen probably represents part of the pyroxenite mass on the southern margin of the Magnet Dyke at the Persic Mine.

On the western side of the albite porphyrite at the Magnet Mine, there lies a decomposed pyroxenite. It is weathered to a brownish-yellow rock which contains decomposed crystals of pryoxene, similar to those of the eastern mass. In places this rock has an orbicular structure, containing abundant spheres with the same mineralogical composition as the general mass of the rock. The occurrences of the pyroxenites bounding the albite porphyrite appears to be limited to the Magnet and Persic Mine areas, the only areas of mineralisation along the " Dyke ".

Another feature of the " Dyke " at the Magnet Mine is the inclusion of a large block of the Bischoff quartzites between the easterly pyroxenite and the albite porphyrite and a smaller block within the pyroxenite itself (Nye, 1923).

The origin of the " Dyke " is uncertain. Several features indicate an intrusive origin: (a) the complex nature of the " Dyke " at the Magnet and Persic mines, (b) the distribution of the " Dyke " along 5 miles of the Cambrian (?)-Precambrian contact and along what appears to be a discordant structure at the mine, (c) the composition of the pyroxenite, and (d) the inclusions of Bischoff quartzites within the " Dyke ".

However, as Scott (1954) has demonstrated, there is a strong petrographical similarity of a large portion of the albite porphyrite with the spilites in the Magnet area and she concluded that the rock was volcanic. Also, Cambrian (?) volcanic breccias are apparently found adjacent to the " Dyke ", specimens 35 N 8 and 35 N 22 from North Magnet and the Persic Section (labelled websterite and diabase porphyrite respectively) being breccias composed almost exclusively of volcanic fragments. The writers agree with Scott on the nature of the albite porphyrite but suggest the pyroxenites are intrusive.

Alteration of the Cambrian Lavas and the Magnet Dyke

These rocks have undergone a pattern of alteration that is characteristic of Cambrian volcanics elsewhere in Tasmania, generally involving the processes of albitization, chloritization, carbonation and silicification. The albite in amygdules and veinlets appears to be related to a late phase of the crystallisation of the flows, see also Solomon, 1960) and probably the chlorite, quartz and carbonate associated with the albite are also of similar (deuteric ?) origin. The cloudy albite forming phenocrysts shows no textures indicating its development by replacement of calcic feldspar and it appears to have crystallised at an early stage of lava solidification. The labradorite from the West Magnet mine shows no replacement by sodic feldspar but it does indicate the presence of at least some low-soda magma in the area.

The presence of albite and augite in ophitic texture in the King Island lavas (Scott, 1951b) is further support for a primary origin and a strong case can be made for the presence of a Na-rich magma during Cambrian volcanic activity.

Bradley (1954) considered the alteration of the Cambrian volcanics to be of Devonian age but it is likely to be Cambrian, because pebbles of altered volcanics occur in basal Ordovician sediments. Scott (1954) suggested that it resulted from the passage of heated, connate soluations rising from the geosynclinal column and causing redistribution of certain elements. The authors suggest that though albite is widespread it is confined to the volcanics and is of primary and/or deuteric nature.

(c) DEVONIAN ACTIVITY

A granite stock, known as the Meredith Granite, outcropping over about 120 sq. miles, extends from Parsons Hood in the south to within two miles of Waratah (Fig. 1). It has been mapped over a few square miles near Waratah and this part is essentially adamellite. It intrudes Cambrian (?) sediments and is pre-Tertiary but by analogy with other similar intrusions in Tasmania it is likely to be mid-Devonian to Carboniferous in age. To the north of this granitic mass are dykes of quartz-feldspar porphyry which intrude the Cambrian (?) sediments and appear to be related to the granite. Quartz-feldspar porphyries and topazised quartz porphyries occur at Mt. Bischoff as a series of anastomosing dykes and sills, one of which apparently extends 3 miles north-east into Deep Creek (the granite mass indicated on the State Geological Map in Deep Creek appears to be a quartz porphyry dyke).

Adamellite

Two types of adamellite occur in the area examined; an even, medium-grained adamellite and a porphyritic adamellite, the porphyritic variety previously being considered as a late stage intrusive into the even grained granodiorite (Reid, 1923).

The even grained variety (30651, (e), (f) and (g) consists of orthoclase, oligoclase (approx. An_{30}) quartz and biotite as intergrown, generally euhedral crystals from 1 mm. to 3 mm. in length. Graphic interwrowths of quartz and orthoclase are common. Other minor components of the adamellite include hornblende, zircon, topaz and tourmaline. Modal analyses of three thin sections of this rock averaged 54.5% total feldspar, 36.1% quartz, 9.0% biotite and 0.5% accessory minerals. Some 20% to 30% of the total feldspar is oligoclase and the rest orthoclase.

The porphyritic variety is similar but contains large phenocrysts of oligoclase up to 2 cm. in length which in places show slight zoning. Modal analyses on four thin sections of this rock averaged 55% total feldspar (including 9% oligoclase phenocrysts), 34% quartz, 11% biotite and accessories. Thus the porphyritic and even-grained adamellites are compositionally similar and are probably variations within the granitic mass rather than distinctive bodies. This is supported by the field distribution which appears to be irregular and gradational.

Aplitic phases, consisting almost exclusively of quartz with minor orthoclase, contain large irregular clots of black fibrous tourmaline which constitute the greater proportion of the rock in places. Contact effects of the granite were not seen for lack of exposure.

Associated Quartz-Feldspar Porphyries

A dyke of quartz-feldspar porphyry extends north from the adamellite and outcrops between the junction of Seven-mile Creek and the Arthur Falls. It consists of large phenocrysts of orthoclase and quartz in a fine-grained ground mass of orthoclase, quartz, a little plagioclase and a ferromagnesian mineral which is probably hornblende. Associated with this rock is a more basic type which macroscopically appears to consist of phenocrysts of feldspar in a ground mass of feldspar and probably hornblende. The latter rock appears to occur mainly along the margins of the main quartz-feldspar prophyry dyke.

A further acid dyke probably occurs some 200 yards north of the Magnet Tram bridge over the Arthur River. The rock is extremely weathered, feldspar being the only recognizable mineral in a dominantly limonitic ground mass. Both dykes intrude Cambrian (?) sediments and contact effects are limited to slight baking for a few feet from the contact.

Quartz Porphyries at Mt. Bischoff

The most prominent feature of the geology of Mt. Bischoff is the profusion of altered porphyry intrusives within the Precambrian sediments. The majority of the porphyries occur as dykes from fifteen to one hundred feet in width, forming an overall radial pattern with preferential trends east-west and north-south, and steep dips to the north and west respectively. Large irregular masses also occur, for example on the summit, and to the north-east of Mt. Bischoff and also at Don Hill, the first two being marging points of several large dykes. Smaller, discordant intrusions of porphyry are common throughout the area, the majority apparently being offshoots from the main dyke system. Relatively thin sills of porphyry are also common, partciularly at the junction of dolomite and Footwall shales (e.g. in the Brown Face and Slaughteryard Face). Alteration of the country rock by the porphyries is limited to slight baking for several feet from the contact.

Breccias composed of country rock fragments are consistently present on the walls of the porphyry dykes, the breccias varying from 2 to 20 feet in width. The fragments are angular or subangular, up to 2 inches in diameter, and are mainly in contact with each other. The matrix is largely crushed sedimentary material and fine grained porphyry. The contact between porphyry and breccia is irregular with small lenticular " splashes " of porphyry (both microscopic and macroscopic) extending into the breccia far several feet from the contact. Xenoliths of baked country rock are also common within the porphyry adjacent to the contact. In several cases, the structure as defined by the dolomite horizon is difficult to correlate across the dykes and in the case of the Western Dyke it is evident that there has been displacement along the line of the intrusion. This evidence, together with the occurrence of contact breccias of quite large dimensions, indicates that the porphyries were intruded into tensional openings containing fault breccias, and discounts the possibility of extreme brecciation during emplacement of the porphyries. The porphyries also exhiibt strong macroscopic banding, cross-bedding structures and small swirls which probably reflect flow movements in the partly crystalline porphyries during intrusion.

Within the general category of quartz porphyry there are several gradational varieties which depend on the subsequent alteration of a primary porphyry type rather than variations within the original parent magma. Remnants of unaltered porphyry occur in the southern portion of the White Face Dyke and Falls Creek, and are recorded by Reid (1923) from the western extremity of the Brown Face Dyke . Analyses of unaltered porphyries are shown in Table 3 (Nos. 1 and 7).

The porphyry from the southern portion of the White Face Dyke (e.g. 30617) consists of bipyramidal quartz phenocrysts up to 5 mm. in diameter with lath-shaped phenocrysts of a soft white substance in a fine ground mass. The laths are orthoclase almost completely altered to clay minerals (mainly kaolinite ?); X-ray powder photographs show strong similarities to orthoclase pattern but most of the lines are offset equal amounts in the same direction, presumably due to alteration. D.T.A. curves confirmed the presence of kaolinite. The groundmass is largely quartz and sericite. Muscovite occurs sporadically throughout the rock as flakes up to 0.5 mm. in length. A modal analysis of a thin section indicated 59% groundmass, 25% quartz phenocrysts, 14% orthoclase phenocrysts and 2% muscovite.

The majority of the porphyries are topazised and contain only an insignificant proportion of original feldspar. These rocks are typified by specimens 30619 to 30629, 2173, 692, 693, 698, 700 and 702, an danalyses of typical samples are given in Table 3 (Nos. 2 to 6). The porphyries consist of a fine-grained ground mass of dominantly quartz and topaz with sporadic occurrences of sericite and fine threads of talc. Small crystals of fluorite and tourmaline are rarely present. The prismatic topaz has been referred to as pycnitc (Reid, 1923). The topaz has refractive indices $\alpha = 1.620$ $\delta = 1.610$ and $2V = 62$ indicating it has a molecular percentage $OH/(OH+F)$ between 6 and 4 (Deer et al., 1962). High fluorine content is indicated in the partial analysis given by Reid, 1923. Quartz phenocrysts are abundant, generally ranging in diameter from 0.5 mm. to 2.0 mm. and in some instances reaching 5.0 mm. These phenocrysts are perfectly formed hexagonal crystals near the margins of the dykes but within the dykes are generally slightly corroded or possess a narrow rim of quartz in optical continuity with the phenocrysts, the outlines of which are still visible. Fluid inclusions are present, and in some instances common, in the quartz which also contains minute inclusions of zircon, muscovite and topaz. The portions of the dykes with non-corroded crystals represent the chilled marginal material. Lath-shaped cavities are also evident, these generally being lined with groups of radiating acicular crystals of topaz growing inwards from the cavity walls; they were probably feldspar phenocrysts (Plate II, Fig. 3). Topaz is also evident as acicular crystals associated with irregular aggregates of anhedral quartz crystals in optical discontinuity, and as partial rims around corroded quartz phenocrysts. Sulphides are generally abundant, occurring as finely crystalline particles; many occurrences form lath-shaped aggregates, probably replacing feldspar (Plate II, Fig. 4). Pyrite is the dominant sulphide mineral although arsenopyrite occurs sporadically throughout the porphyries, and pyrrhotite is common in porphyry sills on the contact of replaced dolomite and slate Finely crystalline sulphides are also found associated with the quartz-topaz ground mass. Oxidation of these sulphides has occurred near the surface and accounts for the high proportion of Fe_2O_3 in several of the analyses. Cassiterite is also present in the porphyries as fine granular crystals replacing feldspar laths and rarely as well-formed zoned crystals up to 0.5 mm. in diameter.

Table 3

Chemical analyses of porphyries from Mt. Bischoff

	1	2	3	4	5	6	7
SiO_2	73.78	66.92	70.16	68.98	68.64	72.30	79.69
TiO_2	0.06	0.06	0.09	0.05	—	trace	+
Al_2O_3	14.35	19.88	21.69	19.96	19.38	17.17	13.49
Fe_2O_3	0.61	trace	0.14	1.05	0.21	trace	0.14
FeO	1.57	0.64	0.35	0.19	0.29	0.58	2.08
MnO	0.09	trace	trace	trace	trace	trace	+
MgO	0.62	0.24	0.22	0.28	0.31	0.29	0.60
CaO	0.44	0.36	0.20	0.20	0.68	0.28	0.46
Na_2O	0.40	0.05	trace	trace	trace	trace	0.08
K_2O	6.01	0.07	0.07	trace	trace	0.37	2.71
H_2O+	2.15	0.98	0.77	0.69	0.96	1.04	+
H_2O-	0.12	0.11	trace	0.05	0.24	0.19	+
P_2O_5	trace	trace	trace	trace	trace	trace	+
CO_2	+	+	+	+	+	+	+
FeS_2	trace	6.62	2.19	4.86	5.85	3.91	+
Ca	+	0.02	trace	0.01	0.01	0.01	+
SnO_2	+	0.07	0.13	0.16	0.08	0.16	+
F	+	6.48	6.63	6.86	6.46	6.15	+
Total	100.20	99.77	99.94	100.39	99.86	99.94	99.64

Localities—

1, 2, 3—White Face Dyke.
4, 5, 6—Western Dyke.
7 —White Face Dyke.

Analyst for 1-6.—Dept. of Mines, Assay Laboratories, Tasmania, 1962.
Analyst for 7. —A. D. Mackay (in Reid, 1923).

Unusual varieties of porphyry occur along the North Valley road (30630 a and b). These are quartz-topaz porphyries but contain abundant rosettes of muscovite in lath-shaped aggregates. A further variety (30631) contains a higher proportion of pyrite cubes, several of which enclose quartz phenocrysts, thus indicating crystallization after the quartz. Large phenocrysts of muscovite are also common in this rock. Muscovite is also common in a porphyry dyke on the contact of the Bischoff sediments with Cambrian (?) sediments to the west of Waratah (30633); this porphyry consists dominantly of sheared quartz phenocrysts with elongate aggregates of sericite in a fine quartz-sericite ground mass. It is unusual in that it has been sheared.

The White Face Dyke (see Fig. 4) was examined in some detail as it provides an opportunity of studying the gradation from a quartz-feldspar porphyry to a quartz-topaz porphyry. It was sampled closely from just south of the Bischoff open cut northward into White Face, i.e., from unaltered to intensely altered material. The unaltered quartz-feldspar porphyry grades into a rock with a felsitic ground mass and idiomorphic quartz phenocrysts and lath-shaped masses of siderite, pyrite and fluorite with some remnants of orthoclase (30618). Biotite and muscovite are also present, generally being associated with talc as minor constituents of the ground mass. This rock then grades into a quartz-topaz porphyry. The intermediate zone described above is only a few feet wide. Analysis 1 (Table 4) is of unaltered porphyry and analyses 2 and 3 are of quartz-topaz porphyry. Aanalyses 4, 5 and 6 are from the Western Dyke, taken at intervals of 2-300 ft., No. 4 being from the old Haulage, No. 5 near Slaughteryard Face and No. 6 just south of Mt. Bischoff peak. Little variation is noted although potassium is more abundant in No. 6 which is the most westerly sample, and may indicate the occurrence of minor original feldspar amay from the main centre of mineralization.

The occurrence of a quartz-feldspar porphyry towards the limit of mineralization at Mt. Bischoff and the consistent occurrence of topaz, fluorite, sulphides and cassiterite in lath-shaped cavities and in the ground mass is strong evidence that the latter minerals are present as pseudomorphs after feldspar during alteration. This was also suggested by Dunn (1922), who considered that the alteration took place homogeneously in a crystal mush prior to emplacement. If this hypothesis were correct, it would be expected that the proportion of topaz and other replacement minerals would be constant throughout the dyke. Sections of porphyry taken across the Western Dyke were examined, 30625a and d being marginal samples and 30625 b and c samples from near the centre of the dyke. Modal analyses of these sections (as percentages) are given below. One thousand counts mere made on 4sq. cm. to determine the phenocryst-ground mass ratio, 1,000 counts on the same area for the composition of the ground mass and 1,000 counts for the composition of the phenocrysts.

	30625a	30625b	30625c	30625d
Ground mass—				
Topaz	41.8	27.6	24.0	39.4
Quartz	29.6	54.8	45.0	33.2
Total Ground mass	71.4	82.4	69.0	72.6
Phenocrysts—				
Topaz	19.0	8.0	14.6	7.8
Quartz	7.4	9.2	14.0	5.8
Pyrite	1.2	0.2	2.4	—
Fluorite	0.2	—	—	—
Miscellaneous	0.8	0.2	—	13.8
Total phenocrysts	28.6	17.6	31.0	27.4

It is evident that the marginal zones of the porphyry contain more topaz and other alteration products than the central zone, even allowing for standard deviations of several percent in the modal anlyses. This suggests that the pneumatolytic vapours or solutions were introduced along the open brecciated walls of the dyke and were not active within the magma prior to emplacement, as imagined by Dunn. Topaz thus replaced the feldspar in the ground mass and phenocrysts while the porphyry was in a solidified or perhaps a semi-solidified state, with crystallized phenocrysts of orthoclase and quartz in a molten felsitic ground mass.

The occurrence of muscovite, fluorite, siderite and talc pseudomorphing feldspar in place of topaz at the extremities of the mine area, and the occurrence of unaltered quartz-feldspar porphyry near Don Hill and in Falls Creek, suggest that a temperature gradient may have existed in the area with extensive topazisation in the areas of highest temperature towards the centre of Mt. Bischoff.

In places, alteration has been so extensive that the original texture of the porphyry no longer exists and the rock can only be distinguished as an alteration product by a gradation into recognizable porphyry. In the White Face, along the walls of the dykes, the topaz has replaced even the quartz, producing spherulitic aggregates of topaz in association with euhedral to anhedral crystals of cassiterite, many of which show marked zoning (e.g. 694 and 698). The spherulitic topaz comprises a central, granular aggregate surrounded by radiating prisms (Plate II, Fig. 4) and needles of topaz, and is rarely associated with radial blue tourmaline crystals.

The porphyries have also been totally replaced in the White Face and near the Main Tunnel entrance by tourmaline, fluorite and siderite. These rocks (30634 a to f) generally comprise large crystals of fluorite several mm. in length, which contain inclusions of sericite and siderite, these being bounded in places by sheaf-like masses of muscovite, producing a halo effect. The fluorite is completely surrounded and " intruded " by aligned acicular crystals of tourmaline which exhibit marked pleochroism from blue to colourless. Coarse crystals of siderite also occur and are themselves riddled with a profusion of acicular crystals of tourmaline. In specimen 30634 d moderately thick veins of sheaf-like muscovite occur in association with the tourmaline.

The tourmaline is dark green in hand specimen and has refractive indices $\propto = 1.6580$, $\delta = 1.6325$ ($\delta = 0.0255$).

An analysis given by Reid (1923, p. 55) is as follows:—SiO_2:36.86, Al_2O_3:36.72, FeO:5.66, MgO:3.92, MnO:0.66; CaO:0.34, Na_2O:3.57; K_2O:1.11; B_2O_3:10.56; F:0.61; total: 100.01. Though no H_2O is given the analysis indicates a composition somewhere between a schorl and dravite type and this matches the optical properties.

The occurrence of these totally altered porphyries is limited and is probably due to very local influxes of pneumatolytic vapours or solutions, particularly on the margins of the porphyry dykes.

In summary, the sequence of events at Mt. Bischoff is considered to have commenced with the diapiric injection of a narrow cupola of granitic material into the hinge of the Bischoff Anticlinorium, the cupola probably being connected to underground extensions of the Meredith Granite (Fig. 3). The diapiric upthrusts produced tensional stress in the roof sediments with the formation of a radial pattern of tension faults splaying outwards from the focus of injection. These tensional openings were then intruded by quartz porphyry dykes, several of which protruded along selective stratigraphic horizons as sill-like extensions. Associated with the emplacement of the porphyries, pneumatolytic vapours or solutions rose up from the cupola along the open channel-ways of the marginal brecciated walls of the porphyries, producing widespread replacements of primary feldspar by topaz, tourmaline, fluorite, sericite and cassiterite and finally, by pyrite, arsenopyrite, pyrrhotite and cassiterite.

As recognized by Twelvetrees and Petterd (1897) the quartz porphyry dykes are similar to the elvans of Cornwall, England. In this area, folded Palaezoic slates and sandstones, and later granitic stocks, are intruded by greisenized quartz porphyry dykes (MacAlister, 1908; Lindgren, 1933; Llewellyn, 1946; Dewey, 1948; and Dunham, 1952). The tin deposits are limited areally to the foci of intrusion with copper and lead-zinc lodes in the surrounding area. Greisenization has been extreme in the Cornwall deposits, the granite along the lode walls being altered to quartz, muscovite and topaz as aggregates pseudomorphing partly altered feldspars. Fluorite is present in places and the secondary quartz is filled with liquid inclusions. The quartz porphyries have also been altred to quartz, tourmaline, topaz and fluorite with kaolin locally. The alteration is limited to areas of mineralization and is not widespread through the granite.

Kaolinization of the granite has occurred over quite extensive areas and is considered a relatively low temperature effect, as in the marginal zones at Mt. Bischoff. In the porphyries there has been an addition of iron, tin, fluorine and boron as at Mt. Bischoff but potassium remains high, probably due to the formation of muscovite. It is probable that similar hydrothermal and pneumatolytic alteration processes occured both at Mt. Bischoff and Cornwall, indicating a similar granitic source.

(d) JURASSIC ACTIVITY

Dolerite

Two bodies of Jurassic dolerite intrude Cambrian (?) sediments in the area. The largest occurs north of the Magnet Mine and is a dyke-like mass extending for about 1500 feet in a north-easterly direction. The second mass is a small intrusive just west of the Magnet Tram, to the north of the contact of basalt and Cambrian (?) sediments. Thin sections of these rocks (715 and 35 G.2-Mines Dept.) show augite and labradorite exhibiting an ophitic to doleritic texture, the individual crystals occurring up to 1.5 mm. in length. Between the larger crystals is a fine ground mass of quartz and feldspar with some fine interstitial magnetite.

The dolerite is identical to phases of the dolerite sills intruding Permian and Triassic rocks in south-eastern Tasmania.

(e) TERTIARY ACTIVITY

Basalt

A basalt sheet, some 50 to 150 feet thick, occurs extensively over the plateau area between Waratah and Guildford, on the Magnet Range, and as small remnants elsewhere in the area. It generally overlies Tertiary terrestrial sediments, the base being at an elevation of 1900 to 2000 feet.

The basalt (30652 and 35 G.6 Mines Department) generally consists of a fine intergrowth of labradorite and augite, up to 0.3 mm. in length, with interstitial calcite and magnetite. Olivine is generally present, occurring as larger crystals up to 2 mm. in diameter that have been slightly serpentinized. Tachylyte also occurs in places, specimen 35 G.7 (Mines Department) consisting of large particles of green glass, up to 6 mm. in length, with a ground mass of labradorite, calcite and augite. In places the basalt is extremely vesicular and in some cases is scoriaceous.

Three thin basaltic dykes occur in the Arthur River intruding Cambrian (?) sediments; one about 1½ miles upstream and one 2 miles downstream from the confluence with the Waartah River, and one about 1½ miles upstream from the old Magnet Tram bridge. These may represent 'feeders' for the main basaltic sheet. A specimen from the basaltic dyke near the Magnet Tram (30652b) contains phenocrysts of labradorite in a ground mass of labradorite, purplish-brown augite and magnetite. Magnetite also occurs abundantly as elongate blebs in the cleavage cracks of the labradorite phenocrysts. Amygdules of chlorite and a fibrous zeolite are also present. Olivine is apparently absent.

STRUCTURE

The dominating structural feature of the district is the E-W trending Bischoff Anticlinorium within which the Precambrian rocks outcrop. This structural trend is unusual in NW Tasmania, where the majority of boht large and small scale structures trend NW or NNE (Carey, 1953; Solomon, 1962).

The Waratah district is supposed to lie between early Palaeozoic geanticlinal ridges, the margins of which trend about NNE in NW Tasmania. Early Tabberabberan folding is thought to have been controlled in trend by these pre-existing surfaces, and later folding, on NW trends, is thought to be due to some "external" cause (Solomon, 1962).

The E-W structures may reflect some much earlier deformation, the trends of which have locally altered the dominant Tabberabberan directions. A pre-Cambrian deformation is indicated by the microscopic fabric in the Precambrian (?) sandstones and by other features to be described.

Devonian Structures

Folding

The form of the Bischoff Anticlinorium is indicated by the map of the Precambrian inlier (Figs. 1, 2 and 3). Its wavelength is approximately 5 miles and its amplitude approximately 2 miles. It plunges gently to the west and probably also to the east, to form an elongate dome. The contact between Bischoff quartzites and slates and the Cambrian (?) sediments on the southern flank shows apparent concordance, with minor faulting, while the northern flank is largely occupied by the Magnet Dyke which extends along a possible fault contact between the two sequences. The main zone of porphyry dykes is concentrated in the axial surface of the anticlinorium and it is suspected that a granite cupola exists beneath Mt. Bischoff.

Smaller folds with wavelengths of 100 to 1,000 feet occur on the anticlinorium; the majority have been mapped by using the base of the dolomite as a marker horizon. These folds have been outlined fairly accurately in the Bischoff mine workings and here they are typically associated with sub-longitudinal tensional faults that tend to obliterate limbs of the folds. In the Brown Face syncline the faulting is slightly oblique to the fold axis and as a result the dolomite base has a "keel" form. The folds of the Bischoff mine have very shallow plunges, dominantly to the west. Previous interpretations of the plunge of these folds (Knight, 1953, Hall & Solomon, 1962) have not recognized the importance of slightly oblique faulting producing keel-like structures. The exposed extent of these folds is limited by NNW faults, almost transverse to the fold axes (Fig. 4).

The Main Tunnel of the Mt. Bischoff mine extends from the north to the south side of the mountain and, although partly filled in, it provides a sub-surface cross section through a zone of minor folds on the anticlinorium. Mapping of the tunnel shows fairly gentle undulations below structures which at the surface have considerable amplitude, indicating that the minor folds on the anticlinorium die out within depths approximating to the wavelengths of the folds.

North East Folds

Distorting this general W trend of folding are smaller folds which show a variable trend, with a distribution of axial surfaces around 60°M. These NE folds and also the larger W structures are highlighted by the plot of axial surfaces shown in

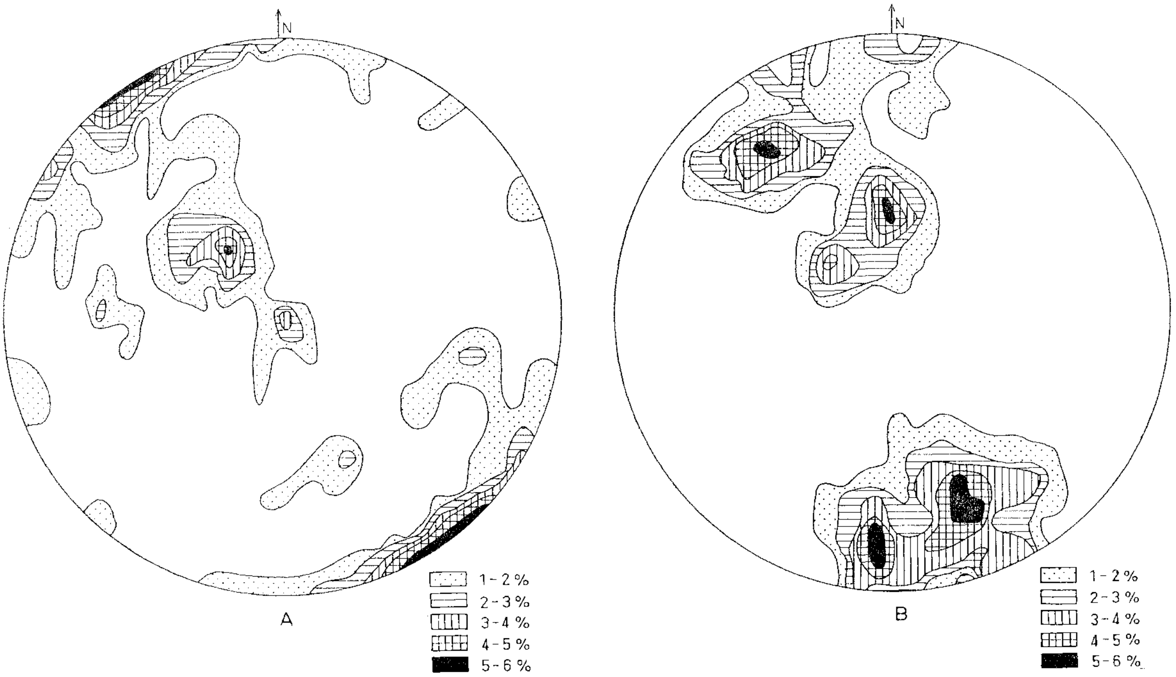

FIG. 7.—Stereographic projection (lower hemisphere) of:—
(*a*) Axial surfaces of folds.
(*b*) Poles to bedding planes.

Fig. 7a, also by the plot of several hundred bedding readings taken between Don Hill and the Arthur-Waratah River confluence (Fig. 7b). These folds which vary in wavelength from 2 to 100 feet, vary in plunge from northerly to southerly. The axial surfaces generally dip towards the SSE on the southern limb of the anticlinorium and towards the NNW on the northern limb, although there are minor variations. The folds are restricted in exposure to areas of thin-bedded shales and quartzites and are abundant in the Mt. Bischoff mine where they are so intense as to almost obliterate the W folding. Small folds belonging to this group are also evident in thin bedded mudstones of the Cambrian (?) sequence. The folds display all variations from a concentric to a similar style of folding, although a concentric style is dominant.

A small group of folds, of similar wavelength and style to the previously mentioned folds, occur with a NNW to NW trend. A large proportion of the folds are restricted to areas adjacent to NNW to NW faults, and were probably produced by local fault movements.

Generation of Folds

There is no reliable indication of the order of super-imposition of the two main fold generations, though it is suspected that the small wavelength folds are later than the larger.

Faulting and Jointing

The majority of known Devonian faults appear to be tensional and either of W or NNW trend. A plot of the poles of faults other than of W trend indicates a variation in strike from between 330° and 350°M, with the majority at 340°M. These faults dip fairly consistently to the west at high angles, though some are vertical and a few dip very steeply east. An important fault of this group displaces the minor W folds on the Bischoff anticlinorium. Other parallel faults cut the porphyry dykes and are mineralized, indicating a post-intrusive age. In a few, shearing of the ore indicates later movement on the pre-existing faults.

Well developed joints, with 6 inches to 2 feet spacing, strike consistently at 340°M and these joints in many cases carry quartz and cassiterite. They occur in porphyry dykes and in both Cambrian (?) and Precambrian sediments. They appear to be later than the folding and dyke intrusion and related to the mineralization phase.

The normal faults accompanying folding, with longitudinal or slightly transverse trend, have already been described.

As previously mentioned the porphyry dykes were probably injected into a set of radial tension fractures formed by rise of a cupola-like mass into the Bischoff Anticlinorium. Some movement along these fractures is indicated by the presence of breccias and by displacements of marker horizons across the dykes. The displacements are estimated to be less than 100 feet. Fissure veins several feet in width occupy tension fractures, some of which appear to be related to the radial prophyry pattern and others to the 340°M trend.

The displacements developed by the north-south folds inferred by Knight (1953) appear to be due to movement on the 340°M faults.

Pre-Devonian (?) Structures

A number of small scale folds and thrusts are confined to the Precambrian sediments and may be related to some pre-Tabberabberan tectonic phase. Isoclinal folds with wavelengths of several feet are confined to relatively thin-bedded quartzites of the Bischoff quartzites and slates. The folds trend 80°M to 90°M and occur within the limbs of the minor, E-W trending folds. The folds plunge shallowly both to the east and west, no steeply plunging folds being observed.

Chevron folds, with a wavelength of 1 to 10 feet are limited to the marginal zones of the Precambrian (?) core, occurring commonly in the Arthur River and Magnet Creek near the confluence of the two streams, and more rarely on the southern contact of the south-east slopes of Don Hill. Up to twenty chevron folds with subparallel vertical axial surfaces have been observed in a single outcrop in the Arthur River area. The folds, which trend between 40°M and 50°M and plunge steeply to the south-west and north-east, occur exclusively in thinly bedded quartzites and shales.

Small recumbent folds, generally with a wavelength of approximately one foot, occur sporadically throughout the area. They appear limited lithologically to thinly bedded shales and structurally to local areas where the isoclinal folding has been less intense than elsewhere. Cascades of several of these folds with slightly variable axial surfaces occur in places, although single folds within shale bands are more common.

Small monoclinal 'warps' are a distinctive feature of the deformation of the Bischoff quartzites and slates. They occur on a small scale throughout the area, generally in shales and rarely in quartzites. The axial surfaces of the monoclinal bends are locally dependent on the orientation of larger folds and are variable throughout the area.

At this stage it is not possible to be certain of distinguishing between pre- and post- consolidation structures, particularly in rocks with a lack of cleavage associated with the folds.

Insufficient structural work has been done to firmly date the age and sequence of development of this group of folds. The quartz microfabric in the Bischoff quartzites indicates an early movement phase and this is further indicated by the presence of isolated blocks of quartzite within shales in parts of the Bischoff succession. These blocks are generally elongate parallel to bedding and taper at their extremities with shales "flowing" around and enclosing the blocks. In most cases it has been impossible to determine whether these blocks represent fold mullions or boudins, but in some cases they appear to be part of a fragmented bed of quartzite.

Tertiary Faulting

The Tertiary terrestrial sediments are generally horizontal throughout the area although on the south-western flank of Don Hill they dip to the south-west at angles up to 50°; these steep dips, and associated folds, may be due to late Tertiary faulting but are more probably due to compaction of the Tertiary sediments against the bedrock cliffs.

The linear nature of the Waratah River, as described in a previous section, is suggestive of a possible Tertiary fault trend.

MINERALIZATION

Mt. Bischoff is situated in a strip of dominantly low grade silver-lead-zinc mineralization which trends north-north-easterly and lies on the north-west flank of the large granodiorite mass centred at Mt. Meredith. Tin mineralization occurs within the granitic mass to the south of the Waratah-Corinna Road, in association with quartz porphyry dykes at Mt. Bischoff, and adjacent to reported quartz porphyry dykes at the Cleveland Mine.

Tin Mineralization

Granodiorite

Mineraliaztion is confined to aplitic and pegmatitic bodies within the main granodiorite mass. The ore bodies are small and largely lenticular in shape and they comprise arsenopyrite, molybdenite, pyrite, chalcopyrite, sphalerite and cassiterite in a gangue of green, fluorine-bearing mica. Quartz and tourmaline are commonly present in association with the ore. The lodes do not appear to have any distinct structural control.

Mt. Bischoff

At Mt Bischoff, tin mineralization has been more localised and more intensive than in the granodiorite. The tin occurs in a number of widely differing types of ore body, which are limited to a circular area of 2000 feet radius from the centre of the mountain. The ore bodies comprise (a) a large replacement body in dolomite, (b) numerous vein deposits, (c) replacements of porphyry and (d) incrustations on joint faces, in and adjacent to porphyry dykes.

(a) The main ore body was formed by replacement of the dolomite bed which occurs towards the top of the Bischoff quartzites and slates. This bed, which was probably folded prior to mineralization, has been largely replaced by pyrrhotite, pyrite, talc, quartz and an iron-manganese- magnesium carbonate. Typical analyses of this secondary carbonate are given in Table 4. Within the replaced dolomite are semi-continuous layers of apparently sheared talc which are possibly secondary after tremolite. This alteration probably results from metasomatic alteration of the dolomite along shear zones.

At the eastern end of the Brown Face open cut is an outcrop of dark gren and yellowish rock that is composed of chondrodite partially replaced by serpentine (chrysotile?) and pyrrhotite. It is colourless and non-pleochoic, has $2V=72+ve$, $\alpha=1.615$, $\beta=1.635$, and is twinned on (001) and also on other composition planes (not yet determined). The identification of chondrodite was confirmed by X-ray diffraction.

The distribution of mineralization is extremely irregular within the body, some sections comprising massive sulphides while others are virtually sulphide free. The distribution of the sulphides themselves is more regular, pyrrhotite being the dominant sulphide towards the centre of mineralization, while pyrite and sphalerite are more common to the north and south. Mineralization was apparently confined to a relatively small area, as unmineralized dolomite crops out to the south in Happy Valley and to the north, on the northern slopes of the Waratah River valley.

The tin, dominantly as cassiterite, occurs throughout the replacement body and although microscopically associated with gangue minerals is most abundant in zones of high sulphide concentration. These zones are commonly slightly oblique to the margins of the dolomite bed and occur in different structural environments throughout the mine area. In general they occur within south-dipping limbs of the dolomite with local concentrations adjacent to fault walls. The zones of highest concentration may represent lode channels for the mineralization.

Table 4

Analyses of Mineralized Dolomite, Mt. Bischoff

	I	II
SiO_2	6.00	1.00
Al_2O_3	0.95	1.56
Fe_2O_3	—	—
FeO	2.56	12.72
MnO	0.92	13.26
MgO	11.75	14.46
CaO	21.08	3.20
Na_2O	—	—
K_2O	—	—
$H_2O\pm$	7.00	6.40
CO_2	49.64	47.40
F	—	—
FeS	—	—
SO_3	—	—
	99.90	100.00

I.—From Happy Valley Face (Reid, 1923, p. 86).
II.—From Mt. Bischoff (Reid, 1923, p. 86).

Stillwell (1945) has divided the ore into three dominant types: (i) carbonate-sulphide ore, (ii) massive pyrrhotite ore and (iii) pyrrhotite-talc ore.

(i) The carbonate-sulphide ore consists essentially of coarse grained carbonates, grain diameter up to 5 mm., containing irregular splashes and veinlets of sulphides, dominantly pyrrhotite, pyrite and arsenopyrite. Small blebs of chalcopyrite and galena and crystals of cassiterite occur rarely in the sulphides. Small clusters of cassiterite up to 0.25 mm. in diameter occur more commonly in the coarse carbonate, and are partially coated with a thin film of chalcopyrite and stannite.

(ii) The massive pyrrhotite ore is dominantly pyrrhotite with colloform masses of pyrite and a little marcasite. Irregular threads of chalcopyrite, bismuthinite and galena are also present, and Stillwell reports minute grains of stannite (0.01 x 0.005 mm.) occurring in chalcopyrite veins. Minor proportions of quartz, fine platey talc, fine carbonate, fluorite and zeolite are embedded in the pyrrhotite.

(iii) The talc-pyrrhotite ore comprises alternate bands of pyrrhotite and talc up to 2 mm. wide. The pyrrhotite bands are crossed at irregular intervals by carbonate and pyrite veins, and contain rare cassiterite crystals. Small chalcopyrite veinlets occur on the boundary of pyrrhotite and talc masses.

(b) Vein deposits carrying cassiterite occur throughout the mountain. These lodes fill fractures which in places displace porphyry dykes and cut the pyrrhotite replacement body; hence they are considered a later phase of mineralization than the dolomite replacement. The veins have strike lengths up to 2,500 feet and dip length up to 1000 feet and they pinch and swell along both dip and strike. The veins also commonly branch and converge forming a complex system of subsidiary ore bodies. The veins comprise cassiterite, in association with pyrite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, galena, jamesonite, bismuthinite, wolframite, stannite, quartz, siderite, tourmaline, fluorite and topaz, the relative proportions of these constituents varying considerably from one vein to another (see Stillwell, 1943). Apart from the major veins with an average width of 2 feet, there are subparallel sets of minor veins, some 1 to 2 inches in width, which commonly consist of quartz and cassiterite. These are generally too small to be economic.

The veins vary in strike from NNW to WNW and generally dip steeply to the west. This is also true of the minor vein deposits.

(c) The quartz porphyry intrusives have been mineralized throughout most of the mine area by topaz, tourmaline, fluorite, pyrite, pyrrhotite and cassiterite; these minerals generally pseudomorph feldspar. In places the proportion of this disseminated cassiterite ore was high enough for quarrying of the porphyry to prove economic.

(d) Well crystallized crystals of cassiterite, with a little quartz and tourmaline, also occur as incrustations on joint faces within the porphyry and in the quartzites and shales, for up to 15 feet on either side of the intrusives. Where the joint frequency is considerable, the rocks have been mined by open cut methods.

Replacement of the dolomite and quartz porphyries probably involved a protracted period of alteration dependent to a large extent on temperature gradients and variations in gass and water pressure. However, the mineral assemblages formed at Mt. Bischoff can be satisfactorily divided into two temperature-dependent groups which are partially gradational. The higher temperature mineral assemblage consists of topaz, tourmaline, cassiterite, muscovite and some fluorite which largely replaces the quartz porphyries. This phase represents the introduction of fluorine and boron-rich vapours which were largely confined to high temperature zones delineated by the quartz porphyries.

Equivalent alteration of the dolomite horizon appears limited, although it is probably represented in the formation of chondrodite, minor topaz and tourmaline and possibly tremolite. Replacement of the dolomite horizon involves widespread magnesium metasomatism with alteration of virtually pure dolomite mineral (Table 2) to magnesium-rich carbonates and talc (Table 5). The dominant assemblage is sulphides, talc, carbonates, " serpentine ", sericite, fluorite and cassiterite probably representing a slightly late more widespread, aqueous phase of mineralization under lower temperature conditions. Replacement of chondrodite by " serpentine " and possible replacement of tremolite by talc confirm this sequence.

Conformable pyrrhotite-pyrite-cassiterite bodies similar to that at Mt. Bischoff occur at Renison Bell and Mt. Cleveland (25 miles south, and 8 miles south-west, of Mt. Bischoff respectively).

The deposits at Renison Bell (Fisher, 1953; and Hall and Solomon, 1962) are gently dipping pyrrhotite sheets, up to 200 feet thick, or steeply dipping fissure lodes comprising pyrite and pyrrhotite. They occur in a Cambrian perhaps partly late Precambrian, succession of mudstones, greywackes, sandstones and dolomite, the pyrrhotite replacement bodies occurring mainly in a succession containing dolomites. The sediments have been folded into NW-trending anticline with normal faulting both parallel and oblique to the fold axis. Greisenized quartz porphyry dykes cut the sediments near the anticlinal hinge. The associations of greisenized quartz porphyry dykes with conformable pyrrhotite replacement bodies in Cambrian-Precambrian successions containing dolomite at both Mt. Bischoff and Renison Bell suggest a similar origin for the two deposits.

At the Mt. Cleveland Mine (Reid, 1923; Hall and Solomon 1962) pyrrhotite sheets replace certain beds in a sequence of Cambrian (?) sediments. As at Mt. Bischoff and Renison Bell, both replacements and fissure veins carrying cassiterite occur. The ore bodies comprise pyrrhotite, pyrite, chalcopyrite, arsenopyrite, quartz and cassiterite. Reid (1923) records that there are quartz porphyry dykes intruding the sediments in this area though later workers have failed to find the dykes. The Cleveland ores are basically similar to those at Mt. Bischoff but occur in a higher stratigraphic horizon and have a less obvious relationship to porphyry dykes.

Silver-Lead-Zinc Mineralization

Isolated, small silver-lead zinc veins are common throughout the Waratah District, intersecting both the Bischoff quartzites and slates and the Cambrian (?) sediments. The largest deposit occurs at the Magnet Mine as a vein, some 10 to 15 feet in width, on the contact of albite porphyrite and websterite poryhyrite of the Magnet Dyke (Fig. 6). In depth this lode has a bifurcated structure with the main body of ore occurring at the junction of the two lodes, which were considered as intersecting shears by Nye (1923), Cottle (1953) and Edwards (1960).

The lode is dominantly ankerite with bunches and veinlets of galena and sphalerite and lesser amounts of arsenopyrite, pyrite, boulangerite, pyrargyrite, tetrahedrite and traces of chalcopyrite in a gangue of manganosiderite and ankerite (Edwards, 1960). Chalcopyrite occurs dominantly as segregation bodies in sphalerite, and pyrargyrite and tetrahedrite as drop-like inclusions in galena. Crustification textures are extremely common, with all sulphides interlayered with mangano-siderite. Cockade textures, developed about fragments of brecciated and serpentinized pyroxenite, are also common. Strong shearing and brecciation preceded the close of ore deposition with the production of elongate bent and brecciated fragments of galena and sphalerite which were later cemented by ankerite. This shearing and brecciation supports the theory of ore control by intersecting shears. Edwards (1960) also suggests that the mode of occurrence of the Magnet ore indicates an epigenetic origin and that the crustification and cockade textures indicate that the ore was, at least in part, deposited in open spaces.

The southern margin of the Magnet Dyke has also been a host for ore deposition, to the north-east of Magnet. A small lead deposit occurs at the Persic Section on the contact of Bischoff quartzites and slates with the Magnet Dyke. It may be significant that pyroxenite occurs on the southern margin of the dyke at this locality and also at Magnet. The Persic lodes are small, irregular and uneconomic, generally occuring as small splashes of galena and siderite within the country rock and not as a distinct vein as at the Magnet Mine. Small veins of quartz and carbonate which contain traces of copper and silver, also occur on the contact of Bischoff quartzites and slates and the Magnet Dyke at Fawkner's Show (North-east of the confluence of the Arthur River and Magnet Creek).

Small pockets of silver-lead-zinc mineralization are also common throughout the Waratah District away from the Magnet Dyke. The majority of these deposits are small, irregular uneconomic veins, the most extensive deposit occuring at the Silver Cliffs Mine to the north-west of Mt. Bischoff. This well banded lode consists of galena, jamesonite, sphalerite, pyrite and minor boulangerite in a gangue of quartz and siderite. Similar small lodes occur on the northern slopes of the Arthur River (Fig. 1). Small lodes of sulphantimonides, jamesonite, stibnite, berthierite and boulangerite occur in Tinstone Creek to the south-west of Mt. Bischoff and are probably related to the silver-lead-zinc deposits, which commonly contain a high proportion of jamesonite. This group of prospects forms a " halo " of lead-zinc mineralization around the Mt. Bischoff tin deposit.

A genetic relationship between the silver-lead-zinc deposits and the Mt. Meredith granodiorite mass is suggested by the occurrence of the deposits in a belt on the north-west flank of the mass and their general lack of areal conformity with other igneous masses in the area. Silver-lead-zinc mineralization probably occurred during the Devonian metallogenetic epoch along fractures in the roof sediments over a large granodiorite batholith which is now partially exposed. Tin mineralization was confied to aplitic and pegmatitic bodies within the granodiorite and an area cut by numerous porphyry dykes at Mt. Bischoff.

Determination of formation temperatures of the lodes in the Waratah District using the pyrrhotite and sphalerite geothemometer (Arnold and Reichen, 1962 and Kullerud, 1953) indicate a local temperature " high " at Mt. Bischoff with zonation outwards from the centre of intrusion. A lower, irregular temperature gradient existed over the remainder of the area, probably locally controlled by the granodiorite batholith.

The spatial association of sulphide-cassiterite and later stage silver-lead-zinc ores is a characteristic also of the Renison Bell and Cleveland mines and is in fact, typical of many tin-rich provinces. Bilibin(1955) suggestes, from a study of similar deposits in the U.S.S.R., that these sulphide-tin ores generally are related to the " late stages " of geosynclinal development, involving the intrusion of small granitic porphyries into fractured zones. He finds the majority of these deposits are Mesozoic or Tertiary.

Oxidation of the Orebodies

Gossans developed during the Tertiary over several outcropping sulphide orebodies. Indigenous gossan at the Magnet Mine is dominantly limonitic with bands of secondary minerals such as cerussite and pyromorphite. Gossans derived from pyrrhotite formed extensively over Mt. Bischoff. Though largely removed by mining, old reports indicate that they were a mixture of indigenous and exotic types. Pyrrhotite is very unstable in temperate conditions and breakdown resulted either in development of a friable limonitic crust with cassiterite concentrated at the base, or in complete removal of iron and sulphur, leaving a cassiterite or cassiterite-quartz sand on the surface. Where the orebodies cropped out on hillsides the cassiterite-quartz sand travelled down slope to form extensive eluvial and alluvial deposits. The spread of the exotic limonite was retarded to some extent by the presence of the dolomite bed but much of the dolomite was removed by the abundant sulphuric acid, resulting in further cassiterite concentration.

GEOLOGICAL HISTORY

Shallow water deposition of well sorted sands, silts and muds began during the Upper Precambrian. Chemical precipitation of dolomite with some contemporaneous deposition of muds and silts occurred towards the end of sedimentation with subsequent deposition of silts. Preconsolidation tectonics occurred in the sedimentary pile with the formation of pre-consolidation breccias and folds. A period of non-deposition, or deposition and erosion, ensued with minor tectonic activity.

Sedimentation again occurred during the Cambrian with the deposition of poorly sorted muds, silts and sands on a sinking sea floor. These sediments were in part derived from local uprisen areas of Precambrian rocks, as indicated by the common occurrence of detrital strained quartz grains, and from volcanic activity contemporaneous with deposition. Volcanic activity resulted in the formation of tuffs, volcanic breccias and spilitic rocks with associated near-surface basic intrusions. The origin of the albite in the lavas is controversial but it is thought to be primary or deuteric. The final phase of the Cambrian igneous activity resulted in the intrusion of transgressive tabular sheets of ultrabasic and basic rocks.

The depositional and tectonic history of the Ordovician and Silurian periods cannot be determined in this area. It is probable from the occurrence of widespread marine sedimentary sequences of both ages in adjacent areas that they were also deposited near Waratah and have been subsequently eroded.

A major orogenic period, the Tabberabberan Orogeny, disrupted sedimentation in the Devonian. Evidence from Eugenana and Point Hibbs indicates that the tectonic movements associated with this period took place between the early Lower Devonian and the late Middle Devonian (Burns and Banks in Solomon, 1962). The first stage of tectonic activity was characterised by arcuate, long wavelength NNE-trending folds formed throughout the NW sector of Tasmania, paralleling the NNE margin of the Tyennan Geanticline.

A local stress pattern, probably in part controlled by pre-existing features, caused the development of E and NE folding in the Waratah area, the major structural feature produced being the E-trending Bischoff Anticlinorium. The intrusion of granitic batholiths, commonly into structural highs, followed folding. A local narrow cupola of a granitic batholith intruded the crest of the Bischoff Anticlinorium at Mt. Bischoff, producing radial dilation in the roof sediments, with the formation of radial fractures. These were filled by quartz-feldspar porphyry bodies injected upwards from the narrow cupola. Pneumatolytic vapours produced intense greisenization of the porphyries with the formation of topaz, tourmaline, muscovite and cassiterite. Hydrothermal solutions rose upwards along the dykes introducing iron, tin, fluorine and sulphur with the formation of pyrite, pyrrhotite, cassiterite and fluorite in the porphyries. During the hydrothermal stage of mineralization selective replacement of the dolomite by iron sulphides, cassiterite, quartz, talc and carbonate occurred. Tensional faulting occurred throughout the area forming sub-parallel sets of mainly NNW-trending faults and joints. These provided the main structural control for subsequent mineralization with the formation of tin-bearing veins over the cupola at Mt. Bischoff and silver-lead-zinc veins over the remainder of the area.

Uplift associated with the Tabberabberan Orogeny apparently initiated a prolonged period of erosion as no further deposition occurred until the late Carboniferous or early Permian. Permian boulders in the Tertiary terrestrial sediments and the occurrence of a Permian tillite in the Hellyer Gorge to the north indicate deposition of Permian sediments although none outcrop in the area. There is no evidence of Triassic deposition in the area and it is probable that an extended period of erosion occurred in the Mesozoic with the exception of small intrusions of dolerite during the Lower Jurassic (?).

Peneplanation of the area during the early Tertiary resulted in the development of an extensive gently sloping plain with rare monadnocks, one of which was Mt. Bischoff. The plain was partly covered by terrestrial sediments during the late Tertiary, with subsequent outpouring of basaltic lava which reached a thickness of about 100 feet. Rapid dissection of this plateau followed and may have been initiated by faulting and uplift. Several of the mineralized areas were exposed during Tertiary erosion resulting in the formation of gossans and residual eluvial and alluvial deposits of cassiterite at Mt. Bischoff.

Recent sedimentation has occurred in the major rivers of the area, tin-bearing alluvium and gravels being deposited in the more mature sections of their course.

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REFERENCES

ARNOLD, R. G. AND REICHEN, L. E., 1962.—Measurement of the Metal content of Naturally Occurring, Metal-Deficient, Hexagonal Pyrrhotite by an X-ray Spacing Method. *Am. Mineral.* 47, 105-111.

BANKS, M. R., 1956.—The Middle and Upper Cambrian Series (Dundas Group) and its Correlates in Tasmania. *20th Cong. Geol. Intern. Mexico,* El Sistema Cambrico, 2, 165-212.

BILIBIN, G. A., 1955.—Metallogenetic Epochs and Provinces. Gosegeoltekhiz-dat. Moscow.

BLISSETT, A. H., 1962.—Geological Survey Explanatory Report, One Mile Geological Map Series, Zeehan. *Mines Dep. Tasm.*

BRADLEY, J., 1954.—The Geology of the West Coast Range, Part I. *Pap. Roy. Soc. Tasm.,* 88, 193-243.

CAREY, S. W., 1953.—The Geological Structure of Tasmania in Relation to Mineralization. *5th Emp. Min. Met. Congr.,* I, 1108-1128.

CHAPMAN, F., 1929.—On Some Annelid Remains from the Arthur River, N.W. Tasmania. *Pap. Proc. Roy. Soc. Tasm.* (1928).

COTTLE, V. M., 1953.—Magnet Silver-Lead Mine. *5th Emp. Min. Met. Congr.* I, 1160-1165.

DAVIES, J. L., 1959.—High Level Erosion Surfaces and Landscape Development in Tasmania. *Australian Geographer.* 7, 193-203.

DEER, W. A., HOWIE, R. A., AND ZUSSMAN, J., 1962.—Rock-Forming Minerals. Vol. I. Longmans, London.

DEWEY, H., 1948.—British Regional Geology, South-West England. *Dept. Sci. End. Res. Geol. Surv. Mus.*

DUNHAM, K. C., 1952.—Fluorspar. *Mem. Geol. Surv. Spec. Rept. Min. Res. G.B.,* 4.

DUNN, J. A., 1922.—Economic Geology of Mt. Bischoff Tin Deposits. *Econ. Geol.,* 17, 154-190.

EDWARDS, A. B., 1960.—Contrasting Textures in the Silver-lead-zinc Ores of the Magnet Mine, Tasmania. *N. Jb. Miner., Abh.* 94, 298-318.

FISHER, N. H., 1953.—Renison Bell Tinfield. *5th Emp. Min. Met. Congr.* I, 1179-1184.

GLAESSNER, M. F., 1957.—Palaeozoic Arthropod Trails from Australia. *Paläont. Z.,* 31, 103-109.

HALL, G., AND SOLOMON, M., 1962.—Metallic Mineral Deposits in the Geology of Tasmania. *J. Geol. Soc. Aust.,* 9, 285-309.

JOHNSTON, R. M., 1888.—Systematic account of the Geology of Tasmania. Govt. Print., Hobart.

KNIGHT, C. L., 1953.—The Mount Bischoff Tin Mine. *5th Emp. Min. Met. Congr.,* I, 1222-1232.

KULLERUD, G., 1953.—The FeS-ZnS System, A Geological Thermomter. *Norsk. Geol. Tids.* 32, 61-147.

LINDGREN, W., 1933.—Mineral Deposits. McGraw Hill, New York.

LLEWELLYN, B., 1946.—A Survey of the Deeper Tin Zones in a part of the Carn Brea Area, Cornwall. *Bull. Inst. Min. Met.*, 479, 1-28.

MACALISTER, D. A., 1908.—Geological Aspect of the Lodes at Cornwall. *Econ. Geol.*, 3, 363-381.

NYE, P. B., 1923.—The Silver-Lead Deposits of the Waratah District. *Bull. Geol. Surv. Tasm.* 33.

PETTIJOHN, F. J., 1956.—Sedimentary Rocks. Harper & Bros. New York. 2nd edition.

SCOTT, B., 1951a.—The Petrology of the Volcanic Rocks of South East King Island, Tasmania. *Pap. Roy. Soc. Tasm.* (1951), 113-136.

————, 1951b.—A Note on the Occurrence of Intergrowth between Diopsidic Augite and Albite and of Hydrogrossular from King Island, Tasmania. *Geol. Mag.* 88, 429-431.

————, 1954.—Metamorphism of the Cambrian Basic Volcanic Rocks and its Relationship to the Geosynclinal Environment. *Pap. Roy. Soc. Tasm.*, 88, 129-149.

SOLOMON, M., 1960.—The Dundas Group in the Queenstown Area. *Pap. Roy. Soc. Tasm.*, 94, 33-50.

————, 1962.—The Tectonic History of Tasmania in The Geology of Tasmania. *J. Geol. Soc. Aust.*, 9, 311-339.

SPRY, A. H., 1957.—Precambrian Rocks of Tasmania. Part I, Dolerites of North-West Coast, Tasmania. *Pap. Proc. Roy. Soc. Tasm.*, 91, 81-93.

STILLWELL, F. L., 1943.—Tin Ore from the North Valley Lode, Mt. Bischoff. *C.S.I.R.O. Minerographic Rept.* 268.

————, 1945.—Tin Ore from the Greisen Lode, Mt. Bischoff. *C.S.I.R.O. Minerographic Rept.* 322.

TWELVETREES, W. H., 1900.—Report on the Mineral Fields between Waratah and Corinna. *Tasm. Parl. Pap.*, 63, 47-67.

————, AND W. F. PETTERD, 1897.—On the Topaz Quartz Porphyry or Stanniferous Elvan Dykes of Mt. Bischoff. *Pap. Roy. Soc. Tasm.* 125, 119-129.

WRIGHT, A. E. AND BOWES, D. R., 1963.—Classification of Volcanic Breccias: A Discussion. *Bull. Geol. Soc. Amer.* 74, 79-86.

PLATE I—

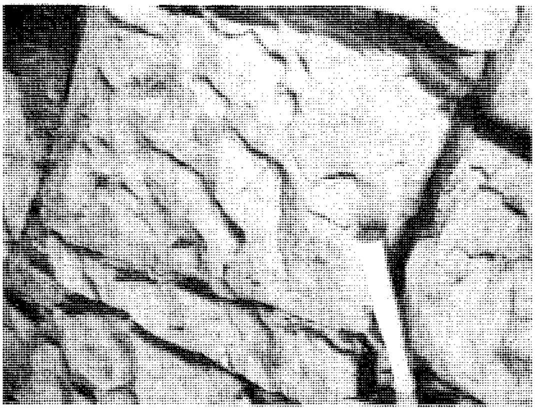

FIG. 1.—Slightly deformed flow casts in Precambrian quartzite, Waratah River.

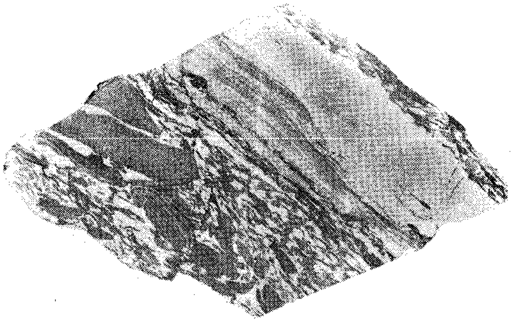

FIG. 2.—Pre-consolidated breccia in Bischoff quartzites and slates, West Mt. Bischoff. 1/16 natural size.

FIG. 3.—Tertiary sediments showing differential compaction (?) against quartz porphyry bedrock, Don Hill, Mt. Bischoff. Plate by courtesy of J. Wilson.

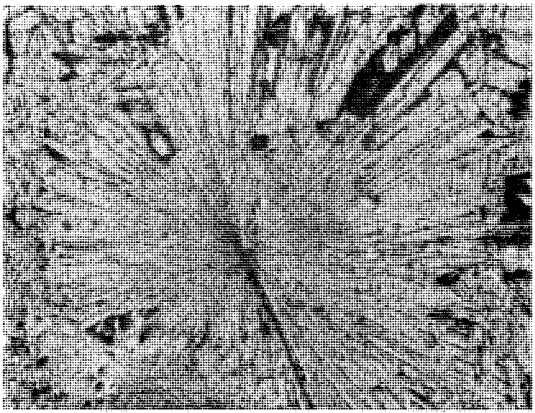

FIG. 4.—Radiating topaz replacing quartz porphyry, White Face, Mt. Bischoff; x 35.

PLATE II—

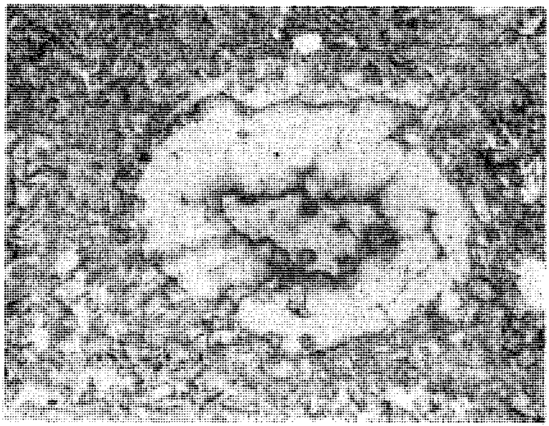

FIG. 1.—Amygdule containing quartz spherulites in Cambrian lava, Arthur River; polarised light, x 68.

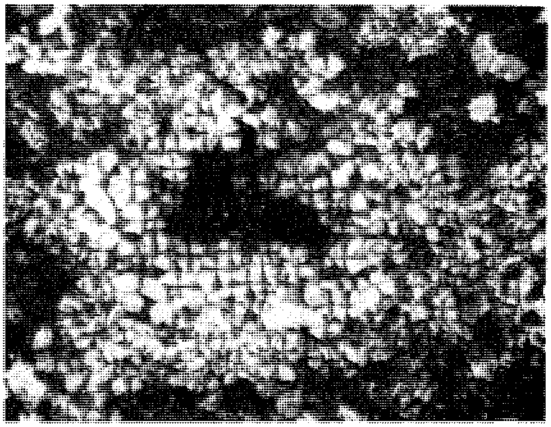

FIG. 2.—Identical field of view, crossed nicols, x 68.

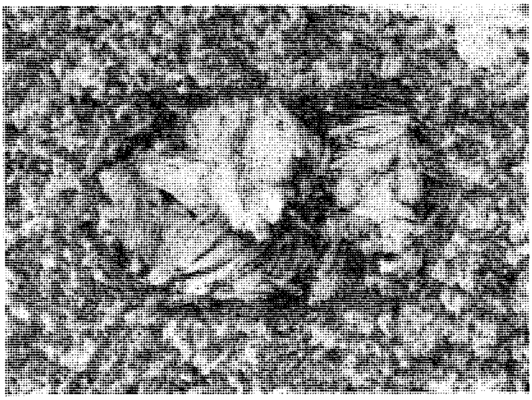

FIG. 3.—Radiating topaz pseudomorphing feldspar in quartz porphyry dyke, Mt. Bischoff; x 68.

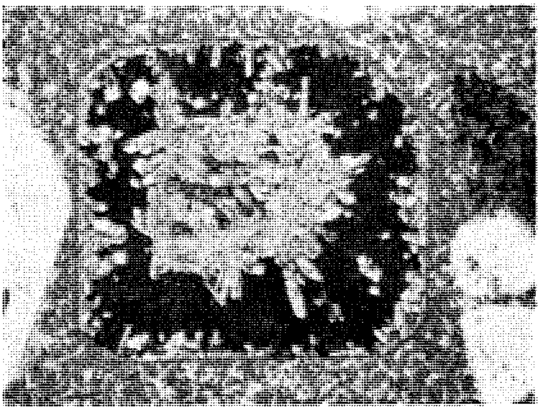

FIG. 4.—Pyrite and topaz pseudomorphing feldspar in quartz porphyry dyke, Mt. Bischoff; x 35.