"Water, water everywhere."
THE GEOLOGY AND MINERAL DEPOSITS OF THE MOINA-LORINNA AREA

by

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The oldest rocks exposed in the area are quartzites and schists of the Dove Group which underwent considerable deformation during the Precambrian. Upper (?) Cambrian acid lavas, volcanics, greywackes, cherts, siltstones and quartzites comprise the Bull Creek Volcanics and the Lorinna Volcanics. These rocks were formed in an easterly extension of the Dundas Trough, north of the Tyennan Block. The Dove Granodiorite intruded these rocks along the southern margin of the Trough in Late Jukesian (?) times. The petrology of the Cambrian rocks is discussed in some detail and it is concluded that the acid lavas were derived from the same magma as the Dove Granodiorite.

Ordovician rocks in this area consist of the Roland Conglomerate at the base, which is conformably overlain by the Moina Sandstone and the Gordon Limestone in turn.

During the Tabberabberan Orogeny, these rocks were folded and faulted into northwesterly trending structures. The Dolcoath Granite intruded late in the Tabberabberan Orogeny causing some metamorphism of the country rocks. It is suggested the granite intruded as a northerly dipping, roughly tabular body. There may be a small cupola in the Stormont area.

The majority of the mineral deposits in this area are genetically related to the Dolcoath Granite. A fairly distinct zone of wolfram-cassiterite deposits surrounds the northern part of the granite. Around this, is a zone of auriferous sulfides. The mineralogy of these two zones is described.
Areas most likely to prove of economic importance are indicated together with suggested sites for a preliminary diamond-drilling programme.
1. INTRODUCTION

During the summer of 1964-65 field work was carried out in the Moina-Lorinna area of central northern Tasmania. It was originally intended to make an intensive study of the mineralization and mineralogy of the area but, although most of the old mines were visited, ore specimens were extremely difficult to obtain as most of the workings are now inaccessible due to falls of ground and thick overgrowth. Specimens were collected wherever possible and polished sections of ore minerals prepared. The Cambrian rocks south of the Dolcoath Granite have been subjected to a fairly detailed petrological study. It was hoped to carry out a number of spectrographic analyses of these rocks and a number of glass discs were prepared according to the method of Norrish and Hutton (1964). Unfortunately, much difficulty was experienced with the counter window of the diffractometer; this could not be rectified in time to carry out the analyses.

The whole area had been mapped regionally on a scale of one inch to one mile by the Tasmanian Department of Mines and the maps produced by them – the Middlesex and Sheffield Geological Sheets – were used as base maps for field work. All grid references quoted in this text refer to the 10,000 yard grid on these sheets. All bearings given are magnetic bearings. The field mapping was done on excellent quality aerial photographs on a scale of one inch to thirty chains, flown in 1958.
All research has been carried out at the University of Tasmania except for the isotopic age determinations of the granodiorites which were done at the Australian National University, Canberra by Dr. I. McDougall. A number of specimens studied were on loan to the author from the Tasmanian Department of Mines and the Queen Victoria Museum, Launceston.

**Location**

The area studied (fig. 1) extended from a few miles west of Moina east to Round Hill and south to the southern boundary of the Dove Granodiorite. In addition, the granodiorite outcropping in the Mersey River area was examined.

**Settlement**

Sheffield and Wilmot are the closest towns of any size but both are well outside the area (see fig. 1). Gowrie Park, an H.E.C. village and service centre, is about fourteen miles north of Lorinna. There are post offices at Lorinna and Erriba (six miles north of Moina). Lorinna was originally quite a large farming and timber community but now only about half a dozen families live here. Moina was once a small mining town, based on the Shepherd and Murphy Mine, but now only one run-down farmhouse and a few outbuildings remain.

**Access**

The Cradle Mountain road passes through the eastern part of the area and the road to Lorinna passes through the western part. Both these roads are gravel and their surfaces are not particularly good. West of Lorinna, several timber tracks are passable when dry, with four-
Figure 1. Locality map
wheel drive vehicles. In the Moina area, there are a few tracks heading east from the Cradle road which are passable, in summer, to cars with a fairly high clearance. The Hydro Electric Commission is constructing access roads to its dam sites and most of these will be passable to all traffic upon completion. Apart from these, there are tracks leading to many of the old mines but most of these are overgrown and difficult to follow.

In the summer months, it is possible to traverse the Forth, Dove and Mersey Rivers without too much difficulty but it is practically impossible during winter and spring. The tributaries of these rivers can usually be followed but generally their courses are quite steep and often thickly overgrown, making movement very difficult.

**Outcrop**

Overall, the outcrop is decidedly poor. Along the Lorinna road from Cethana to one mile north of Lorinna, there is almost continuous outcrop, but the other roads do not present such good sections. In the Forth River, outcrop is quite good though it rarely extends for more than a few yards up the valley sides. The creeks, almost without exception, are filled with rubble and consequently exposures are few. Many of the exposures, especially around the old mines, available to earlier workers have now been covered by dense secondary regrowth which took over after the primary vegetation had been cleared for mining operations.

Between rivers and roads, outcrop is very scarce in areas of Cambrian rocks or granite and it is little better in areas of Ordovician sediments.
Climate

The average annual rainfall at Moina is 71 inches and is 55 inches at Lorinna. Very little rain falls in the December-February period but during winter the rainfall is heavy and is often supplemented by snow, especially on higher ground. During summer, temperatures in the 90's are commonplace in sheltered valleys and the weather is quite pleasant, as few hot days are without a welcome afternoon breeze. Winters on the other hand, are cold and wet; on days without rain there is generally a heavy morning frost on the cleared areas that persists throughout the day in areas protected from the weak, wintry sun.

Vegetation

There are four main types of vegetation:

1. Open grazing lands in the Moina, Lorinna and Daisy Dell areas. Around Moina and Lorinna, the land has been cleared and pasture sown for grazing and fodder. Some farming has been carried out but at the present time, grazing is the main occupation. Access in these areas is good.

2. Open eucalypt forest with sparse undergrowth is found on the higher and flatter areas, generally limited to soils developed on basalt or quartzite. These areas are easy to traverse.

3. Thick eucalypt forest with dense undergrowth occupies the upper slopes of valleys generally on the western or southern slopes of watercourses. Access in these areas is poor due to the thick undergrowth and steep slopes.
4. Myrtle-sassafrass rainforest is common along the wetter, western sides of the Forth Valley, on the northern side of the Dove River and in the lower parts of the larger creeks. Undergrowth is very thick and makes movement through these areas very trying. In several places on the western side of the Forth, the rainforest has been logged.

These four types of vegetation show quite a noticeable climatic and altitudinal control on a local scale. In the more protected, wetter valley bottoms thick rainforest or eucalypt forest predominates. This becomes more open higher up the valley side as rainfall decreases and the amount of protection decreases. The highest slopes and divides are the driest and most exposed areas and open eucalypt forest dominates here.

In the Moina and Lorinna areas, many of the creeks are completely choked by blackberries making movement impossible along the creeks. This is especially noticeable in Bismuth Creek at the Shepherd and Murphy Mine.

**Economic Pursuits**

Lorinna is the only settlement in the area studied and here, some half a dozen families are engaged in cattle grazing. Transhumance is practised in the Moina area and on the Middlesex Plains. Some fodder crops are grown on the banks of the Iris River at Moina.

Several areas are being logged on the Middlesex Plains, west of the Forth River and west from the Dove Mill which is well south of the area.
The All Nations, Iris and Narrawa Reward Mines are worked in a desultory fashion by the lessees and prospectors occasionally sink a trench or two in search of quartz-bearing wolfram or cassiterite veins, or alluvial gold and cassiterite.

The Hydro Electric Commission is active in the northern and north-western parts of the area, to the south at Lemonthyme Creek and at a number of points in the Mersey River. The Forth River will be dammed about half a mile north of Narrawa Creek by the Cethana Dam. The river will be about 200 feet deep at the dam and water will back up in the Forth to about 1\frac{1}{2} miles south of the Dove-Forth junction. A smaller, storage dam is planned to dam the Wilmot River just north of the Lea-Iris confluence and this will flood some of the grazing lands at Moyna. Water from this dam will eventually be transferred to the Cethana dam via a tunnel and a power station at the Cethana end of the tunnel. Other power stations are planned to be built below the Cethana dam and at Lemonthyme Creek, the outlet of a tunnel which transfers water from the power station below the Parangana dam on the Mersey River, to the Cethana dam.

These works are part of the Mersey-Forth Power Development Scheme which will have an installed capacity of approximately 290MW produced at a capital cost of about $A 103 million.

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2. **HISTORY OF THE MINING FIELDS**

Early in the 1860's, James "Philosopher" Smith discovered alluvial gold in the Forth River near Lorinna and carried out preliminary prospecting. His results were encouraging enough to make him return a few months later with more provisions and assistants to sink a number of shafts to determine the extent of the wash. Although the results were good, the work was abandoned due to water problems. The party then prospected the Dove River, finding a little gold and a galena lode near the Devon Mine. Returning down the Forth, gold was found near Geales Bridge and another galena lode was located at the mouth of Claude Creek.

In the following years, explorers battled their way up the creeks and rivers but it was not until 1878 that a worthwhile deposit was found. In this year, Weeks and Shepherd discovered galena in sandstone near Round Hill and in 1880, the Mt. Claude Silver Lead Company was floated in Launceston to develop this deposit. However, operations were unsuccessful and the Company folded up in 1884. 1885 saw the discovery of a gold lode at Campbells Reward Mine in the Forth River and a year later, the gold lode which led to the establishment of the Great Caledonian Mine on Five Mile Rise, was discovered. The latter mine threw light upon the Five Mile Rise area and in a short time a number of mines were started to explore auriferous and argentiferous gossan outcrops. These included the Golden Hills, the Golden Cliffs, the Union, the Thistle, the Glen and O'Rourke's Hydraulic Mines. However, the deposits proved to be unpayable below the surface where gossan gave way to low grade sulfides,
and operations soon ceased. Malcolm Campbell discovered the Devon lode about this time and this was later operated with moderate success for some time.

Cassiterite and wolfram were discovered on Dolcoath Hill in 1891 and later the same year, the Iris Mine began operations on an alluvial cassiterite - wolfram - bismuthmite deposit. The ever active Malcolm Campbell found rich alluvial gold south of Bell Mount in 1891 and this led to a minor gold rush which, at its peak in 1892, saw some 200 men engaged in frenzied scratching for nuggets.

The Shepherd and Murphy lodes were discovered in 1893 by T. Shepherd and T. Murphy and were soon being developed. This has been the most successful of all the mines, having been in continuous production since its discovery until a fire destroyed the mill in 1919 forcing the mine to close. Operations began again in 1921 but ceased in 1924 as the original shafts had not been unwatered and the present owners were loathe to put profits back into the mine for development. Between 1933 and 1950, J. P. Godwin carried out sluicing operations in a desultory fashion, concentrating on the area near Bismuth Creek. The Moina Tungsten Tin Mining Company N.L. began unwatering the shaft levels in 1953 and erected a new mill and concentrating plant. Production continued until 1958 when the mine again closed, possibly for the last time. As with most of the mines in this area, the owners of the Shepherd and Murphy have worked the mine on a 'get-rich-quick' basis, which led to rich ore being removed and ore which would be payable on a long term basis, was left.
If profits had been used to develop the mines rather than to line the shareholders' pockets, this mine might possibly still be in production. Mine management also seems to have been conducted on a non-scientific basis - in one case, a thirteen feet wide drive was put in following an eight inch wide lode: needless to say, the miners were being paid on the basis of amount of material removed, not volume of ore mined!

After the discovery of the Shepherd and Murphy lodes, the area was thoroughly prospected and many small wolfram and/or cassiterite deposits were developed. These smaller workings were abandoned by about 1910 and with the exception of the All Nations, Lady Barron, Iris and Narrawa Reward, have not been worked since. The latter mines have been worked in fits and starts from their discovery till the present day and have returned their workers tidy profits.

The Round Hill Silver-Lead Company began operations at Round Hill in 1913 and was very successful until 1925 when ore began to run out and the Company ceased operations in 1927. The leases lay vacant until the West Mt. Claude Mining Syndicate took them up in 1948 and began exploratory work. This Syndicate was still engaged in exploration in 1955, when the Tasmanian Department of Mines was asked to report on the area. Soon after this, the Syndicate ceased operations presumably after studying the report. The report was published by the Department of Mines in 1958 (Jennings, 1958).
3. PREVIOUS LITERATURE

In the early days of this mining field, many reports of a preliminary nature were written, dealing mainly with new mineral discoveries. These include reports by Thureau (1889), Montgomery (1894), Smith (1897, 1899), Waller (1901) and Twelvetrees (1908). The first comprehensive and systematic description of the Middlesex-Mt. Claude mining field was prepared by Twelvetrees (1913). This report dealt with the general geology and mineralization and describes most of the mine workings in detail. Hills (1916) surveyed the tungsten and molybdenite resources of Tasmania and dealt with this area in Part II of his report.

A. M. Reid visited the area in 1917-1918 and published his report in 1919. The report is based on Twelvetrees (1913) but it brought the mine descriptions up to date as there had been considerable development of some mines since Twelvetrees' visit.

Since Reid's report, very little was written on the area until 1958. Nye (1928) had reported on the Devon Mine, Nye and Blake (1938) briefly mention the area in their report on the mineral resources of Tasmania, and Reid (1943) reported on the Moina area.

The Tasmanian Department of Mines began a regional mapping programme in 1952 which culminated in the publication of the Middlesex and Sheffield Geological Sheets in 1958 and 1959 respectively, and the comprehensive Explanatory Notes to accompany the Middlesex Sheet (Jennings, 1963). Whilst these sheets were being prepared, a number of publications appeared, dealing with specialized topics arising from the
regional work. Among these were Elliston's work (1953) on Moina in *Geology of Australian Ore Deposits* (revised by Jennings, 1965) and papers by Jennings (1957) and Burns (1958a, b, 1959, 1960). Other work by the Department of Mines includes reports by Blake (1956), Robinson (1958), Jennings (1958) and Jack (1960) on various mines requested by the lessees.

The only work published outside the Department of Mines is a paper by Williams (1958) on the mineralization at the Shepherd and Murphy Mine and papers by Spry (1958, 1963) on the Precambrian rocks in the upper Mersey and Forth Rivers.
4. PHYSIOGRAPHY

Topography

The topography of the area is one of high relief, brought about mainly by the difference in resistance to erosion between Ordovician and Cambrian rocks. The high mountains are capped by Moina Sandstone or Roland Conglomerate with the exception of Bell Mount (fig. 2) which is capped by Minnow Keratophyre. Where streams have cut through the sandstone or conglomerate exposing the less resistant Cambrian rocks, the rate of erosion has been increased, resulting in steep, deep valleys.

Erosion Surfaces

The tablelands between the major rivers - the Forth, Mersey, Iris and Lea - are fairly flat with a slight northerly dip. Most of this tableland is covered by Tertiary basalt that lies as a thin cover over Ordovician rocks. The surface at about 2500 feet corresponds to Davies' (1959) St. Clair Surface. At Moina, this surface is at 2300 feet, east of Lorinna it is 2600 feet and at the top of Five Mile Rise 2700 feet. Although the surface is quite deeply dissected when viewed from the top of Bell Mount, it can be traced almost as far north as Wilmot and as far south as the Dove River. South of the Dove, the St. Clair surface backs into the Lower Plateau Surface (3000-3500 feet) whilst north of Wilmot, the Higher and Lower Coastal Surfaces dominate. Figure 3 shows the surfaces developed to the east and southeast of Lorinna. Mounts Claude, Van Dyke and Roland are High Monadnocks protruding above the St. Claire Surface.
Fig. 2 Bell Mount from the southeast.

Fig. 3 Surfaces east of Lorinna.
Dissection of the St. Clair Surface began in the Tertiary, prior to the extrusion of basalt which filled many of the old valleys.

**Rivers**

In this area, all rivers and streams are still in their youthful stage, rapids being common in the Forth, Mersey, Iris and Lea and small waterfalls plentiful in their tributaries. The main rivers are down-cutting at a faster rate than their tributaries many of which, enter the main river in a series of small waterfalls.

Valleys are generally steep sided and V-shaped with many gorges. The Dove River is deeply entrenched for nearly all its course and has cut a gorge 1800 feet deep below Five Mile Rise. Similarly, the Forth occupies a gorge for most of its course through the area and the Mersey has many gorges, one of the steepest being in the region of the Fisher-Mersey junction. The H.E.C. plans to dam the Forth River at the Cethana Gorge (fig. 4) and the Mersey River north of the Fisher River.

South of the Dolcoath Granite, the tributaries of the Forth are generally short and steep with relatively straight courses. This is due to the entrenchment of the Forth. In the northern part of the area, many of the creeks show northwesterly trends, being controlled by the structural trends of the Ordovician rocks.

In general, the main rivers are superimposed on the structure and are only locally affected by structure e.g. the Forth north of the Lorinna bridge flows along a northwesterly trending thrust for a short way; the Lea River is deflected by a syncline in Moina Sandstone near its junction with the Iris River.
Fig. 4  Forth River in the Cethana Gorge. (Looking down stream).
Basalt flows blocked many of the pre-basalt valleys and caused a general reorganization of drainage. The deep leads of the area have been compiled by Burns and Gee (1962) and are shown in figure 5. The deep lead map shows an original Forth was blocked by basalt and the present Forth and Mersey Rivers resulted from twinning of this original Forth River.

**River Terraces**

Northeast of the Iris bridge at Moina, a system of terraces is fairly well developed on Tertiary greybilly and basalt overlying the Gordon Limestone. The most extensively developed terrace is about twelve feet above present river level. This terrace also appears about one mile upstream from the bridge where it is about sixty feet wide (fig. 6).

Terraces are poorly developed in the Lorinna area. Here, the Showground is sited on the most extensive terrace, twelve feet above river level, cut in alluvial gravels overlying Gordon Limestone. Poorly preserved remnants of old terraces can be seen higher up the valley sides south of the Lorinna Post Office.

**Limestone areas**

Where the rivers flow across limestone areas, the valleys widen, more or less well-developed river terraces appear and other features of limestone topography may appear. Streams flowing off non-limestone areas may disappear underground on reaching the limestone. Several examples of this are found in the vicinity of Lorinna. Figure 7 shows a swallow hole.
LEGEND

- TERTIARY Basalt
- Sediments
- Contours on base of Tertiary
- Modern summit
- Present river
- Deep leads

Key to deep leads
1. Middlesex
2. Moina
3. Lorinna
4. Liena
5. Bell Mount
6. Stormont
7. Cethana
8. Staverton

FIG. 5
DEEP LEADS — MOINA—LORINNA AREA

Fig. 6 Terrace - 12 feet above Iris River, 1 mile upstream from Iris bridge.

Fig. 7 Swallowhole near Moina.
near Moina, down which a stream disappears. The stream is flowing off basalt and goes underground at the basalt-limestone boundary. A dry valley extends from the swallow hole to the Iris River.

Small sinkholes are found around Moina; the largest, next to the farmhouse is about thirty yards in diameter and about thirty feet deep.
5. GEOLOGY

The geology of the area is shown in figure 8 and the geological sections in figures 9a and b. The two major structural or palaeo-geographic units are the Tyennan Block (Carey, 1953) of Precambrian metasediments, flanked by a westward extension of the Dundas Trough. The Dundas Trough began in the Cambrian System, receiving sedimentation and being the centre of igneous activity. Ordovician rocks unconformably overlie the Cambrian System and occupy much the same sedimentary basin as the earlier rocks. Tertiary basalt and Recent scree and talus cover much of the area.

STRATIGRAPHY

Precambrian Rocks

Schists and quartzites of the Dove Group outcrop in the southern part of the area in the vicinity of Dove and Forth Rivers. Jennings (1963) defined the Dove Group as "that group of rocks, dominantly quartz-sericite schist and garnetiferous quartz-sericite schist which outcrops along the Forth Valley between the southern boundary of the granite at the Dove River and the boundary of the Fisher Group half a mile south of the Dove sawmill."

In the type area, the northern boundary is the intrusive contact of the Dove Granodiorite. Close to the granodiorite boundary in the Forth River, the rock is a grey, fine grained sericite schist with a marked lineation plunging $80^\circ$N at $227^\circ$ and a less marked lineation plunging $84^\circ$SW at $310^\circ$. Quartz augen up to four inches long and half an
inch wide are present together with small quartz veins that cut across the schistosity. The schist-granodiorite boundary is not exposed.

Brown to grey well-laminated quartzites represents the Dove Group in the Dove River at the easternmost granodiorite boundary. The quartzites strike 280° and dip 70° to the south. The granodiorite has metamorphosed these quartzites at the Devon Mine to a massive, apparently structureless grey quartzite. Quartz veining and disseminated pyrite are common in the vicinity of the Devon Mine.

The granodiorite-Dove Group boundary is not exposed in the Mersey River, but it can be placed to within a few feet. Here, the Dove Group is intruded by pink feldspar dykes, aplite dykes and quartz veins. Patches of recrystallized quartz are common. Pyrite mineralization is plentiful, the pyrite sometimes being dodecahedral in form with a shiny, dark brown coating of iron oxide (?). The dodecahedra are up to 3 mm. across and are similar in appearance to black garnets. In order to check the identity of the dodecahedra, several of them were picked out of the rock, crushed and powder photographs taken. The resulting photograph showed the mineral to be pyrite.

Baking of the Dove Group by the granodiorite has destroyed the original metamorphic texture on a macroscopic scale though Jennings (1963) states that a directional texture may be seen in thin section. The baked rock is a medium to fine grained hornfels with quite irregular banding. Flakes of biotite are common and these, together with granular quartz up to 1 mm. in diameter, are set in an opaque, white matrix.
The Cambrian System

The Bull Creek Volcanics, Lorinna Volcanics and Minnow Keratophyre have sediments intimately associated with the volcanic rocks. As lavas are the dominant members of these three groups, they are described under Cambrian igneous rocks.

Cambrian Unassigned

North of the Cethana damsite, sheared quartzites and greywackes outcrop between the Moina Sandstone and the Minnow Keratophyre. These quartzites and greywackes were correlated with the Lorinna Greywacke by Jennings, et al. (1963) but the author considers this assignation invalid in the light of the nature of the Lorinna Greywacke (now renamed the Lorinna Volcanics). The Lorinna Volcanics outcropping some seven miles upstream in the Forth, are a series of lavas, tuffs, greywackes, quartzites and cherts which are petrologically distinct from these unassigned rocks.

The field relationships of the unassigned rocks give no evidence as to their age. They are thrust over the Moina Sandstone and in turn, the Minnow Keratophyre is thrust over the unassigned rocks. They are assigned to the Cambrian System as they are more extensively sheared than the Moina Sandstone and are petrologically distinct from any Ordovician rocks in the area.

Ordovician Rocks

MAGOG GROUP

The Magog Group consists of the Roland Conglomerate and the Moina Sandstone. Johnston (1888) did not differentiate between these two units when he named the Magog Group, but later workers e.g.
Twelvetrees (1913), Reid (1919), Elliston (1954) and Jennings (1958, 1963) recognised the conglomerate and sandstone as separate formations. Both formations have been known by different names in the past and the stratigraphic nomenclature is discussed fully in Jennings (1958): the formation names used below are after Jennings. As the Roland Conglomerate and Moina Sandstone have previously been comprehensively discussed (Jennings 1958, 1963) full descriptions of them will not be given here as this would only involve unwarranted repetition. The descriptions below are thus summaries of Jennings' work, together with relevant new information from field mapping and thin sections prepared by the author.

**Roland Conglomerate**

The Roland Conglomerate is a correlate of the Owen Conglomerate on the West Coast of Tasmania. Jennings (1958) defines "The Roland Conglomerate is that formation of quartz conglomerate lying unconformably above the Dundas Group rocks and conformably beneath the Moina Sandstones on the north face of Mt. Roland. The type locality is between co-ordinates N894.3 to N894.7 and E425.4 on the western side of the walking track to the summit of Mt. Roland." The maximum thickness is about 800 feet in the Mt. Roland area but it thins rapidly south from Round Hill to Tin Spur and Oliver Hill where it is only about twenty feet thick. Further south, in the Lorinna area, it is completely absent and the Moina Sandstone rests on Cambrian rocks. Overlap of the conglomerate is probably for the outcrop pattern in the Lady Barron Mine.
area where Moina Sandstone overlies the Bull Creek Volcanics. In the vicinity of Beswick's workings, there is further evidence for the conglomerate lensing out (see figure 11).

The conglomerate is generally pink in colour and is composed of subrounded fragments of quartz, quartzite and quartz schist in a fine grained siliceous, or in some places, argillaceous matrix. The pink colouration is due to fine grained haematite in the matrix and/or haematite staining of the pebbles. Beds range up to thirty feet in thickness and generally, bedding within the conglomerate is difficult to see. In the middle of the conglomerate, white quartzite beds are found in the Cethana damsite area (G. Rawlings, pers. comm., 1965).

The Cambrian-Ordovician unconformity is exposed along the Lorinna road half a mile north of the Round Hill Mine. Here, the basal conglomerate beds contain pebbles of the underlying Cambrian sheared quartzfeldspar porphyries and siltstones. There is a small thrust fault (fig. 10) just below the unconformity which may represent a décollement between the Ordovician and Cambrian rocks.

Around the Dolcoath Granite, the conglomerate has undergone recrystallization to a dense white quartzite which has previously been called the "Ghost" Conglomerate (Elliston, 1954b) as faint outlines of the original pebbles can be seen in the quartzite.

In contrast to the Moina Sandstone, the Roland Conglomerate is rarely the host rock to mineralization associated with the Dolcoath Granite.
Fig. 10  Unconformity between the Roland Conglomerate and the Minnow Keratophyre, Lorinna road.
**Moina Sandstone**

Jennings (1963) defines the Moina Sandstone as "That formation of marine sandstone, quartzite, shale and conglomerate about 800 feet thick which occurs stratigraphically below the Gordon Limestone and above the Roland Conglomerate. The formation may be observed at many places within the Middlesex and Sheffield Quadrangles but it is best exposed along the Fossey Mountains and in the vicinity of Round Hill and Moina." The Moina Sandstone is thus equivalent to the "Fucoid Sandstone", "Tubicolar series", "Worm-cast sandstones" and "Pipestem Series" of earlier workers.

Generally, the Moina Sandstone is a white to pale grey, fine grained and well indurated quartzite or quartzose sandstone. Minor bands of shale, conglomerate, grit, calcareous sandstone and pyritic sandstone are present in places e.g., Round Hill and on Five Mile Rise. Bedding is up to eighteen inches thick and the rock shows a well-developed joint system which gives it a blocky and in some places, flaggy appearance. The formation has undergone faulting and concentric folding and there are signs of movement along practically every bedding plane. In all cases of the folding, the shaley members have acted as the incompetent beds.

Tubicolar casts are abundant in some horizons of the Moina Sandstone and also in the quartzite band in the middle of the Roland Conglomerate at Cathana (G. Rawlings', pers. comm., 1965). These casts are useless for stratigraphic purposes or as age indicators as the
tubicolar organism, *Diplocraterion*, has a range from the Lower Cambrian to the Triassic. Most of the beds of this formation are unfossiliferous but a few beds have been found containing poorly preserved brachiopods, gastropods and fragments of trilobites. Such beds are found on Five Mile Rise where crinoid stems plus other unidentifiable fossils are preserved in a leached grey quartzose sandstone. One quarter of a mile upstream of the bridge over the Forth at Lorinna, a friable brown sandstone outcrops on the eastern bank of the Forth River at and below water level. This bed contains many fairly well preserved brachiopods close to *Orthorhynchula*. A correlate of the Moina Sandstone outside this area (the Caroline Creek Sandstone) contains a rich trilobite fauna of Arenigian age.

In the Moina-Round Hill area the Moina Sandstone conformably overlies the Roland Conglomerate except at some places on Dolcoath Hill and at 890,310N, 408,400E in a drive recently put in by Mr. C. Beswick, where the Sandstone overlies a sheared quartz keratophyre of the Bull Creek Volcanics. This is due to lensing out of the Roland Conglomerate in this area (see fig. 11). Mr. J. Smith who works the All Nations Mine, reports that in an easterly drive, he passed from white quartzite straight into reddish porphyry similar to that in the mine at the top of the hill (the Lady Barron Mine), without encountering any conglomerate. On Five Mile Rise and in the Forth River at 883,200 N, 411,300 E the Moina non-conformably lies on Cambrian lavas and quartz porphyries. In this area the basal bed of the Moina is a pebbly sandstone. This bed is about
Fig. 11. Sketch section from 890400N, 408100E on the Cradle Road to Beswick's workings (890060N, 408400E).

C.E.GEE 1965
three feet thick where it is exposed in the Forth River at 883,200 N, 411,300 E and can be traced up the eastern side of the river for a few chains. Where the Cambrian-Ordovician is exposed along a timber track heading southwest from the Lorinna bridge, the pebbly sandstone is about ten inches thick. The pebbles consist of rounded quartz, quartzite, acid lavas and porphyry in a subordinate matrix of clay and chlorite. The maximum diameter of the pebbles is 5 mm. and the average grain size decrease up through the bed to about 1.5 mm. at the top of the bed.

The Dolcoath Granite is intrusive into the Moina Sandstone in the Dolcoath Hill-Tin Spur area, causing strong induration of the sandstone. Numerous dark grey veinlets and some quartz veins cut a grey impure quartzite in Narrawa Creek at 891,300 N, 411,100 E. Thin sections show these veinlets to consist almost entirely of pleochroic brown chlorite in randomly orientated laths up to 0.05 mm. long. Occasional clear, anhedral garnets occur in the veinlets and these are elongate along the veinlets. The quartzite consists of rounded quartz grains (50% of the rock) with an average diameter of 0.1 mm. but occasional grains are up to 0.6 mm. diameter. The grains are not in contact but are separated by a matrix of dirty green, pleochroic chlorite in tabular grains (0.05 mm. long), clay and some patches of clear sericite. Some quartz grains show partial recrystallization. Garnet rarely occurs as small, irregular grains in the groundmass together with small euhedral zircons. Overlying this bed is a grey, fine grained, indurated quartzite containing irregular green segregations very similar in appearance to the
segregations in the Bull Creek Volcanics at Geales Bridge and along the Lorinna road. This quartzite has an average grain size of 0.01 mm. but there are veins of recrystallized quartz in which anhedral quartz is up to 2 mm. across. In these veins, quartz contains tiny inclusions of green diopside. Diopside occurs in a clay-chlorite groundmass as scattered crystals up to 0.08 mm. across and aggregates of small crystals up to 2 mm. across. Ragged, pleochroic green hornblende crystals (to 0.2 mm. long) are sometimes found associated with the diopside aggregates. The diopside has probably resulted from alteration, due to the Dolcoath Granite, of calcareous sediments from the Moina formation in this area. Remobilization of the diopside resulted in its emplacement, together with garnet (probably grossularite), in the quartzites. Twelvetrees (1913) reports a greenish contact rock at the Moina Sandstone-Dolcoath Granite contact, in a mining trench on the southern bank of Narrawa Creek. The contact rock is a quartz-pyroxene (diopside ?) rock carrying quartz-wolfram veins.

A pale grey rock with yellowish-white bands and small dark grey spots outcrops in the Forth River below the Dolcoath Granite at 891,100 N, 412,000 E. Quartz veins up to 3 mm. wide cut the rock but no mineralization associated with these veins was noted. In thin section the rock has an average grain size of 0.5 mm. and contains lenticular patches up to 1.5 mm. diameter of quartz grains as well as patches of cherty quartz. The dark grey spots consist of small laths of biotite which are randomly orientated in the spots, up to 0.5 mm. long and pleochroic from red-brown
to pale yellow-brown. Many biotite laths have pleochroic haloes around minute zircon (?) crystals. The groundmass is mainly shredded sericite with many zircon needles (to 0.2 mm. long). These, together with biotite laths, are included in larger, recrystallized quartz grains. There are also traces of a mineral tentatively identified as andalusite. This mineral has a high positive relief, is faintly pleochroic from pink to colourless and occurs in irregular grains and skeletal crystals up to 1.5 mm. long. It shows first order grey birefringence, an extinction angle of $-40^\circ$, positive elongation and two poor cleavages at about $90^\circ$. The optical angle is about $50^\circ$ and it is optically negative. (Andalusite has a larger optical angle and parallel extinction.) The rock was probably an impure, fine grained siltstone that has been metamorphosed by the Dolcoath Granite, to a spotted hornfels.

The Moina Sandstone at the Shepherd and Murphy Mine is an impure quartzite containing rounded quartz grains up to 1 mm. in diameter, some of which show partial recrystallization. Inclusions of small zircon needles and liquid-gas bubbles are not uncommon. The quartz grains are generally surrounded by white mica with the shredded appearance of sericite. The changes in the Moina Sandstone are due to contact metamorphic effects of the Dolcoath Granite and these are discussed further under the host rocks of the Shepherd and Murphy Mine.

The majority of the known orebodies associated with the Dolcoath Granite are located in the Moina Sandstone. As the Sandstone is strongly folded by a complex pattern of northwesterly and easterly trending
concentric folds, with associated thrust faulting, structural control is important in the location of ores within this formation. This is discussed in greater detail under the heading of Mineralization.

**Gordon Limestone**

Limestone conformably overlying the Moina Sandstone in the Moina and Lorinna areas, has been correlated with the Gordon Limestone by Jennings (1957, 1963). In the Moina area at 890,040 N, 405,400 E the limestone conformably overlies Moina Sandstone but nowhere in the area is the top of the limestone exposed as extensive erosion took place before the deposition of Tertiary lacustrine sediments at Moina and Recent alluvial gravels at Lorinna.

The limestone outcrops sparsely in the Moina and Lorinna areas where it is preserved in the cores of synclines.

About ten chains north of the bridge at Lorinna, dense grey limestone dipping 25°E210°, forms cliffs up to forty feet high. Half a mile southeast of Lorinna, the limestone dips \(-40°N300°\), contains *Maclurites* and has numerous white, coarsely crystalline calcite clots and veins. Limestone from this area was dissolved in acetic acid but no conodonts were evident.

Approximately five hundred feet are exposed in the Iris River upstream of the bridge at Lorinna. Unfortunately, exposures are poor and detailed stratigraphy was not attempted. The basal beds (equivalent to the Florentine Valley Mudstone ?) conformably overlie the Moina Sandstone and consist of ninety to one hundred and thirty feet of
alternation of dirty sandstones, dark grey siltstones, dense white chert bands and lenses, and dolomitic limestone in beds about four inches thick. The sequence dips 25-30°N at 30°. Green epidote crystals are occasionally found along bedding and joint planes of the sandstones. These are probably related to the mineralization at the Shepherd and Murphy Mine (q.v.) The amount of limestone increases up the succession and at the Iris bridge, the rock is fairly pure, dense, dark grey limestone.

Two quartzite beds, twelve feet apart, are exposed in a small cliff of limestone at the Iris bridge. The lower quartzite bed is greenish-grey, about four feet thick and fairly pure except for small patches of disseminated pyrite. The upper quartzite band is about six inches thick and overlain by about thirty inches of limestone with quartz grains up to 2 mm. in diameter. Above this are six feet of "normal" grey Gordon Limestone.

Poorly preserved corals and bryozoans occur here and Stromatopora was identified by Twelvetrees (1913).

Downstream from the bridge, in the vicinity of the Lea-Iris confluence, small, scattered limestone outcrops occur, dipping in a southerly direction. This implies an east-west trending syncline between the Lea-Iris confluence and the bridge. Tertiary greybilly, basalt and agglomerate overlie the limestone at Moina.

Metasomatism by the Dolcoath Granite has altered the Gordon Limestone to a garnet-pyroxene-magnetite-epidote rock (calca-flinta,
skarn or tectite) at the Shepherd and Murphy Mine (q.y.). Further outcrops of skarn are reported as inliers in synclines in the vicinity of the Stormont Mine and Fletchers Adit by Burns (1959). Twelvetrees (1913) reports "curious garnetiferous contact metamorphic rock ..... west of the Iris River" and along the old track to Stormont. Skarn also outcrops south of Tin Spur Creek at 391,300 N, 412,200 E (Jennings, 1963).

**Tertiary Sediments**

Sub-basaltic Tertiary sediments outcrop in the Moina area and just south of Bell Mount. On the valley flats around Moina a conglomerate very similar in appearance to the Roland Conglomerate crops out (fig. 12). This contains well rounded pebbles up to four inches in diameter cemented with chalcedonic quartz. It is poorly sorted and the pebbles are dominantly of Moina Sandstone and reworked Roland Conglomerate pebbles. This rock is interpreted by Paterson (pers. comm., 1965) as a Tertiary lake sediment which has been silicified by the overlying basalt. Paterson has named this rock a greybilly.

Clays and sands occur in the Bell Mount gold-diggings, below the basalt and above the Gordon Limestone. Similar sediments have been identified between the Limestone and basalt in drill-holes along the H2E2C. tunnel line from the Wilmot dam to the Cethana dam (Paterson, pers. comm., 1965).

On a small hill across the Iris River from Moina, a ferromanganese gossan occurs in sparse outcrops. It is below the basalt and above the
greybilly, at an altitude of about 1750 feet. Burns (1957) describes a similar gossan from the Bell Mount gold-diggings and states "There is no doubt that these 'gossans' are iron-cemented sub-basaltic deposits of Tertiary age, and are remnants of a capping that originally extended across the area at a general elevation of 1775 feet."

From the evidence above and considering the pre-basalt drainage (fig. 5), it seems that there was a Tertiary lake in the Moina valley which received water from the Stormont and Bell Mount leads. This lake drained to the southeast via the Moina lead.
Quaternary deposits

Alluvium

Alluvial deposits are not widespread in this area, being restricted to thin covers overlying Gordon Limestone around Moina and Lorinna. Much of the alluvial material is reworked fluvioglacial.

Talus

Talus accumulations are widespread in the conglomerate, quartzite and schist areas and around the edges of the basalt plateaux, especially east of Lorinna where they are accompanied by landslips. "The presence of these slips and widespread talus accumulation is due to the presence of sub-basaltic clays providing a suitable slip plane and to the closely spaced joint system in the basalts which facilitates rapid disintegration of the slip masses." (Jennings, 1963)

Igneous Rocks

Cambrian

Introduction

Cambrian acid lavas, granodiorites and volcanics with associated sediments outcrop in the southern part of the area. These are the Bull Creek Volcanics, the Lorinna Volcanics and the Dove Granodiorite which together make up the Dove Igneous Suite.

Keratophyres and quartz keratophyres with subordinate rhyolites and sediments make up the Minnow Keratophyre which outcrops to the north of the area.
DOVE IGNEOUS SUITE

Bull Creek Volcanics

These rocks have previously been referred to as the "Porphyroid Group" (Twelvetrees, 1913), "Porphyroid Series" (Reid, 1919), "Bull Creek Formation" (Jennings, et al., 1959; Jennings, 1963) and the "Bull Creek Pyroclastics" (Jennings and Burns, 1958). Twelvetrees and Reid included all Cambrian rocks (including the Dove Granodiorite) in the Porphyroid Series which was correlated with the West Coast "porphyroids" of Waller (1904).

The name Bull Creek Volcanics is applied to the complex assemblage of sheared porphyritic acid lavas, greywackes, siltstones and cherts which outcrop in the Forth River between 885,900 N and 888,800 N and is also exposed in the road cuttings from two miles north of Lorinna to half a mile south of Tin Spur. As the exposures in the Forth River will soon be inundated by water backed up from the Cethana dam, it is suggested the section along the Lorinna road be adopted as the type locality. The bottom of the Volcanics is not exposed and their thickness is unknown. As yet, the sedimentary rocks are unfossiliferous and the age and stratigraphic position of these rocks cannot be accurately determined. The only certain facts about their age is that they are pre-Roland Conglomerate (Lower Ordovician) and post-Precambrian (from which they are lithologically distinct). This problem is discussed in more detail in the section on Synthesis of the Dove Igneous Suite where it is suggested the Bull Creek Volcanics are in part at least, equivalent to the Mt. Read Volcanics on the West Coast.
Petrology

In general, the Bull Creek Volcanics are composed of dynamically and hydrothermally altered porphyritic acid lavas with minor bands of tuffs, greywackes, siltstones and cherts. In the field it is extremely difficult to differentiate between the non-porphyritic lavas, tuffs and greywackes and even in thin section, it is difficult to decide whether some rocks are igneous or sedimentary. Due to paucity of outcrop, no flow structure, pillow structure, vesicles, etc., could be found; bedding in the sedimentary members was difficult to locate and it was impossible to trace individual bands for more than a few yards.

Burns (1960) subdivided the Bull Creek Volcanics into the Upper Porphyry Member (at least 700 feet thick), the Geales Bridge Member (about 500 feet of greywacke, sandstone, conglomerate and siltstone interbedded in places with porphyry) and the Lower Porphyry Member (at least 300 feet thick but possibly four times this thickness). However, careful mapping in the Forth River by the author failed to find any real evidence to substantiate this and it is suggested that this subdivision be dropped. Certainly, correlation of outcrops in the Forth with those along the Lorinna road, as attempted by Burns, is very doubtful.

It is not certain whether the igneous rocks are intrusive or extrusive but it seems likely that both types are present. Elliston (1954, b) stated the whole assemblage to be due to wholesale assimilation of an original basic rock by a granitic magma, with the Dolcoath Granite being the end product of assimilation. However, the intrusive nature of the Dolcoath Granite can be demonstrated along the Lorinna road and in the Forth River.
Porphyritic acid lavas

In hand specimen, these are dark grey rocks with glassy, cracked quartz phenocrysts in a fine grained, indeterminate groundmass. Due to hydrothermal alteration and shearing, the original texture has been obliterated in many specimens.

Thin section studies show the degree of alteration to vary considerably: some rocks can be recognised as quartz keratophyres and dacites that have been only slightly altered whereas others are so altered that only the quartz phenocrysts remain unaltered.

The quartz keratophyres are pale greenish grey rocks with large, glassy quartz phenocrysts and subordinate dark brown laths of biotite (originally) in a fine grained groundmass. The quartz phenocrysts are up to 5 mm. in diameter, generally well rounded and show well-developed resorption embayments. Sometimes the quartz trends towards crystal outlines. Figure 12a shows embayed quartz, and altered biotite in a fine grained groundmass. The feldspar is completely sericitized but crystal outlines up to 3 mm. across can still be seen (fig. 12b). Brown chlorite and iron oxides pseudomorph original biotite laths (to 4 mm. long). The groundmass is fine grained, roughly equigranular and composed of quartz and potash (?) feldspar in approximately equal amounts together with tiny sericite flakes. Veinlets of quartz cutting these rocks are common.

Quartz keratophyres are best exposed in the lower workings of the Pig and Whistle Mine and in trenches on Beswick's lease (890,060 N, 408,400 E).

Dacites outcrop along the Lorinna road south of the Dolcoath Granite contact, and in the Forth River one mile north of Geales Bridge.
Specimen 33499(b)  x 11  x nicol

Fig. 12a  Resorbed quartz and biotite laths in quartz keratophyre, Beswick's workings.

Specimen 33540  x 12  x nicol

Fig. 12b  Sericitized feldspar, quartz and biotite laths in quartz keratophyre, Lorinna road.
These are dark grey, sheared rocks with glassy quartz phenocrysts (to 5 mm.) in a fine grained groundmass. The quartz phenocrysts are less numerous in the dacites than in the quartz keratophyres. Some of the quartz phenocrysts are resorbed and others show roughly triangular outlines, whilst rare crystals tend towards square outlines. Both the square and triangular outlines are characteristic of β-quartz (or high-temperature quartz) which crystallizes as hexagonal bi-pyramids. β-quartz forms above 573°C and is characteristically found in acid lavas and porphyries. Below 573°C, β-quartz inverts to α-quartz (low-temperature quartz) and as this involves a volume change, inversion cracks should be visible. However, practically all the quartz phenocrysts are cracked and inversion cracks could not be identified.

Tiny flakes (0.1 mm.) of criss-cross biotite form clusters up to about 3 mm. long and appear to pseudomorph original hornblende crystals and biotite laths. (figs. 13a and b) The biotite is strongly pleochroic from deep chocolate brown to pale brown and although the aggregates show a preferred orientation along the cleavage, the individual flakes are randomly orientated within the aggregates.

Tabular feldspar crystals (1-2 mm.) are again completely sericitized and in some crystals, slight embayments can still be seen. In specimen 33532, very fine grained brownish-green chlorite is intimately associated with the sericite formed from feldspar phenocrysts and these minerals have been slightly drawn out in the direction of shearing.
Fig. 13a and b. Criss cross biotite pseudomorphing hornblende in dacite (?).
The phenocrysts are surrounded by a fine grained quartzo-feldspathic groundmass containing much chlorite and "shredded" sericite. Occasional small patches of the groundmass consist of roughly equigranular quartz grains (0.02 - 0.05 mm.) which have sutured boundaries. This indicates slight recrystallization of the groundmass and is probably related to the shearing of these rocks.

As the Dolcoath Granite is approached along the Lorinna road, these rocks become lighter in colour until, next to the granite, they are pale grey in colour with small dark brown patches which are roughly parallel to the cleavage. In thin section, the main change is that the groundmass contains less sericite and chlorite, the criss-cross biotite becomes coarser (to 0.3 mm.) and the pseudomorph aggregates become less distinct. Occasional xenoliths of the Bull Creek Volcanics are included in the granite. One of these xenoliths (specimen 33542) appears identical in handspecimen with the dacite next to the granite. In thin section, the xenolith is composed of irregular aggregates (to 3 mm.) of criss-cross biotite laths up to 0.5 mm. long. These are contained in a recrystallized groundmass of equigranular quartz and orthoclase (fig. 14a) Irregular white mica crystals (0.5 mm.) are associated with coarser patches of the groundmass.

One thin section (specimen 33537) of dacite close to the granite shows two small veinlets of white mica traversing weathered dacite and cutting through sericitized feldspar tabulae. The same section shows a quartz veinlet through the dacite and where this veinlet reaches a quartz phenocryst, its course through the phenocryst can be distinguished as it appears as a vein of recrystallized quartz.
Fig. 14a  Xenolith of Dull Creek Volcanics (dacite ?) contained in the Dolcoath Granite.

Fig. 14b  Porphyritic acid lava.
Other igneous rocks of the Bull Creek Volcanics are too altered to be accurately named and are referred to as porphyritic acid lavas. A feature of these rocks is the strong development of green, fibrous hornblende and/or epidote in the groundmass, replacing ferromagnesians and as veins, knots or segregations. The latter are discussed in more detail on page 56.

Specimen 33509 is fairly typical of the porphyritic acid lavas. This is a dark grey sheared rock with glassy quartz phenocrysts up to 5 mm. in diameter and irregular, small (4 mm.) dark green patches. The dark green patches are generally surrounded by haloes of lighter coloured, siliceous material. Disseminated pyrite cubes (0.1 mm. side) occur in the groundmass. It is only in thin section that differences between this rock and the dacites can be seen. The quartz is cracked and many crystals show deep resorption embayments and undulose extinction. Feldspar crystals are wholly or partly replaced by sericite with minor epidote, chlorite and rarely, calcite and hornblende. Ferromagnesian minerals have been replaced by small, fibrous, radiating crystals of pleochroic green hornblende and slightly pleochroic yellow epidote which is usually granular though it is sometimes acicular. Intimately mixed quartz, feldspar, chlorite and sericite comprise the groundmass which is very fine grained though not uniformly so, as some patches are coarser and consist dominantly of small (0.02 mm.) quartz grains with sutured boundaries. Figure 14b shows one of these acid lavas with resorbed quartz and hornblende-epidote in the groundmass.
Other acid lavas differ mainly in the amount of hornblende and epidote present, the character of the groundmass and the number of quartz phenocrysts present. Figure 15a shows the strong development of hornblende-epidote which is beginning to replace the groundmass. In many sections the groundmass is so cloudy that it cannot be determined; the cloudiness is a later event than the hornblende-epidote development for these minerals, together with quartz phenocrysts, are cloudy as well. The number of quartz phenocrysts varies considerably: in general they comprise about 10-15% of the rock but may be as high as 25% or as low as 1%.

Rocks with vitroclastic (?) groundmass are tentatively identified as crystal tuffs. These rocks have the same quartz phenocrysts as the acid lavas but in thin section, they sometimes appear fractured. Plagioclase crystals (to 2 mm.) are present and although they are too altered to determine their composition, multiple twinning can be distinguished. Large (3 mm.) hornblende crystals are now replaced by hornblende-epidote intergrowths. Small fragments of acid lava are rarely present. The composition of the groundmass is indeterminate (devitrified glass ?) but shadowy outlines with the form of shards (?) are present. Large (3 mm.) globular plagioclase crystals and tabular ferromagnesians are set in a groundmass of devitrified glass (?) in specimen 33530(b) (figure 15b) and this rock is tentatively identified as a keratophyre tuff.
Specimen 33522

Fig. 15a  Hornblende-epidote replacing groundmass in acid lava.

Specimen 33530(b)

Fig. 15b  Globular plagioclase in keratophyre tuff (?).
Sediments

The greywackes are dark grey, fine grained rocks that in the field, generally show a poorly developed schistosity. In thin section, they consist dominantly of angular quartz fragments up to 0.5 mm. across and comprise up to 40% of the rock, with occasional fragments of acid lava, quartzite and chert in a fine grained clay and chlorite matrix (fig. 16a). The greywackes at Geales Bridge contain numerous epidote-hornblende segregations. These segregations tend to be ellipsoidal in shape (fig. 16b). In thin section, acicular hornblende crystals appear to be developing at the expense of the matrix in these segregations. Chert pebbles up to four inches long are common in the greywacke fifty yards north of Geales Bridge. The pebbles tend to be ellipsoidal with their longest axes along the cleavage and they are commonly separated from the greywacke by a thin layer of dark material that is milky-white under reflected light.

Thinly bedded siltstones outcrop in the Forth River one and a half miles north of Geales Bridge and at various places along the Lorinna road. Siltstones in the river near the granite have undergone slight thermal metamorphism and are beginning to take on a slightly spotted appearance due to the development of small clots of biotite up to 1 mm. across.

Comparison of the Bull Creek Volcanics with similar rocks.

Six analyses of "quartz-feldspar porphyries" from the Lorinna road, are given in Burns (1960) and are reproduced here in Table 1.
Specimen 33514

Fig. 16a  Greywacke of the Bull Creek Volcanics.

Fig. 16b  Hornblende-epidote segregations in greywacke, Geales Bridge.
Using these analyses, norms have been calculated and compared with norms calculated for other rocks of similar composition.

Analysis number 4 is very similar in chemical and normative composition to the dacite from Canberra (no. 8). The other five Lorinna rocks have very high potash:soda ratios and differ from the average dacite in Barth (1962, p. 58) by having higher potash and lower soda contents. This results in more normative orthoclase and less normative albite respectively for the Lorinna rocks. The high amounts of normative quartz and feldspar in the Lorinna rocks implies that the groundmass is quartzo-feldspathic as thin sections reveal some quartz and feldspar phenocrysts, but not nearly enough to account for more than about half the normative quartz and feldspar. Much of the lime in the normative anorthite is actually in the epidote and hornblende observed in thin section, so the normative anorthite is somewhat misleading. No pyroxenes were observed in thin section and the ferromagnesians are, in fact, hornblende, chlorite and biotite. Bearing in mind the limitations of the normative compositions and that the normative anorthite is likely to be too high, the Lorinna rocks are classified as follows:

1. Toscanite
2. Dacite
3. Toscanite
4. Dacite
5. Rhyolite
6. Rhyolite
# Table 1

**Chemical Analyses and Norms for the Bull Creek Volcanics and Similar Rocks**

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<sup>1</sup><sub>-6</sub> Quartz-feldspar porphyry, Lorinna Ed., Burns (1960)

<sup>7</sup> Quartz porphyry, Canberra, Joplin (1963) p.141

<sup>8</sup> Dacite, Burrenaku, N.S.W., Joplin (1963) p.141

<sup>9</sup> Sodi-potassic trachyte, Saddle Creek, Rosebery, Joplin (1963) p.167

<sup>10</sup> Propylitized dacite, Hesket, Victoria, Joplin (1963) p.155

<sup>11</sup> Keratophyre, Harz Mts., Germany, Johannsen (1945) vol. III, p.51

<sup>12</sup> Trachyandesite, Sabinyo, Turner and Verhoogen (1960) p.238

<sup>13</sup> Average dacite, Barth (1962) p.58
The porphyritic acid lavas of the Bull Creek Volcanics are very similar to a series of rhyolites, toscanites and dacites described by Joplin (1955) from the Cloncurry mineral field. The acid lavas from Cloncurry are porphyritic and have undergone regional, dynamic and thermal metamorphism in different localities. The Cloncurry dacites originally contained hornblende phenocrysts which are now pseudomorphed by criss-cross biotite. Illustrations of thin sections of dacites from Cloncurry are practically identical with thin sections of dacties from the Lorinna road. Unfortunately, there are no analyses available for these Cloncurry rocks.

**Segregations in the Bull Creek Volcanics**

In the vicinity of Geales Bridge and in the road cuts four miles north of Lorinna, the Volcanics contain numerous ovoid patches of fibrous, dark green hornblende and granular, olive-green epidote, commonly surrounded by white haloes of cryptocrystalline siliceous material. These patches are ellipsoidal in outline at Geales Bridge and average three to four inches long with their intermediate axes in the plane of the schistosity (fig. 16b). Along the Lorinna road, the patches tend to be more circular and are up to fourteen inches across. The larger knots are composed dominantly of acicular, dark green hornblende crystals. Some knots have a white core (two inches maximum diameter) of coarsely crystalline calcite which, rarely, has a further small core of chalcopyrite. The smaller patches (one to two inches diameter) are usually granular epidote with minor hornblende. In most cases, these segregations or knots are in acid lavas, but one hundred yards north of Geales Bridge, they occur in greywacke.
The segregations at Geales Bridge generally replace the groundmass in lavas and the number of quartz phenocrysts remains fairly constant from the lava through the segregations. The knots along the Lorinna road, however, completely replace the host rock. Burns (1960) reports "In one locality near Geales Bridge, there occurs a joint oblique to the schistosity. Where this intersects the segregation, the segregation is locally elongated in the direction of the joint. This is not due to deformation and appears to be due to the joint-fracture acting as a locus of alternation. Another joint in the same locality has narrow elongated segregations along its length."

Veins of hornblende and/or epidote up to three inches wide occur along the Lorinna road between 887,620 N and 887,720 N. These are dominantly of acicular hornblende, randomly orientated in the vein, with minor epidote and occasionally with central portions of potash feldspar, quartz or magnetite. On weathered surfaces, the more resistant veins stand out as crosses. These veins cut the schistosity and according to Burns (in Jennings, 1963) "appear to be structurally controlled by shear joints symmetrically related to schistosity. This would date the veins towards the end of the tectonic movement."

As the schistosity is Tabberabberan in age (see chapter on Structure) it is likely that these segregations, veins and knots are related to the intrusion of the Dolcoath Granite late in the Tabberabberan Orogeny.
Similar though less pronounced veins occur in the Lorinna Volcanics in the Lorinna Gorge. Segregations of hornblende and diopside are found in the Moina Sandstone close to the granite in Narrawa Creek and just north of the Cethana dam site, the Moina Sandstone is cut by quartz-hornblende-chlorite veins.

Veins of chalcopyrite, quartz and calcite occur beside the Lorinna road at 887,200 N and in this vicinity pyrite commonly occurs in small disseminated patches. Disseminated pyrite is abundant in the Bull Creek Volcanics at many points in the Forth River, notably 885,800 N, 886,500 N and just north of Geales Bridge.

**Lorinna Volcanics**

The name Lorinna Greywacke was assigned by Jennings (1963) to "an assemblage of greywacke, chert, quartzite and volcanic rocks which underlies the Moina Sandstone on the Five Mile Rise and also outcrops in the Forth River about half a mile north of the Lorinna Bridge." The author has examined the sparse outcrops on Five Mile Rise and could find no evidence of greywackes, cherts or quartzites. In fact, the Cambrian rocks outcropping on Five Mile Rise appear, in the field, to be altered granitic rocks, practically identical with many outcrops of the Dove Granodiorite in the Forth River. The rocks outcropping north of the Lorinna bridge consist of porphyritic acid lavas and tuffs with greywacke, chert and quartzite bands, all of which are cleaved to a greater or lesser extent. Thus, the rocks outcropping below the Moina Sandstone on Five Mile Rise and in the Forth River have been grouped with the Dove Granodiorite and
those north of the Lorinna bridge have been named the Lorinna Volcanics. The latter are probably equivalent to the Bull Creek Volcanics further downstream. Field relationships between these two groups of volcanics cannot be determined as the Lorinna Volcanics have been thrust over Gordon Limestone and in turn, are thrust over by the Moina Sandstone. However, the majority of the porphyritic acid lavas in the Forth River, are similar to many of the porphyritic acid lavas of the Bull Creek Volcanics.

In the Forth River at the proposed H.E.C. dam site (now abandoned), cleaved siltstones outcrop below the Moina Sandstone. Below the siltstones, is a sequence of porphyritic acid lavas, strongly sheared in the vicinity of small thrust faults. These lavas contain quartz phenocrysts up to 10 mm. in diameter in a fine grained sericitic groundmass. The rock is foliated and the foliation wraps round the phenocrysts. The quartz crystals are rounded, cracked and show deep resorption embayments. Shadowy, sericitized feldspar crystals are smeared out in the direction of the schistosity. Magnetite that is oxidizing to haematite and hydrous iron oxides, is a common accessory mineral.

The porphyries are very patchy. Some, like the one described above, are very porphyritic and grade into less porphyritic patches which have smaller and less numerous quartz phenocrysts. Occasional quartz crystals show squarish sections characteristic of α-quartz.

A porphyritic quartz keratophyre outcrops one hundred yards north of the proposed dam site. This is a greenish-grey rock with corroded, cracked quartz phenocrysts (to 3 mm.) in a fine grained quartz-feldspathic groundmass. Shadowy feldspar crystals are more or less
altered to sericite but multiple twinning can still be seen. The groundmass is equigranular quartz and feldspar (0.1 mm. diameter). The feldspar in the groundmass has a negative relief (with respect to quartz), shows incipient multiple twinning and is tentatively identified as albite.

Further south of the dam site at the head of the Lorinna Gorge, acid lavas, greywackes, and quartzites with minor chert bands outcrop. The greywackes contain angular fragments of quartz, quartzite, acid lavas and chert in a sericite-chlorite matrix (fig. 17a). One greywacke bed (specimen 33550) contains fragments up to 10 mm. long and haematite replaces the matrix in places. Small quartz veins up to three inches wide commonly cut the greywackes and quartzites. In one quartzite bed, segregations of dark green, granular chlorite occur. These are irregular in shape and up to one inch across. Some quartz veins through this quartzite have minor chlorite and green hornblende. In these veins, the quartz is invariably in crystals elongated at right angles to the walls of the veins.

East of the Forth River at the southern end of the Lorinna Gorge, a grey, fine grained quartzite outcrops. This bed is cut by a multitude of white quartz veins (fig. 17b) up to six inches wide. The quartz veins show no preferred directions.

The origin of the Lorinna Volcanics is discussed in the section on Synthesis of the Cambrian Rocks.
Fig. 17a Greywacke of the Lorinna Volcanics, Lorinna Gorge.

Fig. 17b Quartz veining in quartzite, Lorinna Volcanics, north of the Lorinna Bridge.
The Dove Granodiorite

The age of a series of granite, granodiorite, adammellite and associated porphyritic rocks outcropping in the Dove River, at and north of the Dove-Forth confluence and in the Mersey River, has long been the subject of conjecture. Twelvetrees (1913) regarded the "quartz porphyries" outcropping south of Lorinna, as belonging to the pre-Silurian group of porphyroids. Reid (1919) thought these rocks were petrologically similar to the Devonian Dolcoath Granite and suggested they represented "porphyroids resorbed by the later (Devonian) granite magma, proof of which has been established regarding the similar rocks occurring northward." Spry (1958) and Jennings (1963) regarded the granite in the Mersey as intrusive into Moina Sandstone and hence Devonian in age. Jennings correlated on petrological grounds, the three outcrops of granite occurring along or near, the Precambrian-Lower Palaeozoic boundary.

In the above and following discussion, the term granite (sensu lato) is used as a general term including all granitic rocks except where stated as granite (sensu stricte) which is a rock where potash feldspar is greater than two thirds of the total feldspar.

Since Jennings' work, new evidence has established a pre-Ordovician age for these granitic bodies. It can be demonstrated in several places that the Moina Sandstone was deposited disconformably on the Dove Granodiorite. The best exposures are in the Mersey River at the northern boundary of the granodiorite, in the Forth River three quarters of a mile
south of the Lorinna bridge and in a small creek flowing into the Forth one mile south of the bridge. The granodiorite-Precambrian boundary is quite definitely intrusive with aplite and feldspar dykes penetrating the schists. The schists have been thermally metamorphosed whereas the character of the granodiorite-Moina Sandstone boundary is quite different, there being no apparent change in the sandstone.

McDougall and Leggo (1965) have dated several specimens of the Dove Granodiorite using the potassium-argon method on biotite and hornblende and their results are reproduced in Table 2. Although the dates range from 454 - 498 million years, they are reliable minimum ages, clearly indicating the granites are pre-Devonian. According to the time scale of Kulp (1961) the granites are Middle Ordovician but it can be shown they do not intrude Lower Ordovician rocks. According to McDougall and Leggo (1965), "the most reasonable interpretation of the results is that the granites were emplaced during the Late Cambrian Jukesian Movement .... and that argon and strontium leakage took place during the Tabberabberan Orogeny in the Devonian, when strong folding took place." Petrologically, many specimens of the Dove Granodiorite are identical with specimens of the Murchison Granite. The latter is considered to have been emplaced during the Jukesian Movement (Brooks, 1962) and both the Murchison and Dove granites are petrologically distinct from nearby Devonian granites at Granite Tor and Heemskirk and Dolcoath Hill respectively.
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Rb/Sr date on sample 617, 487 m.y.

After McDougall and Leggo, (1965).
Petrology

The Dove Granodiorite comprises coarse to medium grained hornblende-biotite granodiorites, granodiorite porphyrites, adamellites, granites (*sensu stricto*), granite porphyries and associated dyke rocks; of which the granodiorite is the dominant petrological type.

In general, the non-porphyritic rocks consist of anhedral quartz, euhedral plagioclase, anhedral to subhedral potash feldspar, dark green hornblende crystals and black biotite laths with tourmaline, zircon, apatite and sulfides as accessories.

The porphyries have large (4 mm.), rounded quartz crystals, biotite laths (3 mm. long) and feldspar tabulae (4 mm.) as phenocrysts in a fine grained equigranular matrix.

Hornblende granodiorite and adamellite are exposed west of the Mersey River along the Tasmanian Board Mills road to Emu Plains. The granodiorite is deeply weathered and has been deuterically altered; even in the freshest-looking samples, the feldspars are slightly turbid and partly sericitized. The freshest rock is a greyish, holocrystalline granodiorite with milky quartz (10%) up to 5 mm. across, greenish plagioclase in euhedral tabulae (30%) up to 4 mm. long and pink orthoclase crystals (15%) some showing simple twinning and up to 10 mm. long. Black biotite flakes (15%) are up to 8 mm. long and dark green to black hornblende crystals (10%) average 4 mm. long. Small sulfide segregations and occasional small tourmaline nodules occur.
In thin section (specimen 33583), the quartz is seriate to 5 mm. across and often shows incipient graphic intergrowths with the feldspar. Larger quartz anhedra commonly show undulose extinction whilst there are occasional small "pools" of quartz containing granular, unstrained quartz about 0.1 mm. in diameter.

Plagioclase is quite altered to fine grained sericite, but normal zonation, Carlsbad, pericline and multiple twinning can be distinguished. The plagioclase is generally euhedral and may occur in glomeroporphyritic patches up to 7 mm. in diameter. (fig. 18a) Both positive and negative relief plagioclase is present, suggesting a composition in the oligoclase range. This is supported by a few extinction angle readings on the multiple twins which give a composition of approximately Ab$_{74}$. Alteration of the plagioclase begins in the centre of the crystals and some of the larger crystals have unaltered rims.

Orthoclase shows poorly developed microperthitic texture with rare Carlsbad twinning. The orthoclase appears to be interstitial to all other minerals.

Biotite is pleochroic from very dark brown to pale yellowish brown and sometimes includes small apatite crystals as well as minute (0.05 mm) crystals of hornblende and plagioclase. In many cases, epidote is beginning to develop along the cleavage of the biotite laths (fig. 18b).

Hornblende is subhedral to euhedral in individual crystals or glomeroporphyritic patches up to 3 mm. across. It is pleochroic from
Fig. 18a Glomeroporphyritic plagioclase in granodiorite.

Specimen 33583  X12  Ord. light

Fig. 18b Epidote developing along biotite cleavage.

Specimen 33571  X13  Ord. light
pale green to deep bluish-green and simple twins are quite common. The margins of some crystals poikilitically enclose quartz feldspar and biotite. Some crystals contain small cores of a colourless mineral with moderate birefringence and this is tentatively identified as pyroxene. The boundary between the hornblende and pyroxene (?) is very indistinct.

Accessory minerals are small (0.1 mm.) apatite and zircon euhedra with occasional pleochroic dark green-blue green tourmaline subhedra (to 1 mm. long).

The above description is typical of the granodiorites of the Dove Granodiorite. Other specimens differ in degree of alteration and the relative amounts of hornblende and biotite present. The ferromagnesians together total between 10 and 30% of the rock.

In the Mersey River, outcrop is more or less continuous from the southern to the northern granodiorite boundaries. For the most part, the rock is of hornblende granodiorite but a notable difference between this and the granodiorite described above, is the colour of the orthoclase crystals. The colour varies, in apparently random fashion, from flesh-pink to white. Thin section studies have failed to reveal a reason for this colour variation. Near the northern boundary in the Mersey River, a small pebble of granodiorite was found to contain a specularite vein. This was not in situ but could have only come from this granodiorite. It is the only known occurrence of specularite veins from here but they are common in the Dove Granodiorite north of the Dove-Forth confluence. Some thin sections of rocks from the Mersey River showed them to be texturally identical with the granodiorites, but compositionally they are adamellites.