PALAEOZOIC SEDIMENTATION, TECTONICS, AND MINERALISATION IN THE MT. LYELL AREA (TASMANIA), WITH ESPECIAL REFERENCE TO THE ORIGIN AND ECONOMIC SIGNIFICANCE OF THE LYELL SCHISTS.

by

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INTRODUCTION

The purpose of this thesis is to present the writer's interpretation of the geology of the Queenstown area and to describe the nature and origin of the Lyell Schists, with a view to assisting in any general search for mineralisation on the West Coast of Tasmania and also to assisting in more localised exploration for copper orebodies in mineralised areas.

The study has consisted of both regional and detailed field mapping with some laboratory work. Earlier workers in the Queenstown area have disagreed violently on general interpretations and particularly on the Lyell Schists, mainly because the theories have been based entirely on either restricted detailed work or generalised reconnaissance work. For the first time, both regional and detailed mapping have been done as units of an overall examination and the two together have thrown new light on the geological picture.

As will be shown later, mineralisation and Lyell Schist formation took place during the Devonian Tabberabberan Orogeny; thus the Mesozoic and later geology is of little significance from an economic point of view and will be presented in summary form.

The area originally studied is that part of the West Coast Range south of Mt. Sedgwick (see Fig. 1), involving about 300 sq. miles of rugged terrain. This was mapped using aerial photographs of 1 inch = 20 chains scale (or 4 inches = 1 mile) and completion of this work was followed by detailed mapping of the Lyell mine areas in company with the Chief Geologist of the Mt. Lyell Mining and Railway Company. This detailed mapping was done on a scale of 1 inch = 100 ft. and involved an area of a little over 5 sq. miles centred on the West Lyell Open Cut.

Further evidence has been brought in from areas further afield that have been mapped by the writer. These are mainly south and west of the West Coast Range, including the Southern Ocean coast from Cape Sorell to High Rocky Point and the D'Aguilar Range. The general geological picture of this part of the West Coast and the area mapped in more detail is shown in Fig. 2; most of the information relating to the area west of the West Coast Range was supplied by the Hydro-Electric Commission of Tasmania.

In conjunction with the field work, over 200 thin sections were made and examined by the writer.

GEOLOGY OF THE WEST COAST RANGE SOUTH OF MT. SEDGWICK

PREVIOUS LITERATURE

The only earlier works covering the regional picture are those by Loftus Hills (1914), Carey (1953), and Bradley (1954, 56). Loftus Hills described the geology of the West Coast Range south of Mt. Huxley but admitted to being hampered in his conclusions by lack of any comprehensive work on the area to the north.

Carey gave a general account of the tectonic setting of the West Coast but Bradley was the first geologist to undertake a full-scale geological examination of the Range and he extended his work northwards to take in Mts. Murchison and Tyndall. His results were not available when the writer began work and the entire area has been re-mapped independently, generally in more detail.

A small number of other papers refer to particular aspects of the regional geology and these will be referred to later. The papers dealing with the Lyell mine geology, and the Lyell Schists in particular, are discussed in a later chapter.

PHYSIOGRAPHY

The most striking topographic feature of the area is the line of rugged peaks that form the West Coast Range. They rise from a general plain level of between 700 and 1000 feet to an average of 3500 feet above sea level, with a maximum at Mt. Sedgwick of about 4000 feet. The mountains lie along a longitudinal belt of rough terrain that is characterised by wide areas of flatly-dipping, hard, siliceous conglomerate. From north to south the peaks are named: Mts. Sedgwick, Lyell, Owen, Huxley, Jukes, Darwin, Sorell, and South Darwin, the last named marking the southern termination of the Range (see Fig. 3).

This long line of hills is flanked on either side by deep river valleys, the most prominent of which are the King River on the east and the Queen River on the west. The King River is the largest and rises well to the north near Eldon Peak. It flows southward past Sedgwick, Lyell, Owen, and Huxley, but then swings westward and passes through a deep gorge in the Range between Mts. Huxley and Jukes. It is then joined by the Queen River, flowing southward, and winds its way along a soft limestone bed until it enters Macquarie Harbour a mile south of Strahan. The King River Valley east of the Range separates the latter from the rugged Central Plateau of Tasmania. West of the Queen River a gently dipping but deeply dissected peneplain surface slopes westward to the sea.

The King River is the main drainage channel and receives all flood waters except for those flowing into Kelly Basin from the Darwin and Sorell areas via the Nora, Clark and Bird Rivers; those flowing south-east to the Franklin via the Andrew River; and those flowing west via the Yolande River. All rivers show signs of rejuvenation and youth, with steep gradients, interlocking spurs, sharp V-profiles, terraces etc.. Although the King River on the east of the Range shows a mature development, below the knick points north and west of Crotty it has every sign of rapid down-cutting following the regional uplift or lowering of base level.

The ruggedness of the Range has been further accentuated by mountain glaciation both on the western and eastern slopes, and cirques, hanging valleys, ice-smoothed platforms and other classical glacial forms are abundant. The effects of valley glaciation are also seen in the Comstock and Linda valleys, and along the upper parts of the King River.

Bradley (1954, p.196) describes the capture of the headwaters of the Baxter River by the North Andrew River near Divide Hill, and the impending capture of the King River. This would divert the King waters towards the Franklin and Gordon Rivers, via the Andrew River, a drainage pattern that most probably existed prior to the capture of the King River by E - W streams cutting back through the Range between Mts. Jukes and Huxley.

The broad valleys and abundance of river gravels south of Crotty and near the Andrew Divide testify to the presence there, at one time, of a large river.

Geological control of the topography and drainage is complete. The distribution of the resistant Owen Conglomerate formation has an obvious control over the drainage pattern and the major rivers are confined to the underlying or overlying softer formations. Along the West Coast Range the Conglomerate is folded into a broad anticline with a N - S strike and the softer overlying sediments have been stripped off the higher levels near the fold axis, so that they flank the fold in broad valleys. Thus the West Coast Range more or less marks the fold axis in the Conglomerate, and the valleys on either flank are cut in the younger strata. Differential erosion in the younger series of alternating quartzites, shales, and limestones produces still further topographic complications. Of particular importance is the Gordon Limestone immediately overlying the conglomerate for it is particularly susceptible to erosion and its presence is often indicated by wide, flat, marshy valley floors. Much of the King and Queen Rivers are cut in this bed, and along the Range it may be said that, generally speaking, the present topography marks the base of the Gordon Limestone.

The breaching of the Range by the King River near Mt. Huxley reflects a close structural control over topography. The area between Mts. Huxley and Jukes represents an E - W zone of tight folding and close faulting with a broadly synclinal form, not unlike that between Mts. Owen and Lyell. The river has picked out the approximate axis of this structure and has followed the softer rocks and the more crumpled zones in the Owen Conglomerate. Structural control of the King is continued between Dubbil-Barril and Mt. Huxley; its course resembles the section of a north pitching anticline or a south pitching syncline with attendant drag folds, and this has facilitated elucidation of the regional structure.

Faulting plays no mean part in determining topographic form - the steep eastern flank of the Range east of Mts. Sedgwick and Owen owes its origin to strong faulting combined with glacial action. Again the broad open valleys of Linda and Comstock, though slightly modified by glacial erosion, closely reflect the geological structure. They owe their origin to E - W faulting and in the Linda Valley are preserved remnants of the younger sediments that have been stripped off the rest of the more elevated Range. Again, the strong N.W. faults that cut across Mts. Owen and Jukes are clearly indicated by the step-like northern faces of both these mountains.

Old peneplain surfaces are clearly visible throughout the area. The oldest is probably the Carboniferous peneplain (Edwards, 1941), at about 3500 feet, on which lie the Permian tillite and dolerite of Mt. Sedgwick. This level is also seen at Mt. Dundas and along the concordant summits of the Range. Bradley describes a prominent erosional surface at 2750 feet east of Mt. Dundas but there are few signs of it in the Queenstown or Darwin areas. Between Mt. Jukes and South Darwin, broad plateaux at about 2000 feet are prominent (e.g. Intercolonial Spur) and probably represent an old erosional surface.

The other major surface is the Henty peneplain, which slopes westward from about 1000 feet at the base of the Range to about 500 feet near the coast. This level is equivalent to the Little Henty Plain described by Waterhouse (1916) in the Heemskirk district; it has undergone fairly recent (late Tertiary?) uplift and is deeply dissected by a youthful drainage system. The levels reflect a post-Palaeozoic history of restricted sedimentation, prolonged periods of erosion, and a successive lowering of base level as a result of block faulting near the coast stepping up to the east.

STRATIGRAPHY

The approximate stratigraphic column for this area is shown in Table I.

TABLE I

Recent		river gravels and talus
Pleistocene		moraines
Tertiary		river gravels and lacustrine deposits (Macquarie Beds)
- - Unconformity - -		
Jurassic (?)		dolerite sills
Permian		tillite, sandstone
- - Unconformity (the Tabberabberan Orogeny) - -		
Siluro-Devonian	Eldon Group:	Bell Shale
		Florence Quartzite
		Keel Quartzite and Shales
		Amber Shale
		Crotty Quartzite
Ordovician	Junee Group:	Gordon Limestone
		Owen Conglomerate
		Jukes Conglomerate
- - Unconformity (the Tyennan Orogeny - Jukesian Movement) - -		
Cambrian	Dundas Group:	Lavas, pyroclastics, siltstones, and greywack sediments.
- - Unconformity (the Tyennan Orogeny - Stichtan Movement) - -		
Precambrian		Quartzites, schists, gneisses.

Precambrian

East of the King and Andrew River valleys and east of the area mapped, the ground rises rapidly to the west flank of the Central Plateau of Tasmania. This is composed of Precambrian rocks which have acted as a stable core (the Tyennan Block) controlling subsequent tectonics and sedimentation.

The Raglan and Engineer Ranges represent the western edge of the Plateau in this area and are composed of quartz and quartz-mica schists, and dense grey quartzites forming prominent arcuate ridges. North of the Lyell Highway the Precambrian rocks are largely concealed by Permian sediments and dolerite.

Precambrian rocks are also seen on the Southern Ocean coast south of Cape Sorell, at Trial Harbour, and again north of the Heemskirk granite mass. They are mainly a rapidly alternating series of quartzites, dolomites, and shales.

Cambrian - Dundas Group

During at least the latter half of the Cambrian, this area was part of a eugeosyncline which stretched along the west and north-west coasts of Tasmania and across to Victoria (represented there by the Heathcotian Series). The Tyennan Block was either a region of no relief or was submerged at this stage, for there are virtually no beds in the Dundas Group which could have been derived from a Precambrian source. However, if Dundas sediments were deposited on Tyenna then they were later removed by erosion, for Ordovician beds rest directly on Precambrian strata along the Engineer Range. The relationship of the Dundas Group to the Precambrian strata basement is not observable in this area but evidence from elsewhere indicates strong unconformity. Carey and Banks (1954) describe the junction as the Stichtan unconformity from evidence gathered at the southern end of the Sticht Range.

The more important Dundas lithologies found in the area mapped are greywacke conglomerates, varying from coarse to fine, basic pyroxene lavas, intermediate trachytes and acid lavas, pyroclastics, siltstones, and minor sandstones. They are typical of the deposits of tectonically and volcanically active eugeosynclines with island arcs rapidly feeding material into unstable basins. The strata are unfossiliferous but are closely parallelled by rocks mapped by Elliston (1954) in the Mt. Dundas area, which contain trilobites of Middle Cambrian and lower Upper Cambrian age (Opik, 1951). Elliston has traced formations over considerable areas near Dundas and comparison of his maps with those of the Queenstown and Darwin areas highlights the lack of continuity and the individuality of particular lithologies in the latter areas. A logical conclusion is that the conditions of deposition were less stable at Queenstown than at Dundas and were characterised by more localised ephemeral environments. If this is correct then it may explain some of the difficulties in establishing a generalised succession and of determining structure. Both these tasks are further hampered by the fact that the majority of the beds seldom show bedding directions, being, on the whole, rapidly deposited and poorly sorted rock types. Structural forms have only been recognised in a generalised manner but even this has proved useful, for in the Lynch Creek area, the very fact that the rocks are folded is of importance, as Bradley has measured a continuous 2-mile succession across strata that appear to be repeated by folding.

The Dundas Group sediments and volcanics are generally lightly sheared and have been affected by low grade regional metamorphism. Earlier workers regarded the area as intruded by rather peculiar and variable magmas of Devonian age, the obvious sedimentary rocks being floating roof pendants and the lavas and igneous-like rocks being intrusives. Twelvetrees (1902) described this "porphyry complex" in some detail and used the term "porphyroids" for the schistose intrusives; he regarded them as dynamically sheared porphyries. This word "porphyroids" became popular in Tasmania and, until recently, was widely used. Tyrell (1930) defines it as referring to coarse and fine igneous rocks which have been sheared into schists and gneisses, but in which original "phenocrysts" resist crushing and remain as porphyroblasts. Holmes (as quoted in Rice, 1954) states that porphyroid is a term "applied to porphyroblastic metamorphic rocks, intermediate structurally between hälleflinta[1] and granite gneiss, in the same way as quartz-porphyry and granite-porphyry are intermediate between rhyolite and granite. The term has been extended to include porphyroblastic schists of sedimentary origin."

1. Holmes defines hälleflinta as applying to granulose rocks of horny aspect which are compact or porphyritic, and sometimes banded. The mineral composition, quartz, felspar, micas, etc., indicates a metamorphic origin from quartz-porphyry, rhyolite, or corresponding volcanic tuffs.

The definition seems to have become rather loose and it is noticed that neither Turner and Verhoogen (1951) nor Ramberg (1952) use the word at all while discussing metamorphic or igneous rocks. The writer has found the term unnecessary and often misleading and there is no reason for keeping it in service.

The concept of sheared intrusives initiated by Twelvetrees and other workers was modified by Gregory (1903) and Loftus Hills (1914, 1927), who recognised the abundance of re-constituted volcanics near Queenstown, but was returned to by Nye, Blake and Henderson (1934), Edwards (1939), and Conolly (1947). Carey and Loftus Hills (1949), however, re-affirmed the volcanic origin of the porphyroids and in recent years, Carey, Bradley and Scott have developed the concept of eugeosynclinal sedimentation with deposition of greywacke sediments and volcanics, followed by regional metamorphism which has converted sediments and volcanics alike to igneous-looking material.

The chief rock types encountered within the Dundas Group in the Queenstown area are as follows:

Volcanics

As will appear in the ensuing pages, volcanic rocks of the West Coast form three separate chemical provinces. The three groups are -

1. Variable acidity but all soda-rich.
2. Acidic and potassic.
3. Basaltic and soda-rich.

The last group, of spilites, is found along the Southern Ocean coast from Spero River to south of High Rocky Point, while the other two are found near the West Coast Range. Their relative distribution is controlled by an important longitudinal structure, known as the Lyell Shear, which runs from near Mt. Sedgwick to South Darwin. The volcanics along its length are characterised by high silica and potash percentages (group 2.) while the volcanics in flanking areas belong to the first group mentioned above.

The Lavas of the Zone Flanking the Lyell Shear

The volcanic rocks of this zone, which has been mapped in the Queenstown and Darwin areas, have been the subject of controversy and there is considerable argument as to the extent of true volcanic lavas, for Bradley regards many lava-like rocks as the products of metasomatism of greywackesediments and Scott regards the intermediate and acid lavas as derived from basalts by metasomatism.

Without doubt, albite basalts occur along Lynch Creek; they have been described both by Scott (1954) and Bradley (1954) and their extent has been mapped by the writer. Individual flows are limited in extent, in both horizontal and vertical directions and they are associated with considerable developments of volcanic breccias.

The volcanics pass along strike into sediments, mainly finely banded siltstones and conglomerates.

The lavas are green-grey in colour and porphyritic with phenocrysts of green pyroxenes up to 2 c.m. long, and smaller white felspars set in an aphanitic ground mass. Scott has identified the pyroxene as diopside; it occurs in idiomorphic crystals and is generally only slightly chloritised. The felspars occur as highly altered subhedral laths which are generally impossible to identify. Scott, however, states that all the felspar is albite. The ground mass is composed largely of diopside granules and felspar laths set in a dense brown base.

Some of the lavas are veined by clear, fresh albite which tends to occur in veinlets and also in clots and irregular zones, apparently replacing the original rock.

An analysis of this diopside lava by Scott and two by the Mt. Lyell Assay Office are shown in Table 2. The analyses of the pyroxene basalt. have many features in common with that of the average alkali basalts quoted in the table.

The breccias associated with the lavas along Lynch Creek are of interest. They are coarse and consist generally of "boulders" and "pebbles" of vesicular basalt within a basalt matrix, the latter showing signs of "attacking" the fragments. The lava fragments are generally much more vesicular than the matrix. The amygdales are usually spherical and up to 5 m.m. in diameter; they may be lined with felspar enclosing hematite and with a core of chlorite; or filled with calcite; or calcite with a core of chlorite; or chlorite with a core of calcite. The breccias probably originate by the process of autobrecciation in which the chilled gas-laden crust of a mobile lava flow becomes broken up by, and incorporated into, the still molten rock beneath.

Better exposures of a similar phenomenon occur along the West Coast south of the Spero River; here considerable thicknesses of lava breccias are exposed, interbedded with shales and tuffs.

Rather different textured lava is found in a flow near Miners Ridge; it is about 100 ft. thick and extends for several hundred yards. It is composed of diopside and felspar but has a more or less equigranular texture with augite granules set in a lattice-work of fine felspar laths. Its chemical composition is given in Table 2.

The volcanics are often veined by a fibrous amphibole which has been excavated in a small way for asbestos at a number of places along Lynch Creek.

These basaltic lavas of the Lynch Creek area are the only ones about which there is no controversy from a petrological point of view. Bradley, however, maps them as extending for several miles north and south of Lynch Creek and has assigned them a formation name, defining their vertical extent and the underlying and overlying beds. As will be shown later, such accuracy of definition is not considered practical.

Thin lava flows interbedded with siltstones are exposed at the northern end of the Queen River Gorge. They consist of altered felspar porphyries with chlorite lenses that were probably originally ferro-magnesian minerals. At the base of many of the flows, the siltstones are disturbed and fragments become torn off and incorporated within the lava.

The igneous rocks described so far are the only ones to which a volcanic origin can quite definitely be ascribed. However, there is a considerable development of igneous-looking porphyries that may well be of volcanic origin; such rocks are exposed in the King River Gorge, the North Andrew River, and over several square miles east and west of the Zeehan-Queenstown road. Hitherto the writer had considered these rocks as of metamorphic origin, as do Scott and Bradley, but with evidence from outside areas, he realises that they may well be igneous.

The problem of the origin of these rocks is of vital importance, for if these porphyries are primary volcanics that have undergone only minor alteration, then the far-reaching zoning theories of Bradley and Scott are nullified. They envisage a regional metamorphism of existing conglomerates and basalts, with distinct large-scale zones some of which include sulphide mineralisation. If these zones have no significance as far as mineralisation is concerned then they cannot be used as guides in ore search. The recent work has shown that metamorphism accompanying mineralisation is restricted and that the variation in the nature of the igneous rocks that had been ascribed to metamorphic zoning is actually due to structural control of magma distribution.

As will be shown later, many of the Lyell Schist types are presumed to be derived by alteration of the Dundas Group and a knowledge of the nature of the original material is obviously important in discussing chemical and mineralogical changes.

Albitisation and hydrothermal alteration in the Queenstown area, combined with poor exposures, has made determination of the nature of these igneous-looking rocks most difficult. In an area affected by such metamorphism, it is difficult to prove that the porphyries are not metamorphic, as suggested by Bradley and Scott.

However, Jennings (pers. comm.) has mapped many hundreds of feet of similar rocks that are undoubtedly lava flows, both from field and microscope evidence, in an area not affected by hydrothermal alteration. Similarly, the writer has found quartz and felspar porphyries in the Dundas Group of the D'Aguilar Range, well away from any significant metamorphism. In this area it would be unreasonable to ascribe a metamorphic origin to the felspar and quartz phenocrysts.

Pebble outlines and sedimentary-like textures in many of the porphyries has been quoted as support for a metamorphic origin, assuming the original material to have been conglomerate, etc.

However, the writer's work in the Spero River - High Rocky Point area has shown that lavas often exhibit breccia-like structures and flow banding extremely similar to features seen in sediments.

Autobrecciation of thick lava flows results in a conglomeratic-looking rock composed of lava fragments in a lava base. Another feature of these basalts is their wide variation in thickness from a few inches to several hundred feet, and a wide range in grain size between individual flows. The microscope also reveals an extensive range of textures, from porphyritic to seriate, reticulated, or chaotic and nondescript.

It is only the completeness and freshness of the exposures on the shore line that provides proof of the nature and origin of these rocks and which gives the clue to the true origin of the porphyries of the Queenstown area.

It may be pertinent now to describe the more common of these igneous porphyries:

Felspar Porphyries

A variety of felspar porphyries are exposed along the East Queen River. They are characterised by felspar phenocrysts, very fine or micro-crystalline felspathic (?) matrices, and irregular zones of albite-chlorite aggregate varying from several c.m. diameter to less than 1 m.m. Quartz is either absent, or present only in small quantity, and chlorite, augite, and hornblende may show locally in small amounts.

The felspar phenocrysts are normally very altered but show multiple twinning and appear to be albite. Alteration is generally either to a dense brown cloud or to chlorite, while others appear to be changing to fresh albite-chlorite aggregates and losing their identity. Often the phenocrysts occur clustered together to form glomerophenocrysts.

Many of these rocks show amygdales filled with clear albite or albite and chlorite and a specimen collected by Gregory from the Comstock tram line shows an amygdale filled with albite, quartz and epidote. These features probably are evidence of volcanic origin, but one hesitates when one remembers that felspars appear to disintegrate into albite chlorite mosaics similar to amygdales.

The porphyries sometimes show banding and pebble outlines that would suggest a sedimentary origin but the writer has seen similar banding and "pebbles" formed by autobrecciation in unaltered lavas south of the Spero River.

The chemical composition of one of these porphyries is shown in Table 3. On a chemical basis, the rock might be described as a trachyandesite (quoted in the same table) though with the large percentage of albite in the mode, perhaps an albite trachyandesite is to be preferred. The felspar porphyries in general might well be classed as trachytes, trachyandesites, and keratophyres (soda-rich trachytes).

A rather different felspar porphyry may be seen about half a mile south of the upper zig-zag on the Comstock line. It is a pale grey porphyry with grey felspar crystals up to 2 m.m. diameter embedded in an aphanitic ground mass; there are no ferromagnesian minerals. The felspar seldom shows twinning and is fairly altered, while the ground mass appears quartzose. Weathered surfaces reveal fine banding that has been interpreted as flow structure (see Fig. 4). Bradley describes the rock as a soda trachyte but it analyses (see Table 3) closer to a rhyolite and on chemical composition could be described as a sodi-potassic rhyolite.

Quartz-felspar Porphyries

Of the several quartz porphyries in the Queenstown area, most is known about the one outcropping in the West Queen River.

It is a pinkish or grey porphyry, with phenocrysts of clear quartz up to 3-4 m.m. diameter and smaller pale grey felspars set in an aphanitic ground mass. The quartz phenocrysts are typically embayed and contain inclusions of the ground mass, and occasionally show "pressure fringes". All these features are typical of present day acid volcanics and are not necessarily criteria for metasomatic growth of quartz crystals. The form of most of the quartz crystals is typified by the figure of a pitchstone shown by Hatch, Wells, and Wells (1952, p.226).

Felspars, however, which occur in approximately equal quantity to the quartz, seldom show such embayments and inclusions. They occur as hypidiomorphic crystals, sometimes showing good crystal faces, often with marked zoning. The latter may be highlighted by the alteration of the core to chlorite and the rim to sericite (?). The felspars are largely albite, though many show no twinning and could be orthoclase; they are all fairly altered to sericite (?) etc.

Clear albite and chlorite occur in irregular zones in the ground mass, much as in the felspar porphyries already described; the rock is also traversed by fine clear albite veins.

Chlorite and hematite appears to replace idiomorphic lath-like crystals, possibly originally of ferromagnesian mineral.

A chemical analysis of this porphyry (Table 3) is very similar to a rhyolite with rather high soda content and might be described as a sodic rhyolite, though most rhyolites are a little richer in silica.

Field mapping indicates that the grey greywacke sandstones that outcrop in the Queen River Valley near the Mt. Lyell sub-station pass along strike into the quartz porphyry. This might be interpreted as an intrusive relationship, a replacement phenomenon, or a facies change along strike. Unfortunately the field evidence is not conclusive and the problem unsolved; there is no sign of baking or marginal alteration of sediments in the borders of the porphyry and nothing to suggest transformation of greywacke to porphyry, though this could be accomplished without much chemical change.

Quartz felspar porphyries of similar type occur in the King River west of Harris' Reward pack-bridge; in the Garfield River; near Darwin; and at many other parts within the Dundas Group outcrop. They often show bands of breccia, sandstone, or siltstone and their characteristics conform to a series of acid (rhyolitic) volcanics and volcanic breccias which have undergone albitisation.

A rather different type may be seen on the tram-line to the Lower Power House from Lake Margaret. It is variable in colour from grey-blue to yellowish and is composed of phenocrysts up to 4-5 m.m. diameter of quartz, felspar, and chlorite. Even in hand specimen, it can be seen that many of the quartz crystals are idiomorphic and one showed fully developed pyramidal faces. Zoning in the felspars is also conspicuous macroscopically.

An interesting quartz-felspar rock forms tors north of the northern zig-zag on the Comstock tram-line. It is mottled or rudely and coarsely banded in pink and dark green, the bands being several inches thick, and it passes along strike to greywacke conglomerate with sandstone beds.

The microscope shows a more or less equigranular aggregate, averaging about 1 m.m.diameter, of quartz and felspar with some interstitial material. The felspar is fresh albite and occurs in anhedral grains while the quartz often contains inclusions of the matrix and shows ragged borders. The chlorite occurs as interstitial material and has an uneven distribution. This rock has the texture and field appearance of a sedimentary or pyroclastic rock and is probably derived from weathering of volcanic material or is a result of volcanic explosions. Whether the felspar has been altered to albite since deposition or whether it was originally albite is difficult to say.

Kaolinisation of quartz porphyries is noticed at several points, particularly east of the Hospital and around Miners Ridge. The felspars and ground mass are converted to white or greenish clay, which is studded with unaltered quartz grains.

Some of the quartz porphyries and so-called "porphyroid" rocks have been found to be simply sheared greywacke sandstones in which the dominant quartz grains have remained as porphyroblasts while the matrix has become an obscure, wispy, schistose mass of kaolin, sericite, etc. Thus a slide cut from a rather impure sandstone on the east end of Mt. Lyell is identical with one in the Tasmanian Mines Department, described by Loftus Hills as a "porphyroid from the conglomerate at Mt. Darwin".

Hornblende-felspar Porphyries

In the Comstock - Crown Hill area, many of the hill-tops are crowned by tors of hornblende porphyry. This rock is typically a grey or pinkish colour with phenocrysts of felspars and hornblende laths up to 1" x ½" set in an aphanitic ground mass. The laths usually show random orientation and the rock is massive and poorly jointed.

Microscopically, the texture is more seriate than porphyritic and varies considerably from section to section. Felspar is the dominant mineral, occuring as phenocrysts and in the very fine ground mass; it is cloudy and partly chloritised but remnants of multiple twinning are discernible. Much of it appears to have the composition Ab_{70} though Scott (1954) describes orthoclase in similar rocks from the Lake Margaret moraine, several miles to the north. Zoning is common, many crystals showing a clear outer albite fringe enclosing a core of altered felspar.

Hornblende crystals are typically embayed, and contain inclusions of the matrix while some are more of a skeletal framework than a crystal. Some show a dark ferruginous rim and a chloritic core, others are represented by prisms of chlorite and hematite. A typical crystal is shown in Fig. 4. A few quartz crystals are usually present in the form of shards and they tend to occur in clusters showing unit extinction. The remainder of the rock is made up of a dark, probably felspathic matrix and fragments of rock that appear to be largely felspar and pyroxene and are therefore probably lava fragments.

The hornblende porphyry grades through all stages to augite porphyry; the percentage of ferromagnesian in the rock seems to be more or less constant and where there is much of one mineral then there is little of the other; thus they appear to be complementary. The augite is generally in cracked and poorly shaped crystals and is partially chloritised.

A little to the east of Crown Hill, the porphyry develops a brecciated appearance due to veining by albite. Irregular blocks of normal grey porphyry up to 1 ft. across are separated by bands and zones of pale albite-hornblende rock (fig. 4). The albite is fresh and appears to be secondary, replacing the original porphyry. In this area also the porphyry locally shows a fine banding very much like stratification; in one place, a "pebble" depresses the "bedding". This phenomenon may be flow structure, the "pebble" being a fragment of country rock or of previously solidified lava incorporated in the still molten or plastic material. Similar features have been observed near the Wanderer River mouth, north of High Rocky Point.

As previously mentioned, hornblende-felspar porphyry occurs as large boulders on the northern slopes of the Lake Margaret moraine. A characteristic of this rock is the variation in texture and the inclusion of pieces of siltstone, etc. within the rock.

Scott (1954) describes parallel orientation of hornblende laths in one boulder and this feature has aroused much discussion. Scott regards this rock as a metamorphosed basic lava which has undergone silicification, albitisation, etc. to become similar to a hornblende andesite. The hornblendes she regards as growing out of chlorite which results from breakdown of pyroxene during regional metamorphism. This is, of course, the reverse of the usual relationship seen in lavas, in which hornblende becomes "re-digested" to form magnetite and pyroxene. She has not seen hornblende growing out of pyroxene directly.

Scott suggests this rock is a result of metamorphism of basalt though if it is she is at a loss to explain the parallel orientation of hornblendes seen in one boulder. Hornblendes do not pseudomorph augite and grow with random orientation, therefore, according to her, the parallelism cannot be original. But the hornblende orientation direction is at an angle to the cleavage and therefore it is not a metamorphic effect. It would seem highly probable that the University of Tasmania lecturers are correct in calling the rock a hornblende andesite that has undergone albitisation. Thus the parallel orientation would be explained as a flow phenomenon. Corroded and embayed hornblende crystals are typical of hornblende andesites from many parts of the world, though it is usual to see evidence of augite growing as a result of the breakdown of the hornblende. An analysis of typical material is given in Table 3.

A hornblende-quartz-felspar rock exposed on the Lake Margaret tram west of Crown Hill is distinctly banded and has a granular, sedimentary texture. It is composed of more or less equidimensional grains of chiefly felspar (albite) with quartz and hornblende and fine interstitial matter. The average grain size is about 1/3 or ½ m.m. The component minerals are similar to those in the hornblende porphyries of Crown Hill and there are also a few discoloured, fractured augite crystals. The marked banding, which is due to variation in concentration of the components, may indicate that they were deposited in water, possibly after volcanic explosions, and that the rock is therefore of clastic origin. Alternatively the banding may be a result of flowage in lava. The albite in this rock is comparitively fresh and has a brownish tinge; it is very similar to that in the banded quartz-albite rock near Comstock that has already been described (p. 16).

Hornblende also is found in some of the augite lavas of Lynch and Specimen Creeks; it is generally of minor importance and has the typical form of the Crown Hill amphiboles. As the Lynch Creek basalts are accepted as unaltered, then it seems extremely probable that the hornblende is a primary feature and not due to locally high temperature conditions during metamorphism, as suggested by Scott (1954, p.145).

Pyroxene-felspar Porphyries

To the east of the Queenstown-Lynchford road, the grass-covered hills show large tors of felspar-pyroxene rocks. Many of the tors show distinct pebbles of various sedimentary and volcanic rocks, and locally, a banding which could be stratification.

Microscopically the rock is very similar to that above the northern zig-zag of the Comstock tram; it has a rudely equigranular more or less reticulated texture, with grain size about 1 m.m. diameter and sparse interstitial matter. Typically the rock is 80% or 90% felspar in subhedral crystals, the remainder being augite, quartz and some interstitial matter. The felspars are only slightly altered, have a pink tinge and appear to be albite (Ab_{98}); it is similar to that type already described in banded rocks near Comstock and Crown Hill. Augite crystals are anhedral, fractured and partially altered to chlorite. Clear albite veinlets traverse the rock and irregular albite-chlorite clots are typical.

This rock type, like that at Comstock, appears sedimentary or pyroclastic, by virtue of its structure. In this case, where "pebbles" are frequent and bedding not so common, it appears more likely that it is of pyroclastic origin, being the result of volcanic explosions accompanying lava extrusion. Bradley, however, suggests it results from weathering of the underlying lavas and in support of this, calls in evidence of unconformity at the top of the volcanic sequence.

Twelvetrees (1902) and others regarded this rock as intrusive, from field evidence and texture, and they described it as an augite syenite. Certainly its chemical composition is syenitic (see Table 3) but its field relationships hardly support intrusion.

A similar rock occurs east of Little Owen. For the most part it is interbedded with sandstones and tuffs but at one point it is clearly cutting across strike. It shows no inclusions or pebbles and it is possible that this represents a sill. Alternatively it might be a pyroclastic rock or a flow with transgressive relationships near a vent.

The Little Owen rock has approximately equal quantities of pyroxene and felspar with interstitial quartz, felspar (albite), and clear albite-chlorite zones.

The origin of these pyroxene rocks is difficult to determine and suggestions range from lava to pyroclastic, sediment, or sill.

Another indication is given by loose boulders found by Mr. M. L. Wade near the 9-mile post (from Zeehan) on the Queenstown-Zeehan road. Felspar-pyroxene rocks, similar to the Little Owen material, contain fragments of cherty banded siltstone up to several inches in size and showing random orientation. These fragments appear to have undergone some absorption by the matrix and under the microscope the margins appear baked.

Where these boulders have come from is not known, but they provide evidence for an igneous origin and the writer is inclined to think that the Little Owen and Lynchford occurrences are lava flows of trachytic type.

The Potash-rich Lavas of the Lyell Shear Zone

An unusual suite of rock occurs in the Dundas Group along the West Coast Range south of Mt. Huxley. The long narrow outcrop of these rocks marks the line of the Lyell Shear. They are typically pink or grey and relatively unsheared, despite the fact that they act as hosts to several copper orebodies.

Perhaps the commonest rock type is the pink felspar porphyry exposed on Intercolonial Spur and parts of Mt. Darwin. This is a closely jointed pink porphyry studded with crystals up to 3 m.m. diameter of grey felspar and chlorite. Under the microscope, the sparsely distributed subhedral felspar laths appear to be albite, and crystals often show "nibbled" margins. Alteration varies from intense to light. The ground mass, which forms up to 90% of the rock, is mainly composed of microcrystalline, rather crude spherulites. These are generally less than $\frac{1}{2}$ m.m. diameter and typical forms are shown in Fig. 5; they usually have a quartz core and often a rim of clear quartz or dark brown hematite dust.

The notable features of the chemical composition of this rock are the high silica and potash percentages (Table 3). Staining with sodium cobalti-nitrite (Chayes, 1952) reveals that the potassic material is among the ground mass, so presumably much of the fibrous material of the spherulites is K-felspar. The phenocrysts were not affected by the staining.

In several places on Mt. Darwin within the pink porphyry, are outcrops showing bedded rocks, mainly breccias and conglomerates. On the eastern flank a creek exposes siltstones and fine sandstones showing fine banding.

On the basis of chemical analysis and texture, the pink porphyries should be classified as potassic rhyolites and indicate that this part of the Lyell Shear zone was one of intense volcanic activity during the Cambrian, with extrusion of dominantly acid lavas and breccias.

An interesting rock acts as host to the Lake Jukes orebody. It is a dense, mottled, pink or greenish grey "felsite" that in part is similar to those just described but locally is composed largely of a crude microcrystalline intergrowth between quartz and K(?)-felspar. This forms graphic texture and Hills (1914) describes the rock as a granophyre. This texture is usually regarded as of igneous origin though there are instances recorded showing that it may result by metasomatic alteration of sediments (Hatch, Wells, and Wells, 1952, p.217). It is possible that the granophyric texture has been produced as a result of reconstitution of the normal spherulitic material concomitant with ore introduction and deposition.

The Lake Jukes rock mass locally shows cross-bedded sandstone and clearly defined outlines of boulders up to 3 ft. diameter in breccia-conglomerates; these are possibly rhyolite breccias.

A rock similar to that on Intercolonial Spur outcrops at the head of Whip Spur on the south-west flank of Mt. Owen. It is a pink albite porphyry, generally massive but in one place showing fine banding; it is right on the line of the Lyell Shear. The albite phenocrysts are up to 2 m.m. x 1 m.m. in size and lie in a microcrystalline felspathic base in which tiny spherulites abound. These are usually less than 1/5 m.m. in diameter and consist of radiating material with a thin dark circumference. The base reacts positively to the potash etch and stain test.

The pink porphyries and breccias of Mt. Darwin extend south along the western flank of South Darwin; here they are veined by hematite and some magnetite and exhibit a crude foliation that is similar to bedding.

The Basaltic Lavas of the Southern Ocean Coast

South of Point Hibbs, for many miles down the coast, rocky cliffs expose a sequence of basalts and pyroclastic rocks.

The flows are extremely variable in thickness, being from a few inches to over 100 ft. thick and are also variable in texture. They are mainly fine-grained with some coarser zones, and dark or medium grey in colour. They are interbedded with banded shales and tuffs and to a lesser extent with pebbly tuffs and agglomerates.

While some of the flows are homogeneous, others are severely brecciated, often throughout their depth; the brecciated appearance is caused by the presence of fragments of lava embedded in a lava base and the feature is probably due to autobrecciation. The fragments are often in greater quantity than the base and if the rock were poorly exposed, it could well be taken for a sediment.

The basalts are seldom vesicular, but very occasionally show scoriaceous tops. Epidote-quartz veins were seen about ½ mile north of the Wanderer River bay.

The most common lava, in hand specimen, is a grey porphyry, with grey felspars and dark euhedral augites in an aphanitic dark ground mass.

Microscopically, the phenocrysts are slightly chloritised, subhedral albites, and altered pyroxenes which are probably augite. The phenocrysts are generally less than 1-2 m.m. diameter while the ground mass is a dense brown, or is finely microcrystalline with tiny felspar laths discernible. Some thin sections show amygdales which may be circular and lenticular in shape and generally lined with clear albite which encloses a chlorite core.

In other specimens, the microscope shows the ground mass as a coarsely microcrystalline lattice work of albite laths and interstitial pyroxene granules, or the ground mass is so sparse that the rock is a poorly sorted mosaic of albite "phenocrysts".

Some of these spilitic rocks probably extend into the intermediate range though free quartz is only seen in very small quantity. Three partial analyses (Table 3) of different lava types show the range from basic to intermediate.

An interesting variety of the basalts was shown to the writer by J. Gilfillan, of Melbourne University. It is a pale grey-green porphyry, dominated by tabular crystals of albite up to 5 x 3 x 1 m.m. in size, which lie with a few pyroxene crystals in a microcrystalline mosaic of albite laths and augite granules. The rock also shows lenticular albite-chlorite amygdales.

Summary of Cambrian Volcanic Activity

The Cambrian period in Tasmania was characterised by prevailing eugeosynclinal conditions, involving continued and widespread volcanic activity, the nature of which varied from place to place. The principal igneous products ranged from basalt through alkaline trachytes (keratophyres) to rhyolites. At least the basalts, and probably the entire sequence in the Dundas Group, were most probably of submarine origin. Pillow structures in Cambrian basalts have been described from Smithton (Carey and Scott, 1951), Penguin (Scott, 1952), and King Island (Scott, 1950).

The acid and basic porphyries of the volcanic suite have been the subject of controversy for many years, but particularly lately as a result of the opinions expressed by Scott and Bradley. They have allowed for considerable mineralogical and chemical changes resulting from Jukesian (Scott) or Devonian (Bradley) metamorphism of originally basic material.

However, if one assumes that the range of porphyries represents original volcanic material (the associations present in the Dundas Group are typical of many volcanic provinces) then there appears to have been only minor alteration, principally in the form of albitisation.

The original reason for assuming widespread metasomatism of the Dundas Group appears to have been based on field evidence in the Roaring Meg - Lynch Creek area. Bradley (1954) traced the basalts of Lynch Creek northwards and, supposedly following along strike, came upon quartz-felspar rocks, which he assumed to have been derived from the basic lavas by metasomatism.

Re-mapping of the entire area and in particular the Lynch

Creek area, has shown that the lavas do not continue along strike to Roaring Meg Creek and that the folding is much more intense than was originally assumed. In actual fact, the volcanics pass by normal lithological change to siltstones, conglomerates etc., over remarkably short distances and it is this recognition of rapid lithological changes that has necessitated the revision of ideas on structure, stratigraphic nomenclature, and metamorphism.

Distribution of Lava Types

A notable feature of the Dundas Group is the concentration of acid K_2O-rich rocks, both volcanic and intrusive, along the Lyell Shear, particularly south of Mt. Huxley. On either flank of the Shear zone and extending for several miles away from it, the volcanics are essentially Na_2O rich and on the whole, less siliceous than those in the Shear. This implies that the nature of the magma along the Shear differed considerably from other areas. The history of events in the Shear zone was probably one of acid effusion followed during the Jukesian movement by granitisation, the volcanic and metamorphic products being chemically very similar; outside the Shear the magmas produced basic to acid differentiates, the characteristic soda being a component of the magma or picked up from enclosing sediments during extrusion, or a result of albitisation related to granitisation during Jukesian tectonics. There is no doubt the Lyell Shear has exerted strong localised structural control over magma distribution.

Outside the flanking zone of keratophyres, rhyolites etc., the Dundas Group is represented almost entirely by basalts with spilitic tendencies, and associated pyroclastics. This volcanic suite is exposed along the West Coast and is some 10 miles west of the Lyell Shear; it contains a few intermediate-type members but no acidic volcanics and shows only minor metamorphism.

Similar variations in magma type have been recorded from several volcanic provinces of eugeosynclinal type. The variations are usually regarded as being derived initially by differentiation of a basaltic parent magma, combined with the effects of assimilation of wall rock and also of mixing of partially crystallised magmas of different composition derived from similar stock. The abundance of albite suggests a primary soda-rich magma but as Turner and Verhoogen (1951) point out there may be several other causes of the soda enrichment: "......starting with olivine-basalt magma as the parent material. Differentation of this magma, assimilative reaction with rocks situated in the basal levels of the geosyncline, concentration of magmatic water rich in soda, and chemical activity induced by entrapped sea water and rising connate waters squeezed up from deeply buried sediments, are all factors of possible significance in evolution of spilites and keratophyre."

Origin of the Albite in the Volcanics

There is little doubt that the fresh, clear albite of the veinlets and vesicles is of secondary origin. It has a pinkish tinge, is usually untwinned and is often difficult to distinguish from quartz.

That in the vesicles is in all probability derived from soda-rich residues of the basaltic magma and is therefore of deuteric origin. It is also possible that the albite replacing the hornblende porphyry on Crown Hill, and veining the breccias (pyroclastics?) of the Comstock tram-line is of similar origin, being related to late stage phases of volcanic activity. However this latter form of occurrence could also be related to Jukesian movement (as suggested by Scott) or to the Tabberabberan orogeny (as suggested by Bradley). Quartz-albite (and epidote, chlorite, and siderite) veins related to late phases of mineralisation are common within the Lyell mine area and are to be seen occasionally at other points e.g. at Lake Jukes and along the Lyell Highway near the King River. At the latter locality, the veins are in Jukes Conglomerate, suggesting a Tabberabberan age. The albite in these quartz veins and bursts is almost a red colour, rather different from the grey or pink of the albite in the Crown Hill and Comstock material, which also has only minor associated quartz. The writer believes the quartz-albite veins of the Lyell mine area and other points is Tabberabberan, and post-mineralisation. The other secondary albite is considered to be late phase volcanic activity and therefore of Cambrian age.

The felspars other than the fresh, clear albite seem to be of two types - either relatively unaltered albite or intensely altered plagioclase felspar which is extremely difficult to determine.

The altered felspar is grey in colour and generally too clouded by sericite, etc. for positive identification, though much of it appears to be albite and the twinning indicates a composition no more basic than Ab_{65}. Zoning is not uncommon and often shows a clear albite outer fringe; again some of the crystals seem to be altering to clear albite in irregular fashion. Chlorite is a common alteration product of the original felspar. Scott states that the latter is entirely albite throughout the area and though the writer has been unable to confirm this due to the intense alteration, there is no doubt that much of the altered material is albite and none of the remainder is very basic.

The alteration to fresh albite is probably related to deuteric action, as already described and presumably this is linked with the sericiticisation, chloritisation, etc. If this is so, then the original felspar, much of it albite, is probably primary. Primary albite in spilites of the Dundas Group is reported from King Island by Scott (1950). The albite there is in ophitic texture with diopside and this is generally indicative of primary origin. However, she concludes that there is secondary albite also inthe same suite of lavas and similar conditions seem to have existed at Lyell.

The lavas of High Rocky Point are composed dominantly of slightly altered albite which shows no sign of being derived from a more basic felspar and which may well be primary. These lavas are similar to those of Lynch Creek, the Battery volcanics, except for the increased alteration of the felspars in the latter area.

The relatively unaltered albite has a brownish tinge and occurs in the lava (?) alongside the Lynchford road, the banded albite-hornblende rock on the Lake Margaret tram-line, and the mottled rock above the tram-line near Comstock. There is some doubt as to the origin of these rocks and the presence of unaltered albite probably reflects a somewhat different mode of origin to other porphyries. At least two of the three examples are probably pyroclastic and the lack of alteration could possibly be related to the fact that the active deuteric solutions in general only circulate within lava flows, and not in the associated tuffaceous material.

Sedimentary and Pyroclastic Rock Types

Conglomerates and Agglomerates

Predominant among sedimentary rock-types are greywacke conglomerates, with pebble sizes ranging from coarse to fine. They are generally poorly sorted, are often rich in felspar, and show a variety of pebble types. Some are almost breccia-conglomerates, as they contain angular fragments.

It is difficult to distinguish between pyroclastics and sediments in many cases and doubtless many of the so-called conglomerates containing lava fragments should be termed agglomerates. Sediments deposited rapidly and buried with little or no sorting by wave action must appear very similar to material expelled by a volcano and deposited in water. An obvious conglomerate occurs as lenses within finely banded siltstones on Whip Spur. It consists of coarse pebbles of felspar porphyry and slate in a confused matrix of albite crystals, chlorite, and microcrystalline quartz and felspar. Veinlets and zones of clear albite are common.

Another type may be seen near 8218/3588; it is a deeply weathered, grey, felspathic breccia-conglomerate with fragments and shards of slate and sandstone. The constituents are chaotically dispersed through the rock, which was obviously formed under conditions of rapid erosion and burial.

A conglomerate-looking rock forms tors on the hills immediately east of the Queenstown-Lynchford road. Bradley describes this as a greywack conglomerate but it has already been pointed out that this rock may well be of igneous origin.

A prominent rock showing large rounded pebbles outcrops on the spur running north from Little Owen summit. The conglomerate passes along strike to pebbly sandstones and sandstones.

The gorge of the West Queen River exposes greywack conglomerates and sandstones of classical type, though again these rocks could be of volcanic origin and deposited in water.

An interesting type is composed of bands of fine grey sandstone mingled with zones of fine conglomerate which consists of ovate chert pebbles with their long axes parallel to bedding, the fragments varying from microscopic size to 5 x 15 m.m. in cross section. The microscope reveals a typical greywacke-type texture, with the grains largely quartz and subangular, but with a few more rounded ones of felspar-chlorite mosaic which are probably of igneous origin.

Bedding is often difficult to determine in these sediments; they are generally massive and featureless and mapping structures in them is extremely difficult.

Siltstones

These have been found in a dozen or so localities and preservation of the characters of sedimentation (such as bedding, slumping, etc.) has assisted in elucidation of the structure.

Strictly speaking, they should not be classed as siltstones, for they actually consist of alternating fine bands of quartzose shale and coarse silt or very fine sand (using Wentworths particle size classification as in Krumbein and Sloss, 1953). The shaley bands are thicker than the silt bands, and are studded with quartz grains of silt grade. The coarser, narrower silt bands are usually composed of angular and subangular quartz grains in a sparse matrix. These beds are usually rudely cleaved and Bradley terms them "Miners Slates". Locally a tendency to grading may be seen and the silts look much like varves. Very fine ripple marking and erosion of tops of bands are common and good examples of slump structure may be seen on Whip Spur. To give some idea of the frequency of banding, a specimen held in the Mt. Lyell geological museum shows, in a nine-inch face, variation between one band per inch and 35 bands per inch.

These finely banded sediments generally alternate with greywacke sandstone (or tuff) and may include lenses of coarse breccia-conglomerate (or agglomerate) and lava flows. They undoubtedly merge along strike into different lithologies and it is unwise to link all the isolated exposures and refer them to one horizon. The principal and most accessible exposures of the siltstones are along Lynch Creek, in the Queen River Gorge, and along the South Owen Creek east of Queenstown. They may outcrop in ridges or along stream beds depending on the relative resistance of the propinquent beds. Rather similar finely banded rocks occur over a wide area north of Flannigans Flat, but there is considerable doubt as to their age and evidence gathered so far suggests they are a peculiar facies of the Silurian beds. The most continuous siltstone exposure is that in South Owen Creek, along which the bed has been traced for $1\frac{1}{2}$ miles with a fairly constant thickness of about 300 feet. Near to the confluence of the South Owen and Conglomerate Creeks, the siltstones are silicified.

These siltstones would make excellent marker beds for use in geological mapping but there is no doubt that identical siltstones have been formed at several stages during the Cambrian and that the beds merge to other lithologies along strike over fairly short distances.

Tuffs

Positive identification of tuffaceous material in the Queenstown area is not easy, due to the poor exposures. Doubtless the deeply weathered and banded silty material exposed among the lavas along Lynch Creek is tuffaceous and doubtless there are considerable developments elsewhere.

South of the Spero River along the Southern Ocean coastline tuffs of varying grain size are seen interbedded with lavas. Many of the green shales are in all probability lithified volcanic ash and these grade to coarser materials in which lapilli and felspar crystals are visible to the naked eye.

A characteristic conglomeratic rock that occurs at several points consists of subangular and rather discoidal quartz and chert grains up to 1 c.m. or so in diameter embedded in tuff-like material. The grains lie along bedding planes and the rock appears to have been deposited in water. The pyroclastics may be followed along strike to basalts and the nature of one horizon is constantly changing from place to place.

Limestones

Associated with the volcanics near Spero Point are several beds of limestone. They vary from dark grey and fairly pure to dirty brown and fairly impure. They are referred to by Taylor (1956).

No Cambrian limestones have been observed in the Queenstown area.

Sandstones

Greywacke sandstones may be seen at several horizons in the Dundas Group. They are variable in character, lenticular, "dirty" or "muddy" and are the fine-grained equivalents of the greywacke conglomerates described earlier. Thin beds outcrop in the Lynch Creek area and a considerable thickness of sandy sediments may be seen near Little Owen. Many of the sandy beds may well be of volcanic origin and should be described as tuffaceous sandstones.

The one notable exception to the predominating greywacke - type and tuffaceous sandstones is the grey, clean quartz sandstone which outcrops along the crest of Miners Ridge east of Lynchford. It is about 100 ft. thick and can be traced for about 4 miles. The sandstone is lightly sheared, with grain size between $\frac{1}{2}$ m.m. and 1/30 m.m.; it is largely composed of quartz but contains a number of biotite flakes aligned parallel to the rude schistosity. All the quartz grains show strain shadows. It is interbedded with siltstones and is of some importance in that its prominent outcrop makes it a useful marker horizon for "following out" structure.

Stratigraphic Nomenclature in the Dundas Group

Bradley (1954) made the first attempt to draw up a stratigraphic succession for the Dundas Group in this area and he put forward three formational names for the use of later workers. His classification, youngest at the top, is as follows:

Lynch Conglomerate	3,000 ft.
Battery Volcanics	4,000 ft.
Miners Slate	3,000 ft.
	10,000 ft.

This subdivision is based on exposures found along Lynch Creek but the results of field mapping in the same area by the writer indicate two rather important points:

(a) The formations suggested above do not continue north and south of Lynch Creek for considerable distances, as indicated by Bradley.

(b) The type section is fairly closely folded on N-S axes, resulting in the repetition of lithological units.

It is felt that these two factors alone warrant some re-examination of the proposed definitions; it has also been found difficult to follow the details of the published successions in the field and some of the relationships quoted have been disproved, e.g. the Lynch Conglomerate is by Bradley's definition conformable below the Ordovician beds yet evidence at Lynchford suggests that it lies unconformably below the Owen Conglomerate.

In an area where the environment of deposition is subject to local and frequent changes, rapid variations along strike and repetition of similar rock types must be a normal occurrence, hence difficulty in establishing a stratigraphic succession that is valid over wide areas is only to be expected and allowance must be made for this when discussing the subject. With the information so far obtained, it seems to the writer unwise to recognise more than a number of prominent lithologies that may be mapped in the field, i.e. a number of rock types, with no significance in time and in no particular stratigraphic order, and not, therefore, reaching the status of formations.

It is difficult to reconcile the latest information and ideas with earlier proposals and definitions, and though a compromise might be effected, it would hardly be satisfactory in the long run. It is suggested, therefore, that the definitions submitted by Bradley be discarded and that no formations be named for the time being but that certain rock types be named so as to assist in future work.

The most important unit is undoubtedly the finely banded siltstone that Bradley termed the Miners Slate. He named it after the Miners Ridge, a prominent topographic feature trending N-S about 1½ miles east of Lynchford. It is unfortunately named, as this ridge owes its existence to a bed of hard sandstone, which the writer wishes to name independently. The best exposures occur a little to the west in Lynch Creek and it is proposed that these beds be known as the Lynch siltstones. The thickness and details of the term Miners Slates should be abandoned and the definition of these rocks should follow the description already given.

The term Battery Volcanics as used previously, might usefully be retained to describe the albite-pyroxene basalts and associated breccias and tuffs exposed along Lynch Creek. However, the term should not have the status of a formation. Bradley's thicknesses and his descriptions of the overlying and underlying strata are not considered valid in the light of recent field work; for instance, the dips in the Lynch Siltstones to the east of the volcanics suggest that the sediments are younger and not older, as Bradley proposed.

The Lynch Conglomerate, as previously defined, is impossible to trace in the field, even in the type locality, and it is considered advisable to drop this name altogether. In reference to this formation, it is supposed to be equivalent to the Dora and Sorell Conglomerates, which are again supposed to be the topmost conglomerates in the Dundas Group. Yet the Sorell Conglomerate is undoubtedly the equivalent of the Jukes Conglomerate and is in no way similar to Bradley's "Lynch Conglomerate". The writer has not seen the Dora Conglomerate but from descriptions it seems that similar remarks might be applied to this formation too. At Lynch Creek, the supposed Lynch Conglomerate formation is overlain unconformably by purplish Jukes Conglomerate, which in turn is overlain conformably by Owen quartzites and Gordon Limestone.

The only new rock type that the writer considers worth naming is the grey sandstone of Miners Ridge. The obvious name would be the "Miners sandstone".

In summary, the writer considers that the following rock types should be given formal names so as to assist in future work in this area:

Miners sandstone

Lynch siltstones

Battery volcanics

More detailed mapping at some later stage will doubtless result in some modification of these proposals.

Thickness of the Dundas Group

Owing to the nature of the Dundas environment and the difficulty in following structure, determination of a generalised succession with definite thicknesses for individual units is impossible. It is felt that Bradleys total figure of 10,000 ft. and his separate formation thicknesses should not be accepted until further work has been done, or more comparisons with other areas can be made.

Elliston (1954) records 11,500 ft. of Dundas Group volcanics and sediments from the relatively undisturbed anticline near Dundas. The overlying Owen Conglomerate and the underlying Precambrian beds both outcrop in this area and the Dundas rock units are persistent for considerable distances; thus a reasonably accurate estimation of the total thickness of the Group is a fairly simple matter.

The only reliable measurements made so far in this area have been done during detailed mapping along the western slopes of Mt. Owen. The maximum thickness measured was from Little Owen to South Owen Creek, as follows:

1,000 ft.	Conglomerates and sandstones near Little Owen.
700 ft.	Greywacke sandstones and volcanics.
300 ft.	Lynch siltstones, along South Owen Creek.
500 ft.	Blocky, "dirty", sandstone.
2,500 ft.	

This figure of 2,500 ft. is doubtless only a portion of the total but it is the maximum undisturbed thickness recorded. The type area quoted by Bradley along Lynch Creek is confused by folding but it is apparent that several thousand feet of sediments and volcanics occur there.

While drawing horizontal sections through the area it was found necessary to assume a thickness of at least 4,000 ft. for the Dundas Group. As a general rule, a figure about twice this was used.

Hills (1914) suggests a thickness of 21,000 ft. for the Dundas Group in the Darwin area but he points out that the beds may be repeated by folding.

The Jukesian Unconformity

Towards the close of the Cambrian, the deposits of the Dundas eugeosyncline were elevated by folding and faulting and subjected to erosion. This hiatus in sedimentation represents the Jukesian Movement of the Tyennan Orogeny (as defined by Carey and Banks, 1954). It is the major upheaval of this orogenic cycle and Browne (1949) has recognised it throughout Australia. In Tasmania, the youngest fossils below the unconformity are trilobites of lower Upper Cambrian age (Opik 1951, B), while the oldest above this surface are of Ordovician age.

The Jukesian unconformity is defined as the angular discordance between the Dundas Group below and the Junee Group above while the type area is taken at the north end of Mt. Jukes, as described by Hills (1914). Actually, as Bradley points out, the supposed unconformity at Mt. Jukes is only a metamorphic contact - flatly dipping coarse greywacke conglomerates overlie sheared conglomerates with a strong vertical schistosity, a lineation previously interpreted as bedding. This contact is far better exposed on the northern face of Mt. Huxley, where the schistosity appears to eat up into bedded conglomerates. Faint relics of bedding parallel to that in the unaltered beds may be seen in the sheared facies. It is a pity that the unconformity has been defined on erroneous evidence but there is no doubt that a tectonic break does exist at the top of the Dundas

Group and it may be inferred from several places in the area mapped. In the South Queenstown-Lynchford area, there is every indication that the Gordon Limestone and/or Owen Conglomerate rests on tilted and eroded Dundas Group beds and at the Lynch Creek bridge (8148/3576) discordance of dips is apparent. Again at Upper Lake Jukes, flatly dipping Owen Conglomerate and basal hematitic greywacke conglomerates are well exposed in cliffs above the old mine workings while on the plateau to the west, metamorphosed Dundas sediments show steeply dipping bedding traces with strikes discordant to those in the Owen.

Lastly, at South Darwin, the regional trend in the Dundas rocks is N-S, with locally tight folding and replacement of individual beds by granitic rocks. Yet overlying Owen Conglomerate beds and Jukes breccia-conglomerates are flatly dipping and strike at right angles to the regional trend. Unconformity with consequent erosion is also suggested by the presence of granite pebbles in the Jukes Conglomerate. At several other points e.g. north-west of Comstock, in the Linda Valley, and near Little Owen, there are signs of unconformity but the presence of strong faulting in most cases precludes proof of discordance. Elsewhere the relationship appears conformable, e.g. near the Mt. Lyell Company's smelters and the Queenstown Recreation Ground.

Similar observations have been made in the Red Hills and Walford Peak areas by Carey and Banks (1954); they found that the junction of Dundas and Junee Groups may show no signs of a break in deposition in one area but it may be markedly discordant in another. This suggests that the movement associated with the Jukesian orogeny was areally restricted, and was possibly related to localised faulting rather than general folding.

Isopachytes of the Owen Conglomerate (Fig. 6) indicate a zone of no deposition west of the Range and north of the King River. Carey (1953) relates this to movement along the Porphyroid anticlinorium, a broad zone of anticlinal uplift of the Tyennan orogeny. This movement was accompanied by west side up shift on the Lyell Shear, resulting in the formation of a basin of deposition (the Jukes trough) between the Range and the Tyennan Block, and an elevated ridge west of the Range. The latter is known as the Dundas Ridge and it remained an elevated region until well into Owen Conglomerate time.

The regular repetition of coarse grained beds in the Dundas Group as described by Elliston (1954) has led Carey and Banks (1954) to infer eight or more orogenic movements within the Dundas Group, the last being followed by a period of non-deposition and erosion. Regular recurrence of coarse conglomerates unfortunately cannot be proved in the Queenstown or Darwin areas, but it is extremely likely in an unstable active basin like the Dundas eugeosyncline that minor upheavals took place repeatedly and affected the course of sedimentation. Bradley has inferred unconformity along Lynch Creek above the Battery volcanics and evidence of re-working of volcanics and sediments is continually met with in the field in the form of varying types of greywacke conglomerates. There is little doubt that tectonic activity was coeval with deposition.

Field evidence indicates repeated movement on the main N - S structures (e.g. the Lyell Shear) during the Ordovician and it is reasonable to suppose that these elements were also active during the Cambrian sedimentation. Movement on the fault lines was probably accompanied by arching of the Porphyroid anticlinorium and Bradley (1956) devotes considerable space to a discussion of the mechanics of this process.

Granitisation, Ultrabasic Intrusion, and Hematisation Accompanying the Jukesian Movement

The Darwin Granite

The only granite body within the area under examination is a long, thin granitic mass extending from Mt. Darwin to South Darwin. It is approximately three miles long and $\frac{1}{2}$ mile broad. It is complex, being composed of parallel zones of differing composition with a predominance of granitic types, chief of which are a pink orthoclase-quartz rock and a white plagioclase-quartz rock.

The pink granite forms a long line of tors on the eastern side of the Darwin-South Darwin spur. It is coarse grained, has a texture that is typically granitic, not seriate yet not quite equigranular (Fig. 5). The mineralogy is simple, the only constituents being pink orthoclase, colourless quartz, and pale green altered plagioclase felspar. The orthoclase is fresh and shows a fine wispy cleavage; often it also shows perthitic structure, enclosing thin parallel, irregular tongues and lenses of plagioclase felspar, with multiple twinning arranged perpendicular to the length of the tongues, and all units in one host crystal showing similar extinction. It is not clear whether this is an exsolution or a replacement phenomenon. Sutured crystal boundaries are common and these are supposed to be typical of granitised granites as compared to magmatic granites (Goodspeed, 1952).

Quartz, which is locally present in greater quantity than felspar, is finely fractured and shows undulose extinction, indicating that it has been under stress.

The plagioclase felspar is considerably altered to kaolin, chlorite (hence the green colour), etc. and its composition is difficult to determine. It shows symmetrical extinction angles on multiple twinning up to 17^{o} and may be albite.

Generally, the mineralogical composition runs orthoclase greater than quartz greater than plagioclase, but sometimes quartz exceeds the felspars, which occur in approximately equal quantity. Such variations should perhaps be termed adamellites.

Ferromagnesian minerals are rare and only occasionally ragged crystals of biotite or chlorite are to be seen. Two chemical analyses of this granite type are given in Table 4; they closely resemble analyses of typical potassic granites.

The white granite occurs on the west flank of the pink granite and is widest and best exposed near Thompson's workings. It is coarse grained and sometimes almost pegmatitic, and is composed entirely of rather altered, cloudy plagioclase felspar and colourless quartz, present in roughly equal quantities. Alteration of the felspar makes identification extremely difficult but it appears to be oligoclase; it is significant that the alteration products of this felspar are white while those of the felspar in the pink granite are green.

Quartz occurs in aggregates showing sutured boundaries and ragged margins against felspar crystals. The felspars are loaded with inclusions of quartz and have therefore crystallised after quartz or alternatively partially replaced original quartz. A chemical analysis is given in Table 4.

A rather similar rock of finer grain may be seen in the creek bed east of Thompson's workings. It consists of quartz felspar rock containing bands several inches thick of dark hornfelsic material that looks like re-crystallised Lynch Siltstone. The quartz felspar portion varies in grain size and texture; the felspar, which appears to be orthoclase, may occur as interstitial matter to a sandstone-like quartz mosaic, or it may occur in closely interlocking quartz-felspar aggregate. The felspar shows quartz inclusions and quartz shows felspar inclusions.

The general alteration of the plagioclase felspars within the Darwin complex extends to considerable depths, as proved by underground workings, and cannot be a weathering effect; it presumably represents a late hydrothermal affect or perhaps is due to Devonian activity.

Within the granite complex, between the white and pink granites, is a zone of schistose sedimentary-looking material that shows patchy mineralisation in the form of chalcopyrite, pyrite,and hematite. A similar sedimentary zone occurs within the pink granite on the eastern flank of the Darwin-South Darwin ridge.

Bradley describes a creek section across the granite, indicating an alteration of sedimentary schist of "greywacke hornfels" and granite. He illustrates pebble outlines in the granite and similar features have also been observed by the writer.

The margins of the granite mass are unfortunately not exposed in detail and it is impossible to observe any contact phenomena. However, Hills (1914) states that "the boundary-line between the granite and the felsites which it has intruded is sharp and well-defined. This line of contact has been opened up in several places by trenching, and the granite can there be seen in contact with the felsite, being quite as coarse-grained as in the interior of the mass, no transition into finer grained varieties being observable at the margins".

Over a small area west of Thompson's workings, a dark grey hornfels-like rock flanks the white granite but its margins are obscured by secondary growth.

The Darwin granite presents some rather unusual features for a normal igneous intrusion and the possibility of formation by metasomatic replacement or "granitisation" has to be considered.

The principal reasons for thinking in terms of granitisation are as follows:

(a) There is no sign of "doming" or of a "pushing aside" of the host rocks.

(b) The long, thin, tabular form parallels the regional strike and the alternation of granite and sediment suggests certain beds were more favourable to replacement.

(c) The pebble outlines, though rather vague, suggest replacement of a conglomerate.

(d) According to Hills (1914) there is no fining of grain size at the margins, though the contact is sharp and the hornfelsic rocks near Thompson's workings might be invoked as evidence of "baking" by granite magma.

(e) Sutured boundaries between crystals are evidence of granitised material according to Goodspeed (1952).

(f) Variation in texture and mineral content and the presence of perthitic texture which could be due to replacement phenomena.

(g) The lack of accompanying apophyses, aplites, pegmetites, etc. which seem to be typical of most magmatic granites.

These points are not conclusive and Bradley seems rather hasty in declaring that "it is indisputable that the granite complex is a metamorphic one and the Darwin granite a metamorphosed conglomerate".

The writer would rather say that it seems likely that the granite is metamorphic and is a product of granitisation processes, rather than a normal magmatic one.

A similar rather complex and inhomogeneous granite outcrops in the Murchison River, some miles north of Queenstown. This is of interest in that it also occurs in the Lyell Shear zone and must have been formed under similar conditions. The other West Coast granites, at Heemskirk and Low Rocky Point (S-W Tasmania), are both well away from the Lyell Shear and are large batholith-type masses.

Bradley continues to say that the granite is in all probability derived from the Jukes Conglomerate formation by metamorphism and its age is Devonian. This statement has aroused considerable controversy and is thought by the writer to be most unlikely.

As already mentioned on page 23, rocks flanking the granite on its western side often show a crude foliation similar to bedding. The foliae are composed of grey quartz, green chlorite, and orange, iron-rich material. The microscope shows the quartz foliae to consist of rounded quartz grains embedded in a potash felspar matrix, the chlorite foliae to consist of indefinite chlorite-sericite zones, and the orange foliae to be quartz-felspar aggregates stained by finely divided hematite. Sodium cobalti-nitrite staining shows the felspar to be potassic and forming at least 30% of the rock, which might therefore be expected to show a potash content of about 5%.

The fact that this foliation only occurs alongside the granite and appears to cut across bedding directions as indicated by aerial photographs, strongly suggests that it is of metamorphic or metasomatic origin and related to the formation of the granite. On the other hand the foliation is not unlike bedding and the mineralogical segregation could in part be due to original differences in distribution of shaley and ferruginous matter.

Age of the Darwin Granite

The Darwin granite complex is of particular interest in that it provides evidence of Tyennan metamorphism. The basal parts of the Jukes Conglomerate at South Darwin contain quite distinct sub-angular fragments, up to 9" x 12", of pink granite, gneissic granite, and hematite, and smaller pebbles of Precambrian quartz and chert (see Fig. 5). The pebbles are clearly defined in a matrix of granitic detritus and would seem to provide clear proof of pre-Junee Group granitisation. Similar conglomerate occurs below the Owen formation on Mt. Sorell, though the pebbles of granite and hematite are fewer and smaller, and conglomerates carrying chert and granite pebbles have been found alongside the pink granite in the creek running east from Thompson's workings.

Bradley prefers to regard the granite as Devonian (Tabberabberan) in age and the pebbles of granite and hematite, etc. as due to selective replacement, the pebbles simply being parts of the same rock types that formed the original material of the granite complex. To fit this theory, the "grade" of granitisation must be considered uniform over a wide area (including Mt.Sorell), in which the differing rock formations react differently to the metasomatism. Therefore there is no question of zoning of the metasomatism, merely a differential reaction in a uniform metasomatic field.

Probably the principal objection to this is that such variation in rock types over a small area is unlikely; indeed, relict sedimentary features in the pink granite and the pink felsite are much alike and would suggest that the products should be similar. A second objection is that the hematite masses, from which the pebbles are presumed to be derived, do not appear to replace particular beds, as they occur in lenses and irregular masses over a wide area within the pink felsite. The control of hematite distribution seems to be largely structural. How then are the granitisation processes to select individual pebbles in the Jukes Conglomerate for replacement?

Again, the copy of the Kodachrome slide (Fig. 5) of the Jukes Conglomerate shows a large slab of hematitic schist. This rock gradually takes the place of the granitic pebbles as the succession is ascended, until the Jukes Conglomerate is composed entirely of hematitic schist fragments in a hematitic matrix. Now by Bradleys hypotheses, hematite moves ahead of granite in a hematite "front" during granitisation, regardless of the composition of the original rocks; how then do the hematite and hematitic schist pebbles become mixed up with granite pebbles? Again, how does this zoning fit in with the overall uniform grade of granitisation just implied at Darwin?

As a final objection on the subject of hematite, there seems clear evidence in the Linda Valley and at Lyell, that hematitic bodies were being eroded during deposition of the Junee Group. In the Linda Valley, in particular, Bradley must find it hard to explain scattered pebbles of hematite in the Jukes formation away from any known areas of Devonian hematisation.

Problems of this type, involving interpretation of pebbles apparently overlying granite masses, are by no means few in number and are often the subject of much controversy. Bradley (1954) quotes several cases in which such pebbles may well be due to selective replacement, though in the majority of these there seems to be considerable doubt; the pebble outlines are generally vague and shadowy, and by no means as clear-cut as those in the Jukes Conglomerate.

A good example with which the writer is acquainted is the supposed migmatisation of tillite at Mount Fitton, South Australia. Bowes (1954) described in some detail, and with chemical analyses, what appeared to be a classical example of granitisation of tillite; yet Campana (1955) and later Chinner et alia (1956), have established that the granitised tillite is merely a basal arkose underlying normal upper Precambrian tillite, and unconformably overlying an Archaean granite complex.

In an attempt to solve the Darwin problem conclusively, Professor Carey has forwarded samples of Darwin granite to the U.S.A. for age determination of zircons.

An interesting feature of the Darwin granite is the depth of formation. The writer is quite satisfied that the granite was intruded during the Jukesian movement and this being so, then an estimate can be made of the cover existing at the time of formation of granite.

The Jukes Conglomerate was derived from erosion of that part of the Dundas Group exposed along the Dundas Ridge. This probably included the Darwin area, and therefore by assessing the thickness of the Jukes formation, an estimate of the thickness of material removed from the Ridge (and also from above the granite) can be made.

Now the Jukes Conglomerate at Lyell is at least 2,000 ft. thick and the base is not visible, so we may conclude that at least 2,000 ft. of sediment and volcanic rock covered the zone of granitisation.

Ultrabasic Intrusions

Intruded at the same time as the Darwin granite are a number of ultrabasic masses. These occur in the Renison Bell-Dundas area, in Macquarie Harbour, the Spero River, and at Adamsfield. The last-named is the most important from a theoretical point of view for it provides evidence as to the time of intrusion; pebbles of serpentine occur at the base of the overlying Owen Conglomerate and indicate a Jukesian age (Carey and Banks, 1954). These ultrabasics consist of pyroxenites and gabbroic bodies that have undergone serpentinisation and they appear to be the complement of the Darwin (and probably Murchison) granites. In contrast to the granites, there does not appear to be any structural control of the location of the basic material.

Hematisation

Jukesian granitisation was accompanied by limited hematisation along the Lyell Shear zone. This is proved by the presence of pebbles of hematite and some magnetite in the Jukes Conglomerate at South Darwin and Mt. Sorell, and also at Mt. Lyell. Some of those on Mt. Lyell consist of sandstone (?) veined by hematite, suggesting the hematite was of hydrothermal type and not derived, say, from a lateritic crust.

Hematisation accompanying sulphide mineralisation also took place during the Tabberabberan Orogeny but this will be described later.

Further evidence that a hematite source existed prior to Owen deposition is suggested by pebbles of hematite in the Middle Owen Conglomerates of the Lyell mine area. They were probably derived from hematite in Dundas beds exposed during Owen times by movement on the Lyell Shear.

Bradley has suggested that the hematite pebbles in both Owen and Jukes beds originated by selective metasomatism. Hematite is supposed to travel ahead in the van of granitisation, as a sort of "basic front", hematising certain beds or pebbles favourable to such a process. As already pointed out when discussing the Darwin granite, the sudden confusion of basic and granitic zones in pebbles in the Jukes Conglomerate is difficult to explain by this theory; other arguments against granitisation also apply to hematisation and the writer feels that there is no justification in regarding the pebbles as other than material derived from an older land mass undergoing erosion.

Ordovician - Junee Group

The Jukes Conglomerate

The Jukes Conglomerate is the greywacke breccia-conglomerate overlying the Jukesian Unconformity. Originally known as the Jukes Breccia, it has been re-named as the majority of the pebbles are well rounded. It occurs along a narrow belt more or less coinciding with the West Coast Range and reaches a thickness of several thousand feet on the eastern side of the Range. It represents the rapidly eroded portions of the Dundas sediments that were elevated by localised upheavals of the Jukesian movement and it is assumed by Carey to be of Tremadocian age.

Tyennan uplift along the Porphyroid anticlinorium, and movement on the Lyell Shear combined to form an elevated zone west of, and along, the Range at the close of the Cambrian. Considerable erosion of this region (known as the Dundas Ridge) took place prior to deposition of the Owen Conglomerate, particularly along the eastern margin, where Lyell Shear activity resulted in the formation of east-facing fault scarps. Erosion here was rapid and the products quickly buried in a sinking basin of sedimentation known as the Jukes Trough (see Fig. 7); conditions were ideal for the formation of greywacke-type sediments, of which the Jukes Conglomerate is a good example. Rapid degradation and burial continued until uplift of the Precambrian areas commenced deposition of the Owen Conglomerate. Erosion along the western margin of the Dundas Ridge was perhaps less severe and resulted in the formation of conglomerates and sandstones such as may be seen on Mt. Sorell.

Parts of the Dundas Ridge remained elevated throughout much of the Owen Conglomerate deposition, probably as strings of islands. This applies particularly to the area west of the Range and north of the King River, and to a narrow zone along the Range south of Mt. Darwin. The Mt. Jukes area was apparently covered fairly quickly. It is to be expected that erosion of these islands, etc., would form a narrow fringe of Dundas detritus along their margins while siliceous conglomerates were being deposited in the outer areas. Thus, in the area ofthe Dundas Ridge, part at least of the Jukes Conglomerate would be the equivalent in time of the Owen Conglomerate. This idea is amply substantiated by evidence at South Darwin, where Jukes Conglomerate merges along strike to Owen Conglomerate as shown in Fig. 8. Each successively younger Owen bed oversteps the Jukes formation until it rests directly on the once-elevated Dundas surface; and coarse Owen Conglomerates with slabs of Dundas schist may be seen overlying the old surface on a small ridge $\frac{1}{4}$ mile west of South Darwin peak.

Over the Dundas Ridge, weathering of Dundas islands continued right up to the beginning of deposition of the Gordon Limestone and was coeval with deposition of Owen sandstones in inter-island areas. This is deduced from the alternation of beds up to 2 ft. thick of siliceous pebbly sandstones with shaley and weathered Dundas-like material near the Mt. Lyell Sub-station. Again, south of the Lyell District Hospital, Queenstown, typical Owen fine conglomerates and sandstones appear to be interbedded with weathered Dundas material and shale.

Exposures of the Jukes formation are good along the eastern flanks of Mts. Owen and Lyell, on the northern end of Mt. Jukes and Mt. Huxley, at South Darwin, and below Mt. Sorell. It is unfortunate that for considerable distances along the Range, the Conglomerates, being easily weathered, are obscured by talus spreading out below the cliffs of Owen Conglomerate.

The formation is largely of coarse conglomerates with some pebbles and fragments showing angular margins; the matrix is generally felspathic and the degree of sorting is low. The size of the pebbles is variable but lenses with boulders up to 2 or 3 feet are common. The colour is generally a greenish grey but at several points the formation is hematitic and of reddish hue. Greywacke sandstones reach considerable thicknesses locally, and generally contain pebbly bands.

East of Mt. Lyell, at least 1800 ft. of the Jukes formation is exposed and the base is not visible. The change from the siliceous Owen Conglomerate in this area is fairly sudden but the two formations are conformable, and pebbles of vein quartz occur in the breccia for several hundred feet below the base of the Owen. Sandy beds alternate with conglomerates, and bedding planes are often marked by fine dark bands representing a heavy mineral concentration. Anastomosing veins of quartz, albite, and chlorite are visible along the Lyell Highway south of the King River bridge. The pebbles and boulders are largely of nondescript Dundas rocks but quartz and felspar porphyries can be distinguished, and at 8204/3664, pebbles of hematite and hematitised sandstone may be seen. Similar beds occur on the east side of Mt. Owen, where they are about 400 ft. thick.

The succession below the Owen Conglomerate at Mt. Huxley is as follows:

Lower Owen Conglomerate:		Coarse, white siliceous conglomerate.
Jukes Conglomerate:	100'	Thinly bedded dark purplish and locally greenish medium-fine sandy conglomerate with hematite-rich bands, overlying:
	70'	very coarse chaotic conglomerate with porphyry and sandstone pebbles, merging downwards to highly sheared conglomerate and then quartz schist with vertical schistosity.

With varying thicknesses this succession is seen at several points on Mt. Jukes; e.g. at Lake Jukes, Owen Conglomerate conformably overlies about 50 ft. of hematitic fine-grained sheared greywacke conglomerate which, from observations of dips, appears to rest unconformably on conglomerates and sandstones of the Dundas Group.

The exposures at South Darwin have already been mentioned as providing proof of pre-Jukesian granitisation. The controversial conglomerate occurs north of the peak and is composed of angular and sub-angular fragments of pink granite up to 1 ft. square; gneissic granite; some Precambrian quartzites; hematite blocks up to 6" across, and a few chert pebbles, while the matrix is composed of fine granitic detritus. Approaching the summit and going up the succession, granite fragments become fewer and finally are missing immediately below the

Owen beds. Their place is taken by hematitic schist and quartz porphyry, occurring as coarse blocks almost to the exclusion of all other pebble types. This rock type is exposed in situ immediately below the Owen Conglomerate on a ridge half a mile to the west, and indicates that this ridge was elevated and being eroded at least in later Jukes Conglomerate times, while the granite to the N.E. then became submerged.

Along the steep lower eastern face of Mt. Sorell, some 300 feet of brownish medium-grained greywacke conglomerate may be seen. The pebbles generally average 1 inch in diameter but a few reach 1 ft. across. They are chiefly vein quartz, quartzite, and schist with a few small granite and hematitic pebbles, presumably derived from the granite mass about 2¼ miles to the east. This bed has been linked with the Dora Conglomerate of Bradley's Dundas Group but is regarded by the writer as a representative of the Jukes Conglomerate.

Jukes Conglomerates are brought to the surface at several places on Mt. Owen as a result of faulting on N.W. lines. Those at 8177/3641 and 8168/3633 are of pebbly hematitic schists immediately underlying the Lower Owen beds. The exposures are small and faulting has resulted in a high degree of shearing, but traces of bedding indicate that the schists were greywacke conglomerates showing conformable relationships with the Owen Conglomerate. The outcrops of Jukes formation near 8157/3662 are similar to those east of Mt. Lyell.

Hematitic purple greywacke conglomerates with Dundas pebbles may be seen at Lynch Creek bridge adjacent to the Owen Quartzite. No bedding planes are discernible but the bed is probably equivalent to the Jukes Conglomerate, and indicates erosion of the local Dundas rocks.

The Owen Conglomerate

This formation is one of siliceous conglomerates and sandstones derived from Precambrian sources; it indicates uplift and erosion of the older rocks of the Tyennan Block.

The basal beds are coarse grained and confined to much the same zone of deposition as the Jukes Conglomerate, but younger members are finer grained and transgress the boundaries of the Jukes trough.

Owen Conglomerate facies are found mainly along a belt which extends along the West and North Coasts of Tasmania and flanks the older Precambrian core. It marks an arcuate trough of sedimentation more or less coinciding with that in which the maximum deposition of the Dundas rocks took place. South of the West Coast Range, the trough is again encountered in the D'Aguilar Range.

Owen beds are found chiefly along the West Coast Range in the Queenstown and Darwin areas but were also deposited away from the Range, as indicated by exposures at Mt. Arrowsmith, Zeehan, Trial Harbour, and the Elliott Range.

The fact that the Owen Conglomerates are almost entirely composed of rounded, quartzose pebbles suggests continued re-working along old shore lines, a marked change from the conditions of rapid burial and lack of sorting that prevailed in Jukes Conglomerate time. The sudden disappearance of Dundas pebbles at the base of the Owen formation does not necessarily indicate that the older rocks were entirely buried, as pointed out by Carey and Banks (1954). It has already been suggested that parts of the Dundas Ridge remained elevated through much of the Owen deposition, and the absence of Dundas-type pebbles except in the immediate vicinity of the elevated areas, is due to their inability to withstand the prolonged wave action and rigorous conditions.

The Owen Conglomerates form the rugged cappings to the peaks of the West Coast Range and where flatly dipping, form prominent cliffs which rise sharply from the surrounding countryside. They are highly resistant to erosion and the topography moulds itself upon the structure of the formation. For many years these beds were known as the West Coast Range Conglomerates but by virtue of priority of definition, the term Owen Conglomerate has been established (Bradley, p.205, 1954). The essential characteristics of the formation are given below (see also Bradley p.206) and will be enlarged upon in the succeeding paragraphs:

1. It is a quartzose formation, being derived almost entirely from Precambrian source rocks, composed largely of quartz-rich rocks, from which any soft material has been removed by prolonged re-working.

2. It is of late Cambrian or early Ordovician age, being above the Jukesian unconformity (at least lower Upper Cambrian) and below the Ordovician Gordon Limestone.
3. It is essentially conglomeratic but the uppermost beds are mainly sandstones and shaley types with minor conglomerates.
4. Variation in thicknesses and of individual beds along strike is considerable but a three-part division of the formation has proved workable in the field.

The main item lacking in Bradley's description of the formation is a detailed definition of the succession on Mt. Owen; this is now provided in Table 5. Due to rapid variation along strike it is in part generalised but represents fairly closely the succession exposed on the northern faces of the mountain.

Perhaps the most striking feature of the Conglomerate is the gradual reduction in particle size from the base upwards. The lower beds are coarse or boulder conglomerates while the upper are dominantly fine-grained, intervening horizons showing intermediate grain sizes. The reduction in grain takes place in well defined stages which permit a rough classification of the formation along this part of the West Coast Range. Particle sizes quoted in the following divisions refer to the Wentworth Scale:

Upper Owen Beds: Largely grey or pinkish sandstones, generally thin (2' - 2") - or very thin (2" - ½") bedded, and often alternating with dark hematitic shales; locally medium pebble to granule conglomerate beds. Chromite-rich conglomerate and quartzite important at Lyell. Sandstone beds characterised by presence of "pipe-stems" or "tubercles" - tubicolar sandstones.

Middle Owen Beds: Grey or yellowish medium and large pebble conglomerates with thin sandy bands and reddish pebbly sandstones; generally thick (4' - 2') - or very thick (greater than 4') - bedded.

Lower Owen Beds: Coarse yellowish conglomerates with average pebble size very large or greater. In the Lyell area it is split by a sandstone horizon.

The pebbles in the conglomerate are predominantly milky vein quartz, grey quartz schist or sheared quartzite, banded quartzite, dark grey chert, and jasper.

It is believed that these divisions have time significance and are not entirely a reflection of the lithology. The coarser basal member is confined to a narrow trough more or less coinciding with the zone of deposition of the Jukes Conglomerate, while the middle member is encountered over much wider areas within the West Coast Range, and the upper beds are found at points over the entire Tyennan Block and as far west as Trial Harbour and Point Hibbs. This widening of the original trough of sedimentation and the final overall deposition of the top beds took place along with the gradual diminution of the source area, and the extent of the deposition of a particular member is related to the average grain size. Thus, generally speaking, the early beds are coarse and the later ones fine.

The contrast between the young beds that covered the Precambrian areas and those deposited in the flanking trough is well shown in the D'Aguilar Range area. Within the Range, 1500-2000 ft. of coarse grained siliceous breccia-conglomerates are found overlying Dundas rocks, but only a few miles to the east and overlying Precambrian strata, there are only 250 ft. of sandstones and fine conglomerates. The interpretation is that after deposition of the coarse material along a narrow trough, the source areas to the east, and possibly also to the west, were diminished and then the whole area was covered with fine material derived from areas further afield.

Before going into details of the divisions outlined above it may be as well to examine previously published information. Hills (1914) gives an admirable account of the Owen Conglomerate at Mt. Jukes and his succession has been reproduced by Bradley (1954, p.205). The writer assumes there is a printer's error in the thicknesses quoted in Bradley's paper for they do not tally with the original description; neither does the uppermost part of the tabulated succession, though perhaps some additions have been unwittingly made to the original work. Hills (1914) divided the beds into four "étages", each of 400 ft., making a total of 1600 ft. These four groups can be recognised in the Lyell area but are otherwise of rather limited application, whereas the linking of the middle two to form three sub-divisions has been found much more useful. The thickness of 1600 ft. seems rather high, the writer's estimate being nearer 1250 ft., but the opportunity for accurate observations has not yet occurred. The thickness falls to about 700 ft. at Lake Jukes, about 1 mile south of the peak.

Bradley (1954) considers the beds too variable to go beyond a two-fold classification and he only distinguishes any particular type as belonging either to the Tubicolar Sandstone member or the Owen Conglomerate proper. This tubicolar member is described as a "yellow sandstone with pipe stems" and it is apparent from Bradley's description of the Lyell mine area geology, that it is distinguished from other tubicolar sandstones. Judging by his maps this member has a wide occurrence but the writer's work revealed only limited outcrops in the Lyell area and on Mt. Jukes (see Hills, 1914). It is assumed to be equivalent to the chrome quartzite to be mentioned shortly.

As tubercles have been found at varying horizons in the Owen Conglomerate near Tyndall (Mr. M. Banks, pers. comm.) and also occur in the Eldon Group it is felt inadvisable to continue using the term "tubicolar" in a stratigraphic sense.

Conolly (1947) has suggested a fairly detailed sub-division of the Owen formation but it applies only to the area of the mines and is not serviceable elsewhere; the three major divisions suggested in his table are difficult to use in the field and have been somewhat modified. Conolly's classification, and that used in the recent mapping, are compared here:

	Conolly's West Coast Range Conglomerate Series	Present Classification
Upper Series	Chocolate sandstones, shales etc.	Upper Owen Conglomerate
	Razorback conglomerates	Middle Owen Conglomerate
Middle Series	Red Sandstone	
	Mountain Conglomerate	Lower Owen Conglomerate
	Mountain Sandstone	
Lower Series	Lower Conglomerate	
	Breccia Conglomerate	Jukes Conglomerate

The Lower Owen Conglomerate is the coarsest of the three divisions, pebbles being generally greater than 2" or so in diameter, and with lenses of boulder conglomerates showing fragments up to 2 ft. across. It is repeated several times on Mt. Owen by faulting and the lithology can be studied there in detail. The summit of the mountain is formed by one of the boulder beds just mentioned.

Its greatest development is at the east end of Mt. Lyell where 1500 ft. have been measured. The estimated thickness on Mt. Owen is 900 ft. but north and south of these peaks the bed thins rapidly. Elsewhere (except for one area) the Lower Owen is either missing or is represented by less than 50 ft. of coarse conglomerate. The exception to this statement is the occurrence of about 400 ft. of Lower Owen type conglomerate on the ridge running east of Lower Lake Jukes. At a number of points e.g. 8281/3639 and 8127/3618, pebbles of Dundas rocks may be seen at the base.

On Mt. Lyell, a 100 ft. bed of red sandstone occurs about 400 ft. above the top of the Jukes Conglomerate and is matched on Mt. Owen by 100 ft. or so of pale grey sandstone and dark grey shale; these beds are Conolly's Mountain Sandstone. Despite diligent search no fossiliferous rocks have been found at this horizon but the Mt. Owen occurrence shows some interesting current markings on bedding surfaces.

Possible evidence of unconformity above the Lower Owen is given by discordance of strikes at 8025/3650; the discordant angle is about 20° as measured on the aerial photographs. The significance of the unconformity is discussed in the structural chapter of the report.

The Middle Owen Conglomerate is more persistent, though still restricted compared with the Upper Owen. In the Lyell area and on the northern end of Mt. Jukes it is possible to divide this bed into an upper conglomerate with sandstone bands and a lower red sandstone, as shown by the tables published by Hills (1914) and Conolly (1947). Elsewhere, conglomerates and sandstones alternate irregularly. The maximum thickness for this division, mapped as the beds between the distinctive Upper Owen and the coarse Lower Owen, is 850 ft., as seen on Mt. Lyell.

Conglomerate pebbles average about 1½ inches diameter and show less size variation than the Lower Owen pebbles i.e. the beds are better sorted. The lenticular bands of pink sandstone are characteristic of the conglomerate phases, while thin pebbly bands are seen in the quartzitic beds. Evidence for local unconformity in the Middle Owen is displayed in a cliff face immediately south of Lower Lake Jukes where the lower beds in the face are folded more steeply than the upper, the discordance in dips being locally very sharp. This feature is located right on the Lyell Shear and therefore indicates that this structural element was active at this period. Considerable movement on the Shear during deposition of the Upper Owen beds has been proved by detailed mapping in the Lyell Mine area.

The Middle Owen is represented near the Lyell mines by conglomerates and red sandstones with conglomerate bands; all the coarse beds are characterised by an abundance of hematite pebbles and hematisation preceding the Middle Owen is therefore inferred. The Lower Owen, however, is entirely free from such pebbles and the assumption is that either hematisation took place post-Lower and pre-Middle Owen or that the Middle Owen marks the exposing of iron-rich material in the source area.

The Upper Owen Conglomerate is that part of the Owen formation lying between the medium grained Middle Owen Conglomerates and quartzites, and the Gordon Limestone. It may be studied at many localities but to most effect on Mts. Owen, Lyell, and Jukes. It is characterised by the generally fine grain size, the presence of purplish dark hematitic sandstones, "pipe stems" of varying types, and evidence of small scale contemporaneous current disturbance, such as slumping and "balling up" of thin sandy layers.

The change from Middle Owen beds to these sandstones and shales is sharp and easily picked up in the field; the passage upward to Gordon Limestone, however, is obviously transitional, sandstones giving way to shaley sandstones, sandy shales, shales, and then limestone.

The pink, red, purple, or "chocolate" beds are characterised by a percentage of ferruginous matter; this iron content is fairly evenly distributed and presumably indicates either a steady supply of ferrous material from the source area or suitable conditions for the formation of organic iron. Certainly the latter suggestion holds for certain beds in the Upper Owen near West Lyell; in the pink tubicolar sandstone (the Chocolate Sandstone) overlying the Middle Owen Conglomerates there occur at least two beds, between 2 and 3 ft. thick, which are as much as 40% hematite, and composed largely of tiny discoidal elements averaging 1 m.m. in diameter. On seeing a typical specimen, Professor Carter, of the University of Cincinnatti, remarked on its close similarity to the Clinton iron ore beds of the U.S.A., which are, of course, of organic origin.

Of considerable interest is the unconformity near the top of the Upper Owen which has been traced from Gormanston to North Lyell and is known locally as the Haulage unconformity. It is referred to by Bradley (p.209) but he only traced it for 200 yards and regarded is as due to slumping or drag on a local contemporaneous fault scarp. Conolly describes the unconformity in unpublished Company reports and his detailed mine maps show that its entire outcrop was carefully mapped. He does not, however, do more than mention its presence while discussing the geological succession and apparently attaches little significance to it. The erosional surface is cut in the Chocolate Sandstone, and is generally overlain by a rose-pink, small-pebble quartz conglomerate, then a yellowish (grey when fresh) tubicolar quartzite, and lastly by sandy and shaley beds which pass up into Gordon Limestone. The conglomerate and quartzite beds are usually rich in rounded chromite grains and weathering of this mineral often imparts a pale green colour to the rocks; they are known in the mine area as the chromite quartzite and chromite conglomerate. Locally a basal breccia with hematite and sandstone pebbles may be seen on the unconformable surface. The chrome conglomerate has been recognised on Owen Spur where it lies conformably over hematitic shaley sandstones, and is overlain by pink granule conglomerates and pebbly sandstones.

Further evidence of contemporaneous movement is given by the sandstone dykes seen in Middle Owen Conglomerates on the Razorback ridge near West Lyell. They are 3 - 4 inches thick, lie perpendicular to the bedding and are composed of fine pink sandstone. Their mode of formation is revealed in a loose boulder found on the slopes south of the Blow; this illustrates the splitting up of a sandstone bed into blocks with intervening cracks, into which overlying pink sandy material and a few quartz pebbles have fallen. The sandstone layer must have been at least partially lithified before earth tremors formed the cracks. Thin, crumpled bands of pink quartzite in schists adjacent to the Razorback ridge are thought to be sandstone dykes that have been folded by local pressures in the schists.

The chrome conglomerate and the associated basal breccia are characterised by the presence of pebbles of hematite. In the breccia they may be as large as 3 inches in diameter but in the conglomerate they average about 1 inch. They are probably derived from erosion of the hematite-rich iron beds of the Chocolate Sandstone member.

Fossils in the Owen Conglomerate

Pipe-stems or tubercles of the "tubicolar" sandstones have been mentioned repeatedly and are worthy of a few notes. The terms refer to organic-looking "tracks" and "casts" of several types, the majority lying on bedding plane surfaces but a few lying perpendicular to bedding. The most common form is a closely packed jumble of thin, winding "tubes" of sandstone which Professor Caster has suggested may represent the fossil excreta of worm colonies. In section, these sandstone tubes give a knotted appearance to the bedding planes. A specimen collected by Mr. Wade and the writer from the main peak of Mt. Lyell shows interesting sandstone tubes exposed on the bedding surface of a sandstone bed from the Upper Owen. The tubes, generally 1/10 or 1/5 inch thick, either wind irregularly across the surface or are curled up in circles which are generally 1 inch in diameter; the tubes lie in pronounced depressions in the bedding surface. Presumably these have a similar origin to the forms just described. Another common type on Mt. Lyell shows a main winding sandstone column with short branches leading off at right angles to either side and spaced a few inches apart; the "tubes" of sandstone average 3/8 inch diameter. On Owen Spur and near the old North Lyell Open Cut, tubercles perpendicular to the bedding may be seen. Those from the former locality are 1/10 inch in diameter and many are curled up to form a U in section; the North Lyell types are up to 9 inches long and average 3/8 inches in thickness. These perpendicular types are presumably excreta from burrowing organisms and similar tubercles may be seen at certain horizons in the Crotty quartzite.

Nye, Blake and Henderson (1934) describe impressions in the Owen beds on the Gormanston-Lynchford track which runs across the lower western slopes of Mt. Owen. They occur on the bedding surface of a block of Middle Owen sandstone at 8188/3627, on the track from the Gap to Moore's Waterfall. Nye describes them thus: "the tracks consist of a double row of impressions such as would be made by the parapodia of a worm resembling the sand-worm Nereis. Five "tracks" are observable on the rock exposed, one of which is strongly curved".

The only fossils (other than the worm casts) found in the Owen formation are confined to the Upper Owen beds. Local residents report having seen "shells" in the rocks near the top of Mt. Owen, but the only occurrence found by the writer is at 8158/3669, near the old Kelly Basin railway line. The fossils occur in pink and grey sandstones which are interbedded with fine conglomerates; despite confusion of the structural picture in this area by faulting there seems no doubt that the beds belong to the Upper Owen. This is important for Banks (pers. comm.) has recognised Camaratoechia synchoneua among specimens submitted to him and he regards this form as confined to the Silurian.

Thickness of the Owen Conglomerate

Rapid changes in thickness are characteristic of the Owen formation, the maximum range being from 2650 ft. at Mt. Lyell and a possible 3,000 ft. on Mt. Sedgwick, to a minimum of 20 ft. or so along the Queen River Valley. The thickness of the formation has been measured wherever possible and this information has been used to construct an isopachyte map of the Owen Conglomerate (Fig. 6) which highlights the main zone of sedimentation with a thickening northwards from Mt. Jukes, and also shows the Dundas Ridge, on which there was little or no deposition.

Lateral Variations in the Owen Conglomerate

South of Mt. Sorell and South Darwin peak the conglomerates and sandstones merge fairly rapidly into alternating cross-bedded Owen-like sandstones and blue-black limestone, such as are exposed along the lower reaches of the Bird River. South of this again, the sandstones disappear and limestones only are developed. There are two alternative explanations for the absence of the Owen Conglomerate in this area. Either it was at or above sea level during deposition of the Owen beds and therefore received no sediment, or the conditions of deposition were such that while siliceous conglomerates were deposited to the north of South Darwin, limestones and sandstones were forming to the south. The thinning of the Owen towards the Bird River district rather favours the first alternative, while the alternation of limestone and Owen-like sandstone favours the second. This is a problem for the palaeontologist to solve.

This change to limestone or thinning of the sequence is apparently only temporary, for in the D'Aguilar Range, some 12 miles further south, the Owen formation is represented by 1500 to 2000 ft. of coarse to medium grained breccia-conglomerate with minor sandstones. The pebbles in the coarse bands are up to 1 ft. diameter.

Gradation of Jukes Conglomerate to Owen Conglomerate along strike has already been mentioned from South Darwin. Similar phenomena may be seen near the Mt. Lyell Sub-station and the Queenstown Hospital and this interdigitation of Dundas and Owen lithologies is probably characteristic of parts of the Dundas ridge, on which products of the erosion of greywackesand volcanics must have mingled with material derived from Precambrian sources. The possible occurrence of rapid alternations of such widely differing rock types in the Lyell mine area has helped to throw more light on the original nature of the "Lyell Schists".

The Tabberabberan folding and faulting induced prominent vertical jointing in the Owen Conglomerates. Joints are well displayed on Mts. Owen and Lyell and the most prominent set, which shows up well on the aerial photographs, strikes more or less N.N.E.

Silicification

Metamorphism accompanying the earth movements has resulted in re-crystallisation of the Owen formation, giving it a dark, dense appearance on freshly exposed faces. Bradley (1954, p.208) states the lower beds are more strongly "silicified" than the upper, in support of his metamorphic theories, yet the examples of the densest rocks that he quotes near Gormanston lie immediately below the Gordon Limestone. It is possible that some silica was introduced during the Devonian in restricted areas, but for the majority of the Owen the evidence is overwhelmingly in favour of re-crystallisation of existing material.

Caroline Creek Beds

Following reduction in relief of the Precambrian source areas, and the disappearance of small islands on the Dundas Ridge, in the early Ordovician, limestone was deposited over wide areas of Tasmania. Locally, however, the limestone was preceded by impure sandstones known as the Caroline Creek sandstones and shales, which contain trilobites of Lower Ordovician age (Hills & Carey, 1949, p.26). Possible representatives in this area are exposed only at two places, viz. Harris' Reward, and south of Ten Mile Hill.

At the former locality, 40 ft. of soft, grey-green, rather clayey sandstones with brachiopods are clearly exposed lying conformably between pink Upper Owen quartzites and black limestone. There seems little doubt of the stratigraphical position of the beds yet experts of the University of Tasmania suggest the brachiopods indicate a Silurian age, which would place them above the Gordon Limestone (Ordovician). The inference is that the structure here is more complex than the remainder of the evidence suggests, and that Silurian beds are faulted against Owen Conglomerate.

South of Ten Mile Hill, along the old Kelly Basin railway, cuttings expose thin-bedded, brown or fawn, medium grained sandstones locally containing a few poorly preserved fossils. These sandstones are interbedded with pale and dark grey sandy shales and appear to occur near the top of the Owen Conglomerate.

Gordon Limestone

The Gordon Limestone formation in this area consists of dark blue-grey limestone or shale; it varies from pure limestone, to limestone with shale bands, to shales with limestone lenses, to normal shale. Undergoing more rapid denudation than the adjacent conglomerates and quartzites, the formation usually occupies valley floors in which exposures are often concealed by overlying, more resistant material.

The limestone facies is generally a dark, blue-grey colour and is either thin bedded, with ½ - 3 inch bands of dark blue shale, or massive with few visible bedding planes. It is often well jointed and breaks with a knobbly structure, a feature which assists in quarrying operations. It is usually slightly sheared.

According to Hosking and Hueber (1954), the purer West Coast limestones contain between 85 and 95% calcium carbonate.

The main limestone exposures in the Queenstown area are at the old Smelters Quarry; near the Recreation Ground; along Lyell Road; at several points in the Queen River near Lynchford; and at the Hall's Creek Quarry. In the Darwin area, limestone may be seen along the Currie and Garfield Rivers, and in the old Darwin Flux Quarry. It is also well exposed in the Nora and Bird Rivers, where there is some doubt as to its age. The type area for this formation is of course along the Gordon River, where limestone forms steep cliffs along the river valley.

Shaley facies of the limestone are seen associated with the exposures already mentioned and also they are particularly clearly exposed in the creek beds near Linda. Much of the material is non-calcareous but this may be due in part to leaching. These argillaceous facies of the formation often weather to a dark blue-grey clay or "pug", which is easily recognised in the field and serves as a useful marker for tracing the formation.

There is generally a gradual passage up from Owen Conglomerate and quartzite, through sandy and shaley beds to the Limestone.

Transitional beds above the Owen formation may be seen at several points between Linda and West Lyell, and Bradley gives a good account of the limestone base at Lake Margaret.

The lithological change from limestone to Crotty quartzite is comparitively sharp, in that usually there is a sudden increase in the arenaceous content of the rocks. Above the limestone in the Linda Valley (8206/3657) there are several feet of pale brown shales with bryozoa and these are overlain in turn by typical Crotty Quartzite. At the old Smelters Quarry there is an increase in the frequency of the shale bands at the top of the Gordon Limestone, then a sudden change to quartzite. Similarly, pale grey shales are seen immediately below the Crotty on the Princess River (8136/3647) near Lynchford. However, at the old Linda cemetery (8203/3647), very sandy limestone or dark calcareous sandstones with Ordovician trilobites, suggest that a passage from Limestone to sandstone does exist.

The age of the Gordon Limestone has been fairly well established by the palaeontological experts. Hill and Edwards (1941), Gill (1950), and Hill (1955) describe Ordovician corals from the Smelters Quarry and the Recreation Ground, and Carey and Hills (1949) describe the age generally as from Lower Ordovician to Upper Ordovician. Bradley (1954, p.203) quotes M. Banks (University of Tasmania) as saying that the latest collecting shows the age to range from Lower Ordovician to Lower Silurian.

Accurate measurement of the thickness of the formation is difficult, owing to the fact that the contacts tend to be obscured by talus from the adjacent, more resistant beds and that the Limestone thins or thickens to suit the structures in the more competent enclosing quartzites and conglomerates, thus giving an unnaturally wide range of thickness measurements. The limestone at Lynch Creek bridge is relatively undisturbed and measures 500 ft. Carey and Hills (1949) suggest a thickness of 1000 ft. for the whole of Tasmania, but Gill and Banks (1950) record 2000 ft. near Zeehan.

The Gordon Limestone has been used as a flux for smelting operations since 1896. Until 1932 it was removed from the Smelters Quarry in Queenstown but the depth of overburden forced operations to be transferred to a prominent limestone outcrop by the railway, 1 mile south of Lynchford, now known as Hall's Creek Quarry. Limestone for the North Lyell smelters at Crotty was obtained from a low-lying quarry ½ mile east of Darwin township.

Siluro-Devonian - Eldon Group

The post-Ordovician sediments will only be described in a general way as they are only of minor economic significance; Their chief importance is in revealing Tabberabberan structural forms.

The alternating sandstones and shales of the Eldon Group indicate a regular oscillation from shallow to deep water conditions in a miogeosynclinal environment. Gill (1950) has studied this group at Eden, 10 miles south of Zeehan, where the exposures are good and the structure open, and he devotes considerable space to discussing its characteristics; his chief conclusions are as follows:

1. The rocks were deposited in the southern part of the Tasman geosyncline.
2. There is an alternation of rock types with a gradual reduction in contrast between propinquent sediments.
3. There is an overall reduction in grain size of the arenaceous members from bottom to top.
4. All the formations are siliceous, even the shales being essentially siltstones.

He also brings attention to theclose relationship between geology and topography, the alternation of soft and hard rocks producing a series of ridges separated by narrow valleys. All these statements also apply to the Group as seen in the Queenstown district.

The succession at Eden as quoted by Gill (1950), and Gill and Banks (1950) may be roughly matched in this area, the principal differences relating to thicknesses of individual formations and local lithological developments. A comparison of the successions at Eden and the relatively undisturbed area near Lynchford is given below:

Eden		Lynchford	
Bell Shale:	1400'	Bell Shale:	7000'
Florence Quartzite:	1600'	Florence Quartzite:	1800'
Keel Quartzite:	400'	Keel Quartzite and Shales:	1200'
Amber Slate:	800'	Amber Slate;	900'
Crotty Quartzite:	1600'	Crotty Quartzite:	800'

- - Disconformity (?) - -

The Lynchford thicknesses do not hold over the entire Queenstown and Darwin areas but it is the only district where measurements for the whole Group can be made with any degree of accuracy. An examination of the aerial photographs indicated that the Eldon and Junee Groups could be studied to advantage along the railway between Dubbil-Barril and Teepookana but unhappily this area has been extensively silicified and recognition of the formation is very difficult.

The age of the Eldon Group (Gill, p.238) ranges from Silurian to Devonian, the base of the Devonian being tentatively placed at the bottom of the Florence Quartzite. However, Gill points out that further fossil collecting may show the Keel and Amber to be Devonian also. His trial grouping is as follows:

Lower Devonian	(Bell Shale (Florence Quartzite
Siluro-Devonain	(Keel Quartzite (Amber Slate (Crotty Quartzite

Crotty Quartzite

This is a thin-bedded, white or grey coloured, medium to coarse grained sandstone, composed of rounded and sub-angular quartz grains. Pebbly bands and pink beds are found, while the lower part in the Queenstown area is often stained green by copper carbonate. Locally the formation is split in two by shales or reddish stained sand-stone. Bradley's succession and thicknesses given for the Crotty area are not considered of any practical value. Certain beds in the formation are characterised by thick tubercles or pipe stems, generally occurring in clusters arranged perpendicular to the bedding. The Crotty Quartzite is used as a flux in smelting operations at Lyell.

Amber Slate

This formation consists of grey or blue-grey slatey shales, which weather to a rusty brown. A thick yellowish limestone outcropping 2 miles north-east of Darwin may belong to the Amber Slate.

Keel Beds

The sediments between the Amber Slate and the Florence Quartzite vary considerably in lithology in this area. The chief member is a grey-brown, fine grained, thin bedded sandstone not unlike the Florence Quartzite. It usually directly overlies the Amber Slate and is separated from the Florence formation by shales, sandy beds and locally, lenticular crinoidal fragmental limestones.

Florence Quartzite

This is a grey-brown, fine grained, thin bedded sandstone, characterised by patchy iron staining and 2-3 inch bands rich in fossils in the top 100-200 ft.

Bell Shale

The lower part of the Bell formation consists either of dark blue-grey slates and shales, alternating dark shales and grey sandstones, or of muddy sandstones with thin shaley partings. The lower beds pass up to micaceous shales, shales with thin sandstones, and greyish silts and shales in the top-most beds.

Tabberabberan Orogeny

Lower Devonian sedimentation was interrupted by a prolonged period of orogenesis and mineralisation in which the Lower Palaeozoic strata were cast into their present day attitudes and in which all the important orebodies of the field were formed. This stage in the geological history is known as the Tabberabberan Orogeny.

The structure and outline of the mineralisation will be given in later chapters following the brief description of the remaining phases of the geological history of the West Coast.

Permian and Trias

The Tabberabberan Orogeny was followed by a long period of erosion extending through the Carboniferous, during which the area was planed to sea level. This Carboniferous level may be seen to-day on the Sedgwick plateau and concordant summits of the West Coast Range. Peneplanation was accompanied by widespread glaciation which continued until the early Permian, when marine transgression resulted in deposition of several hundreds of feet of sandstones, mudstones, and shales, with tillites showing recurrence of glacial conditions. Sedimentation probably continued into the Triassic.

The only deposits of this age on the Queenstown and Darwin area maps are seen at Mt. Sedgwick. Under a dolerite capping and lying in a shallow depression in the old land surface are about 150 ft. of tillite with sandstone bands containing Permian fossils. The tillite rests on both Dundas Group and Owen Conglomerate beds and is composed largely of Owen Conglomerate fragments, some of which are several feet in diameter. It occurs at about 3,500 ft. above sea level.

Other Permian beds are seen along the Zeehan-Strahan railway and east of Strahan at elevations less than 500 ft. above sea level. If these strata were deposited on the Devonian-Carboniferous peneplain then they have been thrown into their present position by large scale post-Permian faulting (probably early Mesozoic). The Permian (?) tillite exposed on the Queenstown road about 2 miles east of Strahan appears to be faulted directly against Eldon Group formations.

Mesozoic

Permo-Trias sedimentation was followed by extensive intrusion of dolerite sills. The remnant of one sill may be seen capping Mt. Sedgwick; it is of columnar quartz dolerite and is about 300 ft. thick. A similar form of outcrop forms the peak of Mt. Dundas, and other dolerite sills may be seen covering wide areas of the Central Plateau north of the Lyell Highway.

Succeeding elevation of the Permo-Trias sediments was probably accomplished by block faulting stepping up to the east, with the major faults near to the present coastline.

The prolonged period of erosion which followed this elevation reduced the area west of the Range to the peneplain which is clearly visible to-day. Monadnocks of Lower Palaeozoic rocks rise up from the general level but no Permian strata are visible on its surface. They were, however, preserved west of the peneplain edge by earlier faulting which dropped them below sea-level. This planed surface was described by Gregory as the Henty Peneplain, though Bradley apparently terms it the Howards Peneplain (1954, p.195). It falls from about 1000 ft. near the Range to 5-600 ft. above sea-level near Strahan and is equivalent to the Little Henty Peneplain described by Waterhouse (1916) near Heemskirk. Its continuation on the west side of Macquarie Harbour is clearly visible from the Range where it falls from about 700 ft. on the eastern side of the Cape Sorell peninsula to about 300 ft. on the Ocean side.

The Henty Peneplain might well be described as a <u>pediplain</u> (King, 1953) for in all probability it originated by scarp retreat from somewhere near the present shore-line east to the West Coast Range.

Tertiary

Mesozoic peneplanation was interrupted early in the Tertiary by widespread block faulting, largely on similar lines to the earlier Mesozoic phase. Near Strahan and to the north, these faults have a NNW trend (see Fig. 2) but south of Strahan the dominant trend is longitudinal. A particularly prominent fault is known as Lee Fault which runs N-S along the west flank of the D'Aguilar Range. The general result in the area mapped was uplift, bringing base level some 500 ft. below the earlier pre-faulting level and about 300 ft. above the present one. Macquarie Harbour represented a depressed area (the Macquarie Graben) in which several hundred feet of lacustrine deposits accumulated; these are well exposed at Strahan and along the eastern shore of Macquarie Harbour and are known as the Macquarie Beds. They consist of fine-grained semi-consolidated sandstones, shales, gravels, and lignitic horizons, which dip gently westward with angles less than 5°. At Strahan they rise to about 500 ft. but west of Mt. Sorell they appear as high as 1200 ft. above sea level, which suggests they have been tilted after deposition.

Evidence of the early Tertiary erosional phase is seen inland in the Queen River Valley. Isolated gravel deposits occur at several points along the flanks of the valley and generally some 200-300 ft. above the present floor. The principal gravel occurrences are near the Mt. Lyell Sub-station; west of the Mine Office; the Smelters Magazine (8195/3603); Spion Kop; Hospital Hill; South Queenstown (8174/3583); and near Lynch Creek. They attain a thickness of 100 ft. or so locally and consist largely of well rounded boulders and pebbles of Owen Conglomerate, with lesser amounts of dolerite and Eldon Group beds. A planed surface $\frac{1}{2}$ mile north-east of Queenstown (8194/3611) in Conglomerate Creek appears to coincide with the level of these gravels. They are interpreted by the writer as representing the deposits of a Tertiary river following the soft limestone bed and cutting down into the Henty Peneplain subsequent to the early Tertiary uplift.

Late in the Tertiary, movement along pre-existing faults again took place, elevating the entire area so that rivers were re-juvenated and the Tertiary beds of Macquarie Harbour were both lifted and tilted. This movement might be correlated with the Kosciuskan epoch so well developed on the Mainland of Australia.

Pleistocene

The final major event in the geological time scale was the Pleistocene glaciation, which affected the higher parts of the West Coast Range and some of the larger river valleys. Moraines, cirques, ice-smoothed pavements, and U-shaped valleys testify to the work of the Pleistocene ice.

Of particular interest is the King glacier, which flowed down the King River Valley, and forced its way up many of the rivers tributaries against the natural drainage direction. The Comstock and Linda valleys provide examples of these ice distributaries; at the head of each there are extensive deposits of till, with a fair percentage of varved clay, indicating the presence of ice-dammed lakes. The level of each lake was controlled by the elevation of the watershed between the King and Queen drainage systems; and overflow from the lakes drained west towards the Queen River. At no stage did the ice sheet cross either the Lyell-Owen or the Lyell-Sedgwick divides.

The glaciers of the higher parts of the West Coast Range generally melted below 2000 ft., though a few tongues descended to 1500 ft. Associated glacial features are well exposed on the sheltered eastern slopes of Mts. Sorell, Jukes, Owen, and Sedgwick; and also at Lake Margaret, where a large arcuate moraine extends out from the Lake on the lower western slopes of the Range.

Although much of the ruggedness of the area is due to glacial erosion, yet modification of pre-Pleistocene topography by glacial agencies is only of minor significance.

Recent

The only deposits of Recent origin are portions of the extensive screes fringing the mountains, and alluvium and gravels of parts of the King and Queen Rivers.

The raised beach between 20 and 50 feet above sea-level along the coast south of Cape Sorell is a result of Recent uplift.

STRUCTURES OF THE TABBERABBERAN OROGENY

Tabberabberan movement marked the culmination of minor earth movements that characterised the Lower Palaeozoic stratigraphy, and closed the chapter of orogenic instability for this area, for succeeding stages in the geological column were largely ones of quiescence broken only by short-lived phases of block faulting. As a result, the complex structures observed to-day in the West Coast Range are largely related to the forces acting during the Tabberabberan upheaval.

The broad tectonic picture is of a thick, longitudinal sedimentary prism being squeezed against a relatively stable Precambrian core by forces directed towards the north-east. The major structures follow trends that had become established during early Palaeozoic times and which had a profound effect on succeeding tectonics and sedimentation. The Tabberabberan phase merely accentuated a structural pattern that was already in the making.

The principal elements of structure observed in the Queenstown and Darwin areas are six in number. They are:

(a) The N - S West Coast Range anticlinorium, the King-Sophia synclinorium, and related secondary folds.

(b) The N - S Lyell Shear, and the Toft-Crotty structure.

(c) The NW fault-folds, [illegible].

(d) The Linda Disturbance.

(e) The NE Faults.

(f) The NNE Faults.

A number of ENE wrench faults occur east of Darwin and Crotty but only reach major significance in the Precambrian rocks east of the area mapped. Little information on this structural type is available but a few notes are provided after the discussion of the NNE faults. The principal structures are summarised on Fig. 9.

(a) The West Coast Range Anticlinorium, etc.

The West Coast Range Anticlinorium, with its flanking synclinoria, is the major structure of the area, upon which the other features are superimposed. It has a N - S trend and its axis passes a little to the east of Queenstown; it is markedly asymmetrical, the secondary "drag" folds showing vertical or overturned and often severaly attenuated eastern limbs, and relatively flat and undisturbed western limbs. The form suggests E - W pressure with the east-directed forces dominant; thus the thick Palaeozoic sediments of the geosynclinal basins flanking the Tyennan craton were squeezed against the stable mass in a series of major longitudinal folds. The origin of the E - W compression is discussed at the close of the structural section of this report.

North of Comstock, reconnaissance mapping indicates shallow, symmetrical folding of a different type from that along the Range to the south. This change in the tectonic environment indicates the influence of some other factor in the regional picture. The anticlinorial structures are locally confused by later Devonian features, most important of which are the N - S and NW elements. The N - S features, parallelling the anticlinorial axes, usually accentuate the prevailing asymmetrical folds by producing considerable displacements on the steep limbs. The general pattern of NE directed forces and induced shearing couples is maintained. Some of the N - S structures are easily traced e.g. the Lyell Shear and the Toft-Crotty features, but others are not so easily picked up and are found only as broad zones with strong N - S influences.

Several of the secondary folds om the anticlinorium are immediately obvious and assume local importance. Perhaps the most interesting are those developed on the eastern limb of the major fold, chief of which are the Thureau anticline and the Toft-Crotty fold. These features form the eastern side of the anticlinorium from Mt. Owen to South Darwin; north of Owen the eastern limb is sheared out by movement on the King River Fault.

The Toft-Crotty structure includes a more or less horizontal western flank, a central vertical or overturned, east-facing limb, and an east limb dipping west. It is thus a combination anticline and syncline but it is convenient to regard it as one unit of structure. Bradley refers to it as a monocline and though this might be regarded by some geologists as loose terminology it makes for convenient reference. The steep limb of this fold forms the low, straight, N - S ridge running west of the old Kelly Basin railway line. The dips are pre-dominantly vertical though near Crotty rapid variation in dips indicates close folding; again, detailed mapping by the Hydro-Electric Commission geologists near Divide Hill shows that the N-S faulting indicated by regional mapping near Darwin is of greater importance than previously realised. The steep limb is thus one of complex folding, steep dips and longitudinal faulting. In the Toft River Gorge, good exposures show the steep limb to be composed of a series of right angle folds which in profile resemble a steep flight of stairs, which steps down to the east. In this area, the eastern limb can be followed over to the next asymmetrical fold, the Thureau anticline. The steep limb of this feature, exposed east of the Thureau Hills, shows drag folding and overturning, and is affected by N - S faults in similar fashion to the Toft-Crotty structure. As near Darwin and Crotty, the Gordon Limestone is locally sheared out.

<u>The axis of the anticlinorium</u> is roughly indicated by following the Owen Conglomerate beds across the West Coast Range. This is most easily done on Mt. Jukes, and here the formation reaches its greatest elevation on a N - S line coincident with the Jukes Plateau. North of this area, the axis of the anticlinorium has been eroded and its position has to be estimated by extrapolation of structures observed in the Range. ~~(see section 6).~~ The anticlinorium may be traced south of Darwin for many miles. It first re-appears in the D'Aguilar Range where it is asymmetrical with an overturned east limb and has a gentle northerly pitch. This pitch alters to southerly south of Darwin.

Structures on the <u>western limb</u> still reflect dominant east-directed pressure, producing overturned folds. A fine example may be seen on Mt. Sorell; the magnificent cliff that overlooks the Clark River Valley is composed of Owen Conglomerate dipping west at about 45° and conformably overlying Jukes Conglomerate. On the lower part of this face, the breccias dip 80° to the west and are upside down. This overturned, east-facing fold is known as the Sorell anticline. The overturned limb was missed by Hills (1914) and as a result he quotes a far greater thickness of Jukes Conglomerate than actually exists. This is a clear example of how important the determination of structure is to elucidation of the stratigraphic sequence.

Other important secondary folds must exist and are inferred when drawing up sections, but those just described are clearly exposed and picked up in the field, and their characteristics, therefore, permit no argument. A feature of all these N - S secondary folds is a tendency to variation in plunge. For instance, north of the Thureau Hills, the anticline clearly plunges north at about 55° or 60° yet near King Hill the plunge direction on this fold is reversed to south at 45° or 50°; a similar angle and direction may be measured on folds in the Toft River. The southerly plunge in this area causes an apparent indentation of the Owen Conglomerate by the Gordon Limestone and Eldon formations (see Fig. 3 (b)). Elsewhere plunge changes result in the apparent dying out of folds along their axes. Obviously such variations must be related to folding on axes transverse to the anticlinorial trend and it is thought that such folding is a reflection of fault movements in the basement rocks (see the "Linda Disturbance").

<u>The King-Sophia synclinorium</u> lies between the West Coast anticlinorium and the Tyennan block. It is asymmetrical with a steep western flank and exposes largely Eldon Group sediments, which are involved in tight isoclinal folding, details of which can only be picked up locally. On the Queenstown sheet the pitch is northerly, exposing successively younger formations to the north, but in the Darwin sheet the pitch is variable, giving once again an impression of cross-folding. The synclinorium is much narrower than the West Coast Range anticlinorium, its wave-length averaging about 2 miles; it forms a topographic low between the Range and the Precambrian Central Plateau.

West of the Range, Eldon formations occupy a synclinorial zone shown on Carey's structural maps (1953, p.1115) as the Zeehan-Magnet Synclinorium. Fold axes in the Queenstown-Strahan area are dominantly N.W. and plunge northerly. The entire structure has not been mapped as yet by the writer but the main features of the folds have been obtained by aerial photograph interpretation. The fading out of the N - S fold axes away from the Range reflects the decreasing influence of the Precambrian craton on structures in the main geosynclinal basin, and the predominance of the effects of S.W. - N.E. compression. The form of the anticlinorium and the flanking structures is shown in a very general way in Fig. 10 and in the more detailed E - W sections of Fig. 11.

(b) <u>The Lyell Shear</u>

The Lyell Shear is perhaps the most important and interesting feature of the tectonic framework. It parallels the West Coast Range from Comstock to South Darwin and is associated with local overturning and attenuation, with granitisation and mineralisation. Its points of conflict with cross-cutting structures are foci for the deposition of sulphides.

The Shear was active during, and at the close of, the Cambrian; during Owen deposition; and again in the Devonian tectonics, and is probably an old structure of Precambrian origin. It has profoundly influenced the course of Lower Palaeozoic sedimentation and an understanding of its history is vital to the elucidation of the depositional environments. Probably a fracture in depth, it is generally expressed in the rocks exposed at the present day as a zone of overfolding, monoclinal folding, or upturning, with axes dipping towards the west. Fault movement at depth must have been west side up. Also, Carey (1953) suggests that the dragging of N.W. shears towards N - S alignment, as shown up by both the regional and detailed mapping, suggests transcurrent type movement, west side north and Bradley describes the Shear as a "complex dextral tear fault". The writer does not consider the amount of horizontal movement to be very great.

Superimposition of this structure on the anticlinorium locally exaggerates secondary features of the major fold; thus at

Lyell an east facing monocline becomes an overturned anticline with shearing of the steep limb. Whereas in some areas the presence of the shear is made obvious by the local structures, in others it can only be inferred from indirect evidence. This is in part due to offsetting of the structure by tear movement on N.W. faults, and partly du to variation of surface expression induced by varying depths of bedrock and changes in the properties of the overlying sediments. The Lyell Shear has been mapped as a more or less intermittent zone of overturning and faulting from Comstock to South Darwin. Its trend is best shown by the line-up of mineral occurrences along the Range, for with only a few exceptions, these lie on a N - S line from Comstock to Prince Darwin (Fig. 18). From Huxley southwards the Shear follows the east flank of the West Coast Range, but from Huxley to Sedgwick it lies on the western flank. It is significant that south of Mt. Huxley, where the displacement is small and the folding on the Shear zone is comparitively weak, the mineralisation is light and patchy.

The Lyell Shear, from Mt. Sedgwick to South Darwin

North of Comstock, all evidence of the Shear is lost in the gentle folds of the Sedgwick Plateau and it is assumed that E - W tear faults have displaced the structure some 5,000 feet to the west, so that it passes west of the Range.

There is no doubt that the shear structures in the neighbourhood of the Lyell mines show a greater degree of overturning and complexity than elsewhere along the Range. The existence of a prominent N - S structure at Lyell was probably first recognised by Gregory (1905) and he named it the Great Mt. Lyell Fault. Conolly, in doing the first detailed mapping of the mine area in 1940, followed out the structure and named it a monocline, which he referred to as the Razorback fold in his publication of 1947. The Razorback monocline has a steep limb facing east and is generally overturned; it is locally sheared out by N - S faulting. The crests and troughs of the monocline (i.e. the "angles" of the structure) are often seen as contorted zones showing small scale overfolding and thrusting as would result from pressure directed eastward (see Fig. 12). The richer copper orebodies are located in schists occupying the steep limb of the monocline.

A significant outcome of detailed mapping of the mine area in 1955-56 is the discovery of the significance of the Haulage Unconformity. The writer has "unfolded" the unconformity using stereographic methods (Phillips, 1954) and has shown that the Upper Owen movement consisted of localised faulting of N - S trend associated with limited E - W faulting. The movement is similar to that associated with the Tabberabberan Orogeny.

Going south of the Lyell mines, along the western flank of Mt. Owen, there is no sign of N - S folding until the South Owen area, where upturning of the Lower Owen Conglomerate and NW structures can be seen from a mile or more away. In the Huxley-East Jukes area, the influence of the Shear movement is seen in the swing of NW faults and folds to N - S on their western ends. However, structures as severe as that at Lyell are not present. East of Lake Jukes, the structure is interpreted as a vertical fault with down-throw to the east of no more than 500 ft. (Fig. 12). South of Lower Lake Jukes, there is rather a feeble suggestion of west side north movement, as shown by the relative positions of the base of the Owen Conglomerate. At East Darwin, the Shear is apparently offset to the east and is not picked up again until it is recognised in the tight folding near Prince Darwin, and the sharp syncline and faulting in conglomerate west of South Darwin peak. In the latter area, movement along the Shear in the late Cambrian or early Ordovician is indicated by the inferred existence at that period of elevated ridges supplying detritus to adjacent basins. Some of the forms of expression of the Shear at the surface are illustrated in Fig. 12.

It has already been stated that the Lyell Shear has had an important influence on lower Palaeozoic sedimentation. It was in all probability an active element during the Cambrian, producing localised breaks in deposition and exposing recently deposited sediments and volcanics within the Dundas eugeosyncline. Minor intra-Dundas movements culminated towards the close of the Cambrian in a major upheaval (Jukesian movement), which resulted in the formation of a high east-facing scarp, erosion of which poured vast quantities of material into the Jukes trough. Evidence of at least local movement during the Owen is shown by unconformities in the conglomerates at Lake

Jukes and more obviously in the Lyell mines area. There is no direct evidence for movement during the Upper Palaeozoic until the Tabberabberan Orogeny, when the Shear again sprang to life; tectonic activity of this stage was accompanied by sulphide mineralisation.

There are other N - S lines of faulting, and locally high disturbance, which must have a similar origin to the Lyell Shear. Chief of these is the Toft-Crotty structure which has already been described in connection with the West Coast Range anticlinorium. Its surface expression is variable, like the Lyell Shear, and there is a suggestion at 8025/3650, that movement along this line has taken place at more than one period; aerial photographs show a 20° discordance of strike on the steep limb within the Owen Conglomerate, probably between Middle and Lower members. This could be due to faulting but the form of the discordance favours local unconformity. Another less obvious zone of N - S faulting occurs west of the Range on grid line 3540 E. N W structures take on longitudinal trends in similar fashion to the Lyell Shear and the Toft-Crotty lines, and it seems likely that there is also a deep-seated N - S influence in this area. These two longitudinal fault lines show no important mineralisation and they are thus of minor significance compared to the Lyell Shear.

(c) The N W Faults

Superimposed upon the N - S folding is a set of N W trending features expressed either as asymmetrical folds or high angle reverse faults. Their strike averages N 60° W but varies from N - S almost to E - W. They may be regarded as slightly overturned folds in which the steep limb is severely attenuated or faulted out - hence use of the term fault-fold. Conolly (1947) refers to N W folds while Bradley uses the term faults but the difference is negligible; in this description they will be referred to as faults or fault-folds.

The structures are best developed on Mt. Owen, and Carey (1953) describes "Owen-type" folds. There are four NW faults on the mountain, each facing north and stepping down to the north with vertical throws of up to 1000 ft.; in this way, the highest beds of the Upper Owen are beautifully exposed at the summit of the mountain. The step-like northern face of Mt. Owen clearly reflects the fault pattern, which is demonstrated in section in Fig. 13. Bradley describes inclinations of NW faults as low as 40°, in which case they would be more correctly called thrusts, but the writer's field observations suggest the faults seldom flatten below about 70°. Of course, changes of attitude in depth are possible, particularly if the Palaeozoics are dragging over a rigid basement, in which case the frictional effects on the stable surface would cause the faults to flatten as they approached that surface. However, the Precambrian basement in this area appears to have shared in the Tabberabberan deformation and therefore such effects are unlikely. Along N - S fault zones like the Lyell Shear, many of the NW faults swing to a N - S line and lose their identity. They swing northwards on the east side of the N - S features and southwards on the western sides, indicating drag of west side north. The two structural groups must be contemporaneous and result from the same system of forces, for they merge imperceptibly. Conolly (1947) realised the essential unity of the two features when he wrote (p.8) that "the truth is that the foldings cannot be separated". However, some of the NW faults (e.g. the North Lyell fault) cut cleanly across the Lyell Shear, suggesting a later phase of movement, probably of transcurrent type.

The NW faults are very much evident in the Lyell-Owen area, near Mt. Jukes, and at East Darwin. In intervening areas and away from the Range, N - S structures combine with NW schistosity or cleavage. This is primarily a matter of relative competency, the weaker Dundas Group, and some Eldon formations, accomodating themselves to compression by development of cleavage, while the strongly competent Owen beds form widely spaced folds. Both schistosity and faulting are related to the same SW compression.

West of the Range, e.g. along the Mt. Lyell Railway to Strahan, Siluro-Devonian rocks are involved in major NW symmetrical folds that pitch to the north. They may be traced for many miles, allowing for fault interruptions, and reflect the overall crustal shortening from SW - NE pressure.

The principal centres of mineralisation are confined to the neighbourhood of Lyell Shear - NW fault intersections and this fact has laid the basis for exploration outside the Mt. Lyell Company's leases.

The majority of the NW faults face (or throw down) to the north but at Mt. Lyell and at Comstock there is a zone of faults facing in the opposite direction, the result being almost a rift valley structure between N-facing and S-facing groups. This structural "low" is situated in the Linda Valley and Hills (1927) describes it as the Linda "saucer" or basin. This anomalous feature is inherited from deep-seated movements along an old fracture line which is known as the Linda Disturbance; it combines with the Lyell Shear and the N - S asymmetrical folds and the NW faults to form a complexly folded and brecciated zone between Mts. Lyell and Owen, in which the major copper orebodies of the area are situated.

Comments on the more important NW faults, roughly from north to south, are given below:

The Comstock Fault

The Comstock Fault strikes approximately WNW and throws Lynch Siltstones against Lyell schists and Owen Conglomerate. It is a south facing feature and forms part of the northern rim to the Linda saucer. Observations of the fault at the surface and in underground workings suggest it is vertical or inclined at a steep angle to the south. The possibility of a parallel fault, to the north, running at the foot of the scarp of the Sedgwick plateau, is indicated by silicification and contortion at 8260/3617, and by the probable displacement of the Lyell Shear to west of the Range; this indicates N side W movement.

The North Lyell Fault

The North Lyell Fault strikes at N 60° W and is one of the important ore bearing structures of the Lyell copper field. Like the Comstock fault, it is a south-facing fault with a steep dip in that direction, and its influence can be followed from Cape Horn down to the King River Valley, where it is cut off by the King River Fault. Remnants of the steep limb of the original fold are visible north of Linda but have been obliterated elsewhere. In the North Lyell area, the fault is marked by a wide zone of brecciation, crushing, and silicification where it crosses the Lyell Shear - an example of Conolly's "fearful conflict" of folds; this intensely disturbed zone is the home of the rich North Lyell chalcopyrite and bornite orebodies, and thorough prospecting of the zone if a major exploration target. A little north of Linda, closely spaced faulting is apparent in conglomerate and quartzite, with accompanying gold mineralisation (e.g. McDowell's claim). At 8204/3658, Lower Owen Conglomerates may be seen in contact with Crotty quartzite, while near the King River the Owen quartzites are severely crumpled, intensely quartz veined, and locally mineralised by pyrite with a little chalcopyrite. The westward continuation of the fault has not been picked up and it may be possible that it is offset by a fracture parallel to the King River fault. The long straight line of the East Queen River Valley may mark such a zone of weakness.

The fault has a vertical throw, south side down, of between 1000 and 1500 ft., but it also shows an apparent horizontal displacement, north side west, for the Lyell Shear is offset to the west by about 3,500 ft. across the North Lyell fault. Conolly (1947) explains this apparent horizontal offset by vertical movement but a similar type of displacement observed west of Mt. Owen (the South Owen fault) can only be a result of horizontal movement and it is unlikely that this is markedly different from the North Lyell feature.

If the picture of both horizontal and vertical types of movement is accepted, then it becomes necessary to decide if two separate periods of faulting are represented, or whether the two are combined, as is the case with the Lyell Shear, to form a type of oblique-slip movement. Only a few NW faults show this horizontal displacement and the writer considers that they are the result of an early vertical movement in conjunction with Lyell Shear upturning, followed later by wrench[1.] movement offsetting the Lyell Shear.

Bradley (1956) quotes Hills as saying that bornite ore in the North Lyell mineshows horizontal striae, suggesting horizontal post-ore movement. However, observations by the staff of the mine

1. The term "wrench" is taken from Anderson (1951) and is synonymous with "transcurrent".

over a period of many years does not confirm Hill's report.

The Owen Spur Fault

The Owen Spur Fault is the most northerly of the north-facing NW faults and represents the southern margin of the Linda depression. Its presence is marked by the striking escarpment overlooking Gormanston and the Linda Valley. At Gormanston the base of the Middle Owen is faulted against quartzites high in the Upper Owen sequence, involving a vertical throw in the neighbourhood of 6-700 ft.; heavy quartz veining of rocks adjacent to the fault plane is often observed (e.g. at 8188/3646) and is obviously a characteristic feature of these NW structures.

Conolly considered that the Owen Spur Fault was twisted around to pass through the "Blow" Mine, the concentration of mineralisation occurring near the point of upturn, where shattering of the rocks was at its maximum development. Along the eastern side of Mt. Owen, the strike of this fault-fold swings almost to N - S before being cut off by the King River fault. The swing to longitudinal trend east of Mt. Owen, shown by all the faults in this vicinity, probably represents the northerly continuation of the influence of the N - S Toft-Crotty structure.

The North Owen and Owen Faults

These may be discussed together as they join before reaching Moore's waterfall. They are of similar form to the Owen Spur fault and exhibit all the characteristics of the Owen type fault-fold. The three blocks isolated by the two faults may be recognised north of Mt. Owen summit from a considerable distance. At several points along the fault planes, the effects of silicification are seen in the massive slabs of pink dense quartzite in which all sedimentary features have been obscured (e.g. at 8180/3643 and 8165/3652). Similar effects are seen on NW faults north of Comstock and at Upper Lake Jukes.

The nature of these structures is well displayed at the Waterfall on Moore's Creek where the violently upturned and squeezed north-facing limb in Upper Owen beds is faulted against Lower Owen Conglomerates, which themselves are tightly folded against the fault plane. The latter has proved to be a zone of weakness into which the metasomatising agents have penetrated deeply, and small showings of copper carbonates in this shear zone have been opened up east of Moore's Waterfall. As with the Owen Spur Fault, these features swing to almost a longitudinal strike east of Mt. Owen summit.

The South Owen Fault

The South Owen Fault is the most southerly of the Mt. Owen group. It strikes parallel to its northerly neighbours and throws Lower Owen beds against Dundas-like schists, indicating a vertical shift between 500 and 1000 ft., south side up. It differs from the Owen and Owen Spur Faults in that it can be traced for some way west of the mountain, apparently displacing the Lyell Shear in a manner closely parallelled by the North Lyell Fault. This displacement has not previously been described, and is important in that it assists interpretation of the North Lyell Fault movement. Along the conglomerate ridge north of South Owen Creek, there is a sudden change, at 8181/3625, from NW to N - S axes, accompanied by local crumpling and quartz veining; this is presumed to mark the line of the Lyell Shear, which must originally have been continuous with the upturning so well exposed south of the fault, along the western flank of Mt. Owen. The apparent displacement is in the order of 1200 or 1500 ft., and must have been accomplished by wrench movement, for the south side up vertical movement clearly shown along the fault would give the opposite effect to that observed, i.e. it would throw the Shear south side west instead of north side west. Wrench movement is also indicated by the westward swing of the Shear upturn adjacent to the fault zone at 8172/3628, and by slickensides on the fault wall at 8177/3628; these are cut in Owen Conglomerate and dip south-east at about 20^{o}.

This fault has been mapped in some detail for nearly a mile of its length, and details of its appearance at the surface are therefore available. Underground workings at 8181/3624 indicate that the conglomerate face of the fault plane is vertical, while on the mountain it usually dips south at 80^{o}. The conglomerates of the northern wall show local crumpling with overturning on axes parallel to the fault, but only minor silicification. Where both walls show Owen Conglomerate(as near the summit of the mountain), they are separated by a zone of intensely sheared material, now mainly quartz sericite schist; where Dundas beds are thrown against the Conglomerate, the zone is characterised by sericitic and chloritic schists, in several places showing heavy pyrite and chalcopyrite mineralisation (e.g. the Duke Lyell and Great Lyell mines).

For about two miles to the south of this feature NW elements are not in evidence but they re-appear in a contorted zone between South Jukes and Huxley.

The East Jukes Faults

These mark the northern edge of another zone of north-facing NW fold-faults of the Owen type. A crude, narrow, basin structure develops in this area though the south-facing feature is obscure and limited. The most northerly of the faults in the East Jukes area shows evidence of north side up in the King River Gorge (at 8096/3638), throwing Jukes Conglomerate against Middle Owen Conglomerate, and the general pitch in this area is southerly. South of East Jukes peak, however, all NW faults throw down to the north, giving a step-like face to Mt. Jukes. It is interesting to note that the south-facing fault previously mentioned in the Gorge dips steeply south as do the north-facing features, and this odd fact is also observed at North Lyell. The faults at East Jukes tend to fade out in both NW and SE directions into N-S structures.

The Faults on Mt. Jukes

There are two major faults on Mt. Jukes itself, the more southerly, Central Jukes Fault (Hills, 1914) and the North Jukes Fault. The displacements of the striking red and white sandstone and conglomerate beds show up well and the faults are thereby clearly visible from several miles away. They step down to the north with throws of between 200 and 300 ft. and the faults dip steeply south. Silicification of wall rocks is typical and there is usually a narrow zone of highly sheared material between the conglomerate walls. The beds of the downthrown blocks are sharply upturned against the fault planes. There are several small workings in the schistose rocks on the Central Jukes Fault line and strong silicification of the Middle Owen beds may be seen at 8121/3618. South of Lake Jukes a sharp syncline is locally faulted with attendant silicification and upturning; this is the South Jukes Fault-fold.

Another zone of NW faulting occurs on Conglomerate Spur. If the East Darwin orebodies and the faulting there indicate the position of the LyellShear, as seems reasonable, then the latter has been offset to the east. The NW folds here are north-facing and this eastward displacement is anomalous.

West of Mt. Jukes there are several important faults which vary in strike from N - S to NW. They are probably related to the NW faults of the Range, the swing in trend being related to the rock types and N - S shear movements.

(d) The Linda Disturbance

This structural element was first recognised and named by Bradley (1956). It is a regional feature of the utmost significance and obviously has an important bearing on the distribution of the copper orebodies in the Range. For all that, it is not so clearly defined as the structures already described and details must await geological survey of areas to east and west of the Queenstown map.

Between Sedgwick and Owen there is an E - W or WNW zone of extra-strong faulting and folding which extends into the Precambrian to the east and into the Silurian and Devonian rocks to the west. The principal feature of this zone is the presence of N-facing and S-facing fault-folds, producing a narrow rift or downthrown zone, of which the Linda basin is a part and in which the richest orebodies of the Lyell field occur. The NW faults are swung to WNW or almost E - W along the line of the Linda Disturbance. The compressive "rift valley" is confined to the Range in the area mapped but is well displayed again along the Nelson River valley and more particularly at Bubbs Hill. At the latter point, Gordon Limestone and Crotty Quartzite are preserved in the fault zone, wedged in between Precambrian quartzite masses (see Carey and Banks, 1954). Mr. Spry has also indicated, in course of conversation, that several parallel structures have been mapped in the Precambrian of the Raglan Range; they extend for many miles and show a WNW trend.

In the King River Valley east of Mt. Sedgwick, the northern margin of the Disturbance is marked by the appearance of Precambrian rocks adjacent to Devonian sediments, indicating an E - W fault with a considerable vertical throw. The westerly continuation of the Disturbance centres on the Howards Plains Fault which extends for many miles down to the coastline. On the Queenstown sheet the fault throws Dundas sediments and volcanics against Silurian and Devonian formations, indicating a vertical throw (north side up) of the order of 5,000 ft. There is no evidence of significant wrench movement and Carey states (1953, p.1123) that the parallel Henty Fault, some 8 miles further north, is one of only vertical throw. The Howards Plain Fault can be traced eastward into the Queen River Valley and its possible effects on the structures of the Lyell mine area is a problem of first importance. Yet no similar displacement can be seen in that area, the only fault showing similar features being that at North Lyell. Is there a southerly displacement of the North Lyell Fault, or in other words, are the two features really one and the same? Or does the Howards Plain Fault simply die out before reaching the Range? Considering the large throw on the fault, the second alternative seems unlikely and in support of the first, the possibility of a fault along the East Queen River has already been mentioned. Such a fault would be parallel to the King River Fault, which also cuts features associated with the Linda Disturbance and represents a hitherto unrecognised addition to the tectonic framework.

To sum up, the presence of the "Linda saucer", due essentially to the existence of anomalous S-facing folds; the swing in strike of the NW structures; the occurrence of abnormally severe brecciation and crumpling; the distribution of the major copper orebodies; the Howards Plains fault; and the Bubbs Hill structure, all point to the influence of a line or zone of weakness cutting across the area on an E - W or NNW trend. Possibly these features exposed at the present day point to the presence of an old Precambrian zone of faulting which was given a new lease of life during the Tabberabberan orogeny.

(e) The NE Faults

Faults of NE trend are largely normal and tensional, complementary to the NW fault-folds and related to the same system of forces. They appear to be of minor significance with only small vertical displacements, generally south side up.

A few NE faults e.g. at Jukes Proprietary, have been cut off by NW faulting but others e.g. the Halls Creek fault, affect the Lyell Shear upturn and NW folding. It may be significant that the apparently earlier NE phase has associated mineralisation (e.g. Dixon Street Lead and Jukes Proprietary Copper) while the later NE faults only show occasional, insignificant gold workings.

The possible importance of NE faulting in relation to ore distribution has been a source of discussion for some time among West Coast workers. Conolly (1947) and Alexander (1953) indicated a NE control for the Lyell orebodies but were unable to back up their suggestions with field evidence. Bradley (1956) supports these views by mapping a large number of NE faults and by saying (p.76) that "there are hundreds of unmapped small faults and joints which have the same trend..........." He suggested that the NE faults acted as channelways for the passage of hydrothermal leaching solutions which concentrated the ubiquitous, low-grade mineralisation into the rich orebodies of the Lyell area. This is an interesting suggestion but much of the field evidence brought in as a basis for the argument is considered by the writer to be hypothetical. The majority of the NE faults shown on Bradley's map of the Lyell mine area (1956, p.84) cannot be traced in the field, using either regional or detailed methods, and small scale NE features such as joints are conspicuous by their absence. However, at Lyell, it is possible to link some of the orebodies on theoretical NE lines, as Conolly and Alexander have done, and it may be that a NE control is present in the field. Detailed mapping has proved that it is not a major controlling factor in ore distribution.

The NE faults tend to vary in trend from NNE near the West Coast Range to ENE west of the Range. This is presumably related to the increasing depth of the basement to the west.

It is noted that Bradley's maps, both in Part I and Part II, show the King River Fault as part of the NE system. Yet this structural feature shows different characteristics to the usual NE faults, having an opposite and much greater throw, and it is thought that it may belong to a system of different origin to the tensional faults. It has a NNE trend and it is discussed under the heading of NNE faults in a later section of the structural chapter.

(f) The NNE Faults and Joints

There are few representatives of this group on the Queenstown and Darwin maps. The principal feature is the King River Fault which forms a prominent escarpment along the eastern flanks of Sedgwick, Lyell and Owen. Over most of its length it shears out the steep western limb of the King-Sophia synclinorium, throwing Florence and Bell formations against the base of the Junee Group. The maximum estimated throw is about 6,000 ft. It cuts off the NW faults of Mt. Owen and obliterates the eastward continuation of Linda Disturbance features, but appears to die out near the Thureau Hills. As has already been mentioned, Bradley regards this fracture as part of the NE tensional system.

The possible existence of a NNE fault along the line of the East Queen River has already been mentioned. The long straight line of the East Queen links up with the faulted zones mapped in the Queen River Valley near Queenstown, and may mark the course of an important crush zone. It may serve as the link between the Howards Plains fault and the North Lyell fault, as already described.

Joint planes of NNE trend are strongly developed in the Owen Conglomerates of Mt. Owen, particularly near the Lyell Shear. They show up clearly on aerial photographs of the mountain and cut obliquely across NE folds.

(g) The ENE Faults

East of Darwin and Crotty, a number of ENE faults have been picked up during reconnaissance mapping. They are most prominent in the Precambrian rocks but fade out in the Silurian and Ordovician formations exposed in the King-Sophia synclinorium.

The faults show horizontal displacements of Precambrian rocks up to 5,000 ft., north side east. They generally have a gently curving strike and appear to be wrench faults with a movement picture complementary to the NW faults, in that transcurrent movement on these two fault groups results in extension along N - S lines and contraction on E - W lines.

Their lack of persistence into the younger Eldon and Junee sediments flanking the Precambrian core may be related to the difference in physical properties between the younger and older rocks and to the increasing depth of the sedimentary prism away from the core. They are only significant in the Precambrian basement and in the overlying rocks for a short distance above the basement; between two and three miles above the Precambrian rocks, the displacements are negligible.

Schistosity and Cleavage

Throughout the area, the less competent rocks of the Dundas Group have developed a cleavage which is dominantly NW trending. The more massive lavas seldom show cleavage but the siltstones and most greywacke and tuffaceous rocks develop both flow and fracture cleavage.

The NW trend is locally distorted by major structures; thus near the Howards Plains Fault, the cleavage in the Florence Quartzite is E - W, parallel to the fault line and the distorted fold axes. Along the Lyell Shear, the cleavage direction is variable; while near Mt. Huxley it strikes N - S, at Lyell it is dominantly between 300° and 330° but near the massive Owen Conglomerate it often parallels the contact and the strike shows variations on all compass directions. The cleavage is more highly developed along the Shear than elsewhere and assumes the significance of schistosity. The schists involved are re-crystallised under stress and most types show linear structures derived from movement parallel to the planes of schistosity. The schists of the Shear zone, the Lyell Schists, will be discussed in more detail in a later chapter.

The shielding effect of the Owen Conglomerate in regard to the development of cleavage is seen at several points and has already been described at Mt. Huxley. The fading out of vertical cleavage in flatly bedded, incompetent rocks immediately below the massive Owen beds has given rise to erroneous interpretations of unconformity on Mt. Jukes (Hills, 1914) where the original bedding has been destroyed by shearing.

Structural Analysis

The first analysis of West Coast structure was given by Carey (1953, p.1125) and the subject has been further pursued by Bradley (1956). Carey regards the structure pattern as due to shearing parallel to the Tyennan Block combined with some early lateral compression. Varying orientation and significance of structural elements is related to the increasing thickness of the geosynclinal sediments west of the Block. Bradley relates the entire pattern to forces applied from the SW with a resultant N - S shearing couple.

This concept of NE-directed forces seems a logical one and accounts for all the principal structural elements. Each of the elements just described may be related to the one system of forces; they are cognate and penecontemporaneous. Confusion only arises as a result of interplay between structural types which produces locally unique developments. Undoubtedly the major factors controlling the structures in this area are as follows:

(a) forces acting from the SW;

(b) the presence of relatively rigid massif to the east;

(c) the increasing thickness of geosynclinal sediments westwards from the margin of the massif.

Forces acting along SW-NE lines, squeezing the Palaeozoic sediments against the relatively resistant Precambrian rocks, would be expected to resolve into components aligned perpendicular and parallel to the more rigid mass. As the latter's margin has a longitudinal trend in this area, the forces resolve into N - S and E - W components. There is thus a resultant lateral E - W compression on the N - S belt of sedimentation, combined with forces tending to move the sedimentary unit northwards against the stable block. This drag on the margin of the massif will form a shearing couple aligned N - S and acting west side north.

The combination of lateral compression and shearing couple forms the background to the understanding of the structure flanking the craton. Away from the latter, the importance of this combination recedes and the results of direct NE - SW compression becomes dominant. Thus moving westward from the Tyennan Block the tectonic environment is continually changing, and this is expressed in varying orientation and significance of the main structural units. For instance, the NE faults of the Range veer towards ENE trends west of the Range and the NW faults become NW folds.

The tectonic pattern outlined above for the Tabberabberan Orogeny holds good for the entire Palaeozoic era - the patterns for the Cambrian, Jukesian, and Ordovician movements are essentially similar to those of the Devonian. In fact the Tyennan and Tabberabberan orogenies are merely more violent phases of a series of disturbances that continued from Cambrian to Devonian times.

The origin of the individual structure types in terms of the system of forces just outlined may now be briefly discussed.

The effects of lateral compression, with pre-dominant east-directed forces, are seen in the asymmetrical regional anticlinoria and synclinoria of longitudinal trend. They suggest crumpling of the sedimentary strata against the rigid Precambrian rocks.

The superimposed NW faults and folds strike at right angles to the direction of compression and may be regarded as B-structures. But along the Range, one of the expected features of the N - S shearing couple is the presence of a NW thrust (or reversed) fault, so that NW features, depending on their geographical position and perhaps on the stage of deformation, may reflect NW-SW compression or N - S shearing.

Similar remarks apply to the NE faults, which might also be expected both as a result of SW-NE compression, and also from N - S shearing. The resultant fault types in this case would be very similar.

The classical pattern of shearing couple deformation is shown by experimental data. Mead (1920) indicated the effects of shearing couple movement by distorting a wire frame over which was stretched a waxed rubber sheet. The results he obtained are shown in Fig. 14, and it can be seen that there is a close parallel between the main West Coast Range features and Mead's results. It is interesting to note that the tension faults of the experiments form early, yet in the Queenstown area, some form late and some early; this may reflect the dual origin mentioned above.

The only other elements on Mead's pattern that are not accounted for so far are the N - S shear and the approximately E - W shear; these are represented by the Lyell Shear and the Linda Disturbance. These structures once again conform also to the SW compression, being of similar trend to the theoretical shear planes resulting from such compression; this explains the continuance of the Linda Disturbance both east and west of the Range. Thus all the structural elements so far described fit into the overall pattern of SW compression, with N - S shear and E - W compression of local importance close to the Tyennan block.

The significance of the remaining structural elements is less easy to define, and the discussion that follows must be regarded as tentative.

The question of the NNE faults has already been mentioned and it seems to the writer that features like the King River Fault must represent a different phase in the structural pattern from the NE tension faults. A suggestion put forward tentatively is that these fractures are a result of rotational shear, and developed at a late stage, when the physical condition of the sedimentary prism was different from that of the early phases. Reidel (1929) has demonstrated in the laboratory that shear fractures can develop at acute angles to the line of shearing couple (see Fig. 15). He laid a 5 c.m. thick slab of clay upon two parallel and adjacent boards, and by moving one board against the other, a strip of clay above the join developed two sets of fractures. One formed at about 45° with the line of movement and was tensional, the other was a set of shears at angles between 12° and 17° with the line of movement. Similar results have been obtained by Leith (1923), using a block of limestone. It is suggested that the experimental results may be applied in the field and that the NNE faults are, therefore, a result of N - S shearing resulting from SW pressure near the craton. The faults are undoubtedly later than all the other features and are therefore likely to have been formed at a time when the sediments were well consolidated and possessed greater rigidity. This is perhaps a case to which the "stress" ellipsoid can be tentatively applied; many geologists have maintained that rocks which have undergone folding and cleaving and are thereby consolidated will behave, under further stress, as more or less homogeneous, brittle masses similar to those met with in engineering tests, and to which the stress ellipsoid may be applied (see Wilson, 1946). This premise is, of course, wide open to criticism and is refuted by many workers, but there is no doubt that in the case in hand, the theoretical results given by the stress ellipsoid tie in well with experimental data and field evidence (see Fig. 16).

A possible explanation for the ENE faults that become prominent in the Precambrian, and together with the NW to E - W faults form the majority of the faults on the Tyennan block, is linked with E - W compression. Theoretically the NW and ENE wrench faults "complement" each other in that together they produce N - S elongation, which could reflect E - W compression (see Fig. 17). This wrench movement is later than the vertical movement on the NW faults and is earlier than NNE faulting.

In dealing with structures in the Precambrian, there is always the complicating factor of the possible presence of pre-existing lines of weakness. Such lines would render the strata inhomogeneous and would constitute pre-determined zones of relatively easy slip in later deformation phases. This may be the explanation of Devonian structures that locally depart from their theoretical trend due to the influence of older features.

MINERALISATION OF THE TABBERABBERAN OROGENY

The intense folding and faulting of the Tabberabberan Orogeny was followed by localised mineralisation showing strong structural control. The only mineralisation of economic importance was the formation of copper sulphides along the line of the Lyell Shear, foci of deposition being the points of intersection of cross-cutting NW faults. The major deposits are all in the Lyell area and this concentration is undoubtedly related to the influence of the Linda Disturbance. The principal copper mines are shown in Fig. 18.

Apart from the dominating structural control there is a stratigraphic control indicated by the occurrence of all the copper deposits at or near the same level in the geological column, i.e. at or near the base of the Owen Conglomerate. The controlling factor here is not so much one of geological age but rather is related to the differences in physical properties between the Dundas and Jukes beds, and the Owen formation. The relatively easily sheared, incompetent Dundas Group and Jukes Conglomerate allow an easy passage for rising ore solutions, but upward progress is halted by the overlying competent, massive, siliceous Owen Conglomerate. Ore solutions are thus trapped in structural "highs" in much the same way as oil. Only where the Owen Conglomerates are abnormally thin or highly sheared do hydrothermal solutions rise above that formation. This happens at Lyell where the Gordon Limestone beds have undergone hydrothermal alteration.

The most important copper minerals are bornite and chalcopyrite; insignificant chalcocite and covellite occur along with very minor developments of secondary minerals like malachite, azurite, tenorite, native copper, and chalcanthite.

The lack of supergene enrichment and oxidation is probably related to the high rainfall, which removes any altered material as fast as it is formed.

Gold and silver are ubiquitous accompaniments to copper mineralisation and the other important associated mineral is pyrite. Much of the pyrite mined at Lyell in conjunction with the copper is

It seems probable that the source of the ore bearing solutions is at considerable depth, perhaps as an acid intrusive that has risen upward towards the surface along the deep-seated Lyell Shear at a late stage in the Tabberabberan Orogeny. It might be expected to have a similar form to the Darwin granite.

THE LYELL SCHISTS

In the Lyell area, the Lyell Schists occupy the western slopes of the Lyell-Owen divide and flank the tightly folded Owen Conglomerate on the eastern slopes. A detailed geological map of the divide is shown in Fig. 19.

HISTORY OF VIEWS ON THE ORIGIN OF THE LYELL SCHISTS

The origin of the Lyell Schists has been a subject of controversy since the first geologists visited the West Coast at the end of the last century. Gregory (1905) published the first detailed appraisal of the area, concluding that the schists were originally volcanic ash and intrusive porphyries. He described in some detail the previous geological opinions, which included suggestions that the schists were altered sediments interbedded with the Owen Conglomerates (Peters, 1893; Montgomery, 1893; Officer, Balfour and Hogg, 1895); that they were altered basic igneous rocks (Haber, 1900); and that they were metamorphosed porphyries of the Dundas Group (Twelvetrees, 1901).

Hills (1927) regarded the Schists as metamorphosed igneous tuffs (i.e. the Dundas) and he was the first to realise that the alteration of the pyroclastics was a result of ore deposition.

Nye, Blake, and Henderson (1934) agreed with Twelvetrees in describing the Lyell Schists as altered complex igneous rocks intruding the Owen Conglomerate. Edwards (1939) and Conolly (1940, 1947) accepted these views, though Conolly suggested that the intrusive porphyry sills actually replaced rather than "pushed aside" the conglomerates. Alexander (1953) states that replacement of the Owen formation took place "either as the result of an intrusion or by metasomatic replacement".

Hills and Carey (1949) and Carey (1953), reiterated Hills' earlier views that the Schists were largely altered Dundas Group greywackes and volcanics, etc.

Bradley (1954, 1956), however, has supported Conolly's theory that the Schists are largely replaced Owen Conglomerates, exported for use in superphosphate production.

The chief ore combinations are (a) chalcopyrite and bornite; (b) chalcopyrite and pyrite; and (c) pyrite alone. Native copper occurs in the altered Gordon formation and this ore occurrence creates a fourth group.

The groups are not sharply defined; for instance, pyrite occurs locally in the bornite-chalcopyrite bodies of the North Lyell mine and again, bornite is found in some of the chalcopyrite-pyrite ore lenses at Comstock. Bornite often occurs at North Lyell to the exclusion of all other sulphides and the sulphide at Lake Jukes is almost entirely bornite.

Edwards (1939) has shown that pyrite was the first sulphide to form, followed probably by chalcopyrite and then bornite, in order of decreasing iron content.

Mineralisation away from the Lyell Shear is of minor importance and consists mainly of sporadic gold in quartz veins.

The ore deposits of the Lyell Shear are of hydrothermal origin, probably of mesothermal type, and deposition was accompanied by hydrothermal alteration of the surrounding country rock. The products of the various phases of alteration, which are dependent upon the original nature of the host rock, the type of sulphide, and the intensity of mineralisation, are known as the Lyell Schists. They are strongly developed at Lyell but also occur elsewhere along the LyellShear. Their origin and their relation to mineralisation have been the subject of discussion for many years and it is only lately, as the result of regional and detailed geological mapping, that the problem has neared solution.

Mineralisation followed upon formation of the schists and development of schistosity, but locally late stage movement shears both sulphide and host rock.

The source of the hydrothermal solutions is hypothetical for there are no known Devonian igneous bodies to which the mineralisation can be attributed. The nearest body of probable Devonian age is the Heemskirk granite, about 25 miles north-west of Queenstown, and it is hardly conceivable that this intrusion is the cause of the mineralisation along the Lyell Shear.

though Bradley speaks of granitisation and metasomatism rather than intrusion.

As a result of regional and detailed mapping, it is now clear that the majority of the Lyell Schists are hydrothermally metamorphosed Dundas and Jukes Conglomerate rocks but at Lyell there is evidence for assuming very limited alteration of the Owen formation near the contact of schists and conglomerate.

It is intended now to describe the schists in the type area of the Lyell mines and later those developed elsewhere along the Lyell Shear, and to show their relationship to mineralisation.

THE NATURE OF THE SCHISTS

The Lyell Schists are variable in texture and composition but the vast majority fall into one of the following three groups:

(a) Quartz-sericite schists

(b) Quartz-chlorite schists

(c) Quartz-sericite-chlorite schists.

There are continuous variations between these types and it is often difficult to distinguish the true nature of a particular type during field mapping. Weathered surfaces reveal textures and relict sedimentary and igneous structures but superficial bleaching often makes determination of the mineralogical content difficult. On the other hand, the reverse is true when mapping the quarries and open cuts and in this regard, it is unfortunate that the weathered exposures on the original surfaces were not geologically mapped prior to the commencement of the more recent excavations such as the West Lyell Open Cut.

Quartz-Sericite Schists

These are particularly well exposed in the Blow open cut and on the northern and north-eastern faces of West Lyell Open Cut.

They are typically pale grey and normally weather to a yellowish colour due to breakdown of pyrite. They may appear uniform, with quartz aggregates separated by thin films of sericitic material or they may be inhomogeneous, showing rapid variations in grain size and development of schistosity. Sometimes the grain is coarse and the rock is dominated by individual "augen" of quartz which resemble squashed cylinders in form and are packed together like Turkish cigarettes. The long axis of the cylinders is generally steeply inclined down the schistosity, while the intermediate axis parallels the strike of the schistosity. This structure may be seen in all stages of development and appears to result by the shearing of an originally massive homogeneous rock such as sandstone.

Under the microscope, the quartz sericite schists generally appear as a very fine aggregate of quartz crystals speckled with short sericite (?) fibres in parallel alignment. The average grain size is slightly less than 1/15 m.m. but considerable variations are found from specimen to specimen. Occasional coarser optically simple crystals up to 1 m.m. or so in diameter may occur in this aggregate and often show crystal boundaries. Gregory (1905, p.45) reports similar features from "talcose quartz schist" on the Gormanston-Queenstown road. He describes some ".......much larger quartz grains, some of which appear to have had fairly well preserved crystal outlines, while others have been embayed by the ground mass; and these large quartz phenocrysts remain optically simple, except that some of them have passed into a mosaic on their borders." These embayed euhedral quartz crystals are extremely similar to those found in the acid volcanics of the Dundas Group.

The crystals in the ground mass aggregate are closely interlocking and often the crystal boundaries are sutured, indicating recrystallisation. Some crystals have ragged edges which appear to merge to sericite fibres. Many of the slides of quartz sericite schists are studded with black specks which show yellowish white in reflected light. Gregory (1905) described similar phenomena and thought the mineral was leucoxene, but the writer would suggest limonite as more probable.

In the north-east section of the West Lyell Open Cut, in the Honeypot orebody, the sericitic schist has a characteristic pink tinge that is probably due to very finely divided hematite.

On the northern faces of the open cut the schists are very sericitic and fine-grained. This fine sericite hinders flocculation in the flotation mill and results in poor concentration when present in any quantity. These schists with high micaceous percentage merge to others composed entirely of hydrated aluminium silicates, which will be described later.

It is noticeable that when pyrite is present in any quantity, either with or without copper, that the enclosing rocks are quartzose and sericitic.

Sedimentary features are observed on weathered faces in quartz sericite schists. Thus along Philosophers Ridge south of West Lyell, there are extensive developments of schists showing fine banding very suggestive of stratification. The bands, which are individually less than $\frac{1}{2}$" thick, show up by differential weathering of alternating bands of quartz aggregate of varying grain size. The banding is often crumpled, faulted, and drag-folded in random fashion. It often parallels schistosity and a metamorphic origin might be suspected, but near the open cut it swings across cleavage and it seems fairly certain that it is relict bedding. The cause of the contortion of the stratification is not clear; it could be original but may be due to volume changes consequent on hydration and metamorphism accompanying ore deposition.

In some places the quartz-sericite schists show distinct fragmental textures with outlines of pebbles and boulders, and in others they look like silicified breccias. The majority of exposures, however, are massive and featureless.

As a very general rule, it may be said that sericitic schists are dominant near to the conglomerate contact but away from the contact chlorite schists become more important.

The chemical composition of typical quartz sericite schists is given in Table 6; they are typified by a high silica percentage, and high potash and water contents. The composition of the micaceous material is variable; while most of it appears to be sericite (judging by analyses), many specimens show fairly high soda percentages indicating the presence of paragonite. This has yet to be confirmed by X-ray and spectrographic analysis.

Quartz-Chlorite Schists

These are typically dark grey-green in colour and composed essentially of quartz and chlorite. Quartz occurs as a fine aggregate with sheaths of green chlorite and "dusty" sericite (?). The texture varies from an intimate mixture of quartz and chlorite to one of coarse quartz aggregates enclosed by chlorite aligned along schistosity. These quartz-rich aggregates may be several m.m. in diameter and sometimes give a pebbly appearance on weathered faces. At Comstock, chloritic schists seem to have been derived from quartz porphyries in which the phenocrysts have survived but the ground mass has been chloritised. Some of the quartz aggregates have embayed, irregular borders and include portions of the matrix; they are similar to those in the sericitic schists and the unaltered siliceous Dundas volcanics.

The chlorite is normally pleochroic in green and yellow-brown and shows anomalous interference colours, such as dense Prussian blue or dark brown. Often, however, the chlorite is a nondescript "dirty" green and merges with sericite-like material.

Generally the presence of sulphide minerals has no effect on schistosity and mineralogy and it is apparent that ore deposition followed shearing. However, some slides show recrystallisation of green chlorite to a coarser, colourless mica (like muscovite) in the "shadows" of pyrite grains, suggesting that the pyrite and chlorite were sheared together after pyrite introduction.

Edwards (1954) states that chlorite in a Dundas Group tuff from Great Lyell, shows recrystallisation around a pyrite grain, with the orientation of the new, coarser chlorites bearing no relation to schistosity. This suggests that pyritisation followed shearing.

A feature of some of the quartz chlorite schists is a crude foliation seen in thin sections and developed by segregation of quartz and chlorite into wrinkled microcrystalline bands. This foliation has only been seen in a few thin sections and in these it is more or less horizontal and perpendicular to the steep schistosity.

Chlorite is usually accompanied by sericite and other micaceous minerals, and by decrease of chlorite the schists pass into the intermediate quartz-sericite-chlorite series. Muscovite is often seen in the chlorite sheaves in the quartz chlorite schists.

Similar sedimentary features to those shown by the sericite schists may be seen on weathered faces. For instance, in the south-east benches of the West Lyell Open Cut are lenses up to 20 ft. thick of coarse, "knobbly" chloritic schist showing fragments, shards, and pebbles of lighter coloured materials; the original rock may well have been a pyroclastic or a sedimentary breccia-conglomerate.

Pebble outlines in chloritic schists are well exposed near the Glen Lyell workings south of West Lyell. The pebbles are generally rounded, up to several inches diameter, and show a thin white rim. A possible explanation for the latter feature is that the "pebbles" were originally lava fragments thrown up by volcanic explosions and chilled at their margins during their passage through the air, while the hotter interior cooled more slowly. The white rim therefore reflects an original difference in grain size.

A variety of chloritic schist with low quartz content may be seen in distinct bands several feet thick, alternating with the banded quartz-sericite schists described from south of West Lyell.

The bands are homogeneous, dark green in colour, and composed largely of chlorite; they may be a few inches or up to 100 ft. thick and cut across schistosity.

In thin sections, this rock appears as a schistose "dusty" chloritic schist studded with quartz grains and aggregates generally less than 2/3 m.m. across. There are also vague pale sericitic zones with lath-like form that might well be altered felspar crystals. The chemical analysis (Table 6) shows the basic nature of these "beds" and that they are composed largely of chlorite. Originally, they were probably basic tuffs or even lava flows.

Intermediate Quartz-Sericite-Chlorite Schists

Typical of these intermediate schists is a type mapped as "sericite-fleck" schist; it is a chloritic schist in which rectangular white sericitic flecks show on schistosity faces, elongated in parallel alignment down the dip of the schistosity.

This schist type is well exposed just north of the North Lyell Open Cut, and at several points within the West Lyell Cut. The flecks may form a considerable portion of the rock and appear to be altered felspars. This is confirmed by microscopic study, which here and there reveals faint traces of lamellar twinning in the sericite laths. Altered felspars in schist on the south eastern faces of the West Lyell Open Cut appeared to have a composition of about Ab_{90-95}. Gregory (1905, p.108) reports an altered idiomorphic plagioclase crystal from the South Tharsis (= Royal Tharsis) Mine. An analysis of a typical specimen in which the felspars are completely altered is given in Table 6.

There is no doubt that considerable portions of the Lyell Schists were originally felspathic and were either igneous, or sediments derived from igneous rocks; doubtless much of the sericitic material in the Schists was derived from breakdown of felspars. As will be shown shortly, all stages of the change from unaltered felspars in Dundas Group lavas to the highly altered sericite-fleck schists may be traced in the field and with the microscope. The marginal schists exposed west of the mine area provide the intermediate phase of alteration between true Lyell Schists and the porphyries of the East Queen River.

<u>Other Schist Types</u>

(a) Here and there in the schists are found rock types that are clearly of sedimentary type. A typical example is a grey cleaved siltstone specimen gathered from the western side of the West Lyell Open Cut. Under the microscope the rock is clearly a little altered quartzose shale or shaley siltstone, well bedded and studded with "pebbles" of quartz mosaic up to 2 x 3½ m.m. diameter which disturb the bedding in typical sedimentary fashion.

Again in drill hole West Lyell No. 93, the drill log from 1591 ft. to 1610 ft. runs as follows:

1591' - 1600' :	Grey sheared finely banded siltstone with coarser bands and pebbles, fairly rounded and up to 1" diameter, which have been replaced by yellow siderite and pyrites.
1600' - 1602' :	Blue-grey quartz-sericite and locally quartz-chlorite schist.
1602' - 1605' :	Finely alternating dark and pale grey shaley siltstones with coarser greywacke sandstone in bands up to 2 inches thick. Pebbles locally replaced by siderite.

1605' - 1610' : Grey-brown Owen quartzite.

These siltstones are very similar to the Lynch Siltstones and suggest that at this point Owen Beds rested directly upon Dundas Group rocks. That such a relationship is likely has already been demonstrated in the preceding chapters.

(b) Another variety of "schist" of rather unusual nature is associated with some of the larger orebodies, particularly North Lyell, the Blow, and Comstock. It is soft, rather greasy, translucent, generally pale green but also white or pinky grey. It occurs on the flanks of well defined orebodies (e.g. on the 1850 bench at Comstock) and often between the orebody and the conglomerate contact (e.g. at North Lyell and the Blow). It is also frequently seen in the base of the sericitic schists and in some cases forms a large proportion of the rock. It may be schistose or massive.

This "schist" type is probably monomineralic and earlier workers have given it several names such as batchelorite, delessite, damourite, pyrophyllite, margarodite, etc. The chemical composition is usually simple but varies considerably from specimen to specimen; many that look alike analyse differently. The analyses available are shown in Table 6. Specimens have been forwarded to the C.S.I.R.O. for identification but unfortunately no results are yet available. However, it is obvious that these minerals represent a more or less continuous series of hydrated aluminium silicates passing from the so-called batchelorite with 40-odd percent of silica to minerals with analyses similar to some of the hydro-micas. Many are probably mixtures of minerals.

The similarity of some of the analyses to those of clay minerals such as kaolinite, suggest that here there is some representation of the "argillic" type of alteration described from several areas by Schwartz (1947). He describes the concentration of clay minerals in the zones of most intense rock alteration.

(c) Another "schist" type that is met with in areas of more intense mineralisation is a grey quartzite. It consists simply of recrystallised quartz, is relatively massive, and usually charged with pyrite and perhaps chalcopyrite. This quartzite is probably due to hydrothermal silicification.

MARGINAL SCHISTS

Flanking the main longitudinal ore zone of the Lyell-Owen divide and Comstock, and occupying the less elevated areas, are a series of barren or only lightly mineralised schists that represent the transitional stages between the schists of the mineralised areas and the unaltered Dundas rocks. Due to the softer nature of these "marginal" rocks, surface exposures are poor, but underground workings (and in particular the new West Lyell Tunnel) provide excellent material for examination.

The marginal schists differ from those of the ore zone in having a lower quartz content and generally a higher alkali percentage which is largely soda. They are typically composed of sericitic or chloritic material and are greasy to touch.

While those near the ore zone are variable, mainly light coloured, and contain zones of typical Lyell Schist, those near the unaltered porphyries are generally chloritic and dark in colour.

Typical of this chloritic zone are the schists exposed in the first 500 ft. of the West Lyell Tunnel. The rock is a dense, dark grey-green schist which here and there on weathered surfaces shows clear bedding traces and pebble outlines. Fine calcite blebs are discerned when the rock is broken across schistosity. Thin sections show a "dirty" microcrystalline schist with streaks and stringers of bright green chlorite, specks of hematite and "augen" of calcite, chlorite, and felspar. These augen are elongated along schistosity and represent the initial phases of alteration of felspar to chlorite and calcite. The felspar appears to be albite. This type of alteration is typical of propylitisation of felspars near sulphide deposits.

Gregory (1905) describes similar rocks from Stubbs Valley (near to the flotation mill) and like the author, regards them as transitional stages in the alteration of Dundas rocks. He recognises the felspars as albite.

At 740 ft. from the portal in the West Lyell Tunnel, the schists have a clearly defined fragmental texture, with coarse fragments, shards, and pebbles of igneous and sedimentary rocks arranged in typical grewacke or agglomeratic texture.

Many of the schists (e.g. at 830 ft. from the portal) show porphyritic textures similar to those seen in the volcanics of the Dundas Group and seem to be only slightly altered phases. The felspar phenocrysts are now largely pinkish calcite blebs or white sericitic zones and can only be identified in thin sections.

Another typical marginal schist is pale grey, sericitic, soft and greasy to the touch. It is typified by specimens taken at 1721 ft. from the portal of the West Lyell Tunnel. This is a milky grey soft schist with dark patches of chlorite. Microscopically, it is a "dusty" microcrystalline schistose mass with fine specks (generally less than 1/15 m.m.) of quartz and greenish chloritic zones that could represent altered felspars. Another specimen from 1354 ft. in the same tunnel shows a similar microcrystalline base of sericite (?), chlorite, etc. that is studded with quartz aggregates and chlorite zones up to 3 x 4 m.m. diameter. Some of the chloritic patches have a distinct lath form and are probably chloritised felspars.

Marginal schists south of the Blow mine show pebble outlines and bedding traces very clearly on bleached, weathered surfaces. The bedding is most irregular and locally very crumpled but the folding does not follow any pattern; whether this feature is of primary origin (i.e. slumping etc.); is due to the main folding and faulting; or is related to volume changes consequent on hydrothermal alteration, is not known.

The zone of marginal alteration is often not present or difficult to trace and unaltered material may pass quickly to Lyell Schist types. This is particularly so on the southern end of the mineralised zone, where pyritic quartz sericite schists exposed along the Lyell Highway give way rapidly to finely banded siltstones and pyroclastics exposed in Conglomerate and South Owen Creeks immediately to the south.

The extent of the marginal zone in a particular area is rather suggested by the local topography. Thus in the area just mentioned i.e. the southern end of the ore zone, the marginal zone is narrow and this is reflected in the steep topography; however, east of the Smelters the zone is particularly broad and the ground slopes gently from the Lyell-Owen divide to the Queen River Valley. The steeper slopes below

Cape Horn and the Tharsis Ridge mark another thinning of the marginal alteration zone.

The approximate extent of the marginal zone and the true Lyell Schist zone is given in plan in Fig. 20 and in section in Fig. 22.

The possible presence of an outer fringe of alteration is suggested by the occurrence of kaolinised rocks at a few points in the Queenstown area. There is no question of these occurrences forming a zone around the propylitic phase but kaolinisation may well be a feature of hydrothermal alteration at Lyell and therefore of some importance in suggesting the proximity of sulphide mineralisation. Kaolinisation is best observed east of the Lyell District Hospital where a quartz felspar porphyry has been converted to white and greenish clay carrying quartz grains; similar material occurs near Miners Ridge, east of Lynchford.

From the evidence presented so far it is clear that the majority of the Lyell Schists represent altered Dundas Group rocks, both volcanic and sedimentary. However, detailed studies along the contact of Owen Conglomerate and the Schists indicate that some of the Schists are derived from Jukes Conglomerate and some from the Owen formation.

IGNEOUS ACTIVITY

The possibility of the Lyell Schists being sheared intrusives, as postulated by many earlier workers, has been given due consideration. However, the nature of the schists, their sedimentary textures, and their similarity to the Dundas volcanics is considered sufficient proof of their derivation by alteration of Dundas Group rocks. A major difficulty in assuming extensive intrusion is the "space" problem and the lack of evidence of doming and "pushing aside" of the country rocks.

In the lower levels of the Comstock mine, a quartz felspar porphyry occurs betweem Owen Conglomerate and Lyell Schists. The porphyry is massive, relatively unaltered, and unmineralised,and Edwards (1939) suggests this is a late intrusive. However, it is so similar, both in hand specimen and under the microscope, to typical Dundas acid volcanics that the writer is inclined to think that it is simply a lava that has escaped schisting.

The only proven igneous intrusives are post-ore lamprophyre dykes that may be seen in the West Lyell Open Cut, near the Smelters, and on the Queenstown-Gormanston road. They are up to 6 ft. wide and consist largely of olivine, augite, and biotite, with interstitial felspar.

THE SCHIST-CONGLOMERATE CONTACT

The contact between the schist and conglomerate is particularly intricate and it is not surprising that earlier workers regarded the Schists as intrusive. Conolly, however, found such continuity of structure across his so-called dykes and sills that he was forced to regard the schists as igneous replacements of Owen Conglomerate. It now appears that such continuity of strike and dip from conglomerate to schist can, in a general way, at least, be ascribed to facies changes, though a detailed study of the contact reveals anomalies that the writer feels can only be explained by assuming some hydrothermal chemical replacement of Owen Conglomerate. The picture is further confused by the squeezing together of incompetent (the Schist) and competent (Owen Conglomerate) material, resulting in a sort of tectonic "fusion" along the contact, such as is often seen in interbedded shales and sandstones, and also causing movement along the contact, this being a pre-determined plane of weakness.

No single theory can explain all the details and account must be taken of each in dealing with particular features of the contact.

This recognition of facies changes at Lyell is a major breakaway from the work of other geologists in the last few years and is more a return to the opinions expressed by some of the workers of the early history of the field.

A thorny problem of the contact is that schists occur adjacent to almost every member of the conglomerate sequence and that structures in the Schists are compatible with those in the Conglomerate. The writer does not agree with Bradley (1954) that palimpest structures in the Schists are continuous with those in the Conglomerate, but certainly they interlock and give a general impression of a unified structural picture.

The explanation for this is found in the sudden thinning of Owen Conglomerate at Lyell. Whereas to the east of West Lyell, drill holes have proved over 2000 ft. of Conglomerate, yet at Queenstown only 10 or 20 ft. lies between the Gordon Limestone and Dundas beds. This is related to the palaeogeography at Lyell in the Tremadocian, when the Dundas Ridge was elevated on the west side of the Lyell Shear and a trough existed to the east in which siliceous material was being deposited. The margin of the Dundas Ridge was fairly sharp and weathering of sediments and volcanics of Dundas age resulted in deposition of a narrow zone of greywacke conglomerates along the shore at the same time as Owen sediments were being deposited to the east.

This picture has been deduced from the regional mapping and already explained in an earlier section of this thesis. The facies changes involved have been illustrated in Fig. 8 (a), and part (b) of this plan is the result of upturning the illustration; the tie-up with the Lyell area is clearly seen when Fig. 8 (b) is compared with a typical E - W section across the Lyell area (see Fig. 21).

That the Owen beds overstepped onto the original Dundas surface in places is indicated by the occurrence of Lynch Siltstone-like beds at the contact in drill hole No. 93, described on p. 101. If the quartz porphyry at Comstock is an unaltered lava, as the writer believes, then a similar relationship is indicated there.

Thus much of the Schist material along the contact zone might be expected to be Jukes Conglomerate. Unfortunately, shearing has obliterated the original nature of most of the Schists but here and there typical Jukes lithologies are seen; for instance, a piece of core from diamond drill hole No. 103, West Lyell, 500 ft. from the contact, is a typical poorly sorted greywacke conglomerate, medium to fine grained, with a varied assortment of angular and subangular fragments now largely chloritised. Again at Comstock, rather massive and weathered "schists" within 30 ft. of the contact show clearly a coarse grained, poorly sorted, conglomeratic texture with pebbles and boulders of porphyry and Precambrian quartzite. The association of Precambrian and Dundas pebbles is clear evidence of the presence of the Jukes Conglomerate, as proved by the regional geological study. Recognition of the nature of the Jukes formation proves the origin of schists containing boulders of grey quartzite up to 1 ft. diameter in a chlorite base. Schists of this type have been found along Philosophers Ridge and west of the Tharsis Ridge.

Detailed mapping in the mine area has proved an unconformity in the Upper Owen beds which reflects movement along the Lyell Shear, west side up. Such movement might be expected to re-elevate or rejuvenate the Dundas Ridge and cause a flood of greywacke conglomerate into the zone of deposition of siliceous beds. Thus Jukes Conglomerate might be found interbedded with Owen Conglomerate.

That such alternations of Dundas-like material and Owen beds do occur has already been proved in an earlier chapter of this thesis and this gives the clue to several otherwise puzzling features of the schist-conglomerate relationship.

Up to 600 ft. from the contact at the Blow and near the Razorback, there occur bands and lenses of red sandstone from a few inches to several feet thick within and often rapidly alternating with typical Lyell Schists. Again, several drill holes near West Lyell (e.g. West Lyell drill hole No. 102) also pass through alternations of sandstone and schist near to the contact. In one case (hole No. 102) the schist contains fragments of the sandstone and altered felspar crystals. On a bigger scale, this interbedding of schist and Owen Conglomerate is seen at North Lyell and is portrayed in the cross-section of Fig. 21.

All these features are readily explained if the schist involved is assumed to be Jukes Conglomerate that has undergone schisting and some chemical alteration. The crumpling of the thinner sandstone beds and also of the sandstone dykes within the schist mentioned on p.56, is most probably related to movement on the schist-sandstone boundaries due to tectonic stresses, or possibly to volume changes taking place in the incompetent beds as a result of hydrothermal alteration.

Thus some of the principal features of the contact can be explained by lithological variations due to unusual palaeogeography in late Cambrian and/or early Ordovician.

However, there are several critical areas and exposures which facies changes cannot be held responsible for, and at which some other mechanism must be brought in.

A particularly interesting area is the Tharsis Ridge, where a mass of Owen Conglomerate is apparently isolated from the main body by schist (see Fig. 19). Actually the Tharsis conglomerate is connected with, and in structural continuity with, the main body as shown in the section of Fig. 21. The boundaries for this section have been accurately established by surface mapping, underground workings of the North Lyell mine, diamond drilling, and the North Lyell Tunnel.

The first point is that at the southern end of the Ridge, a narrow E - W strip of schist intersects the N - S striking conglomerate. The schist marks the position of a cross-cutting E - W fault (the Consols Fault) and cleavage is strongly developed. The writer suggests that such facies changes as would be required to account for the schist in this position are too rapid and most unlikely. There is the possibility that the schist has been forced into the fault zone in similar fashion to "intrusions" of shale into quartzite seen in folded interbedded quartzites and shales. However, to suggest such a process on the scale seen at the Tharsis Ridge, raises the "space" problem met with in discussing igneous intrusions. It is the writer's contention that the conglomerate has been sheared by faulting and converted by hydrothermal agencies to quartz sericite schists. The contact of schist and conglomerate is well exposed at several points on the Comstock and North Lyell roads and shows conglomerate merging to sheared, easily broken material with slivers of greenish schist, to green or white schist with occasional quartz pebbles, to normal sericitic schist. At one point, slightly sheared conglomerate appears isolated in schist.

Again, the conglomerates of the Tharsis Ridge, part Middle and part Lower Owen, show a well defined E - W fault; the displacement is clearly shown by mapping the boundary of the Middle and Lower members and is horizontally about 180 ft. Yet the contact on either side of the Ridge is not displaced and the schist appears to "heal" the fault movement. Facies changes cannot explain this feature and the only reasonable conclusion is that Owen Conglomerate has been replaced.

Replacement of Owen sediments by schist and sulphide ore at North Lyell is clearly indicated by observations in drives and stopes. Connlly's level maps often indicate a confused contact zone with schist merging to conglomerate and conglomerate relics in schist. Several specimens in the Geological Museum show all stages from bornite with siliceous pebble-like patches to Owen Conglomerate partially replaced by bornite. Mr. G. Hudspeth, Mine Superintendent, has described to the writer solid bornite-chalcopyrite faces that, freshly broken, resemble conglomerate in texture.

At Comstock, in the Mullock Quarry, there is a less definite but important pointer to replacement. Thecontact is normally sharp against porphyry apparently along strike, but at one point the Chocolate Sandstone fades imperceptibly to weathered schist showing the sandstone's texture.

Transitions from sheared conglomerate and sandstone to schist near the contact are repeatedly observed in the field and give a marked impression of gradual metasomatism of Owen beds. In hand specimens and under the microscope, slivers of greenish schist may be seen developing near the contact, cutting across bedding and again leaving an impression that these are the initial stages of alteration.

That alteration of Owen beds does take place is also suggested by the occurrence of kaolinised sandstone and quartz sericite schists below the copper clays at the King Lyell and the Blocks mines. The clays represent shales of the Gordon formation that have been altered by ascending hydrothermal solutions, and the associated schists and kaolinised materials are believed to be associated with the production of the clays.

The extent of the replacement of Owen beds is not easy to determine but is obviously limited. The majority of the contact phenomena may be explained by facies changes and in only a few cases is any metamorphism of the Owen proved. The writer envisages a narrow, variable and locally absent zone at the contact in which shearing stress is particularly high. The high stress is probably due to frictional drag concentrated at the junction of competent and incompetent material and related to the overall N - S shearing couple. That movement has taken place along the contact is indicated at several places, e.g. at the Blow mine, the sharp, steep contact has the appearance of a fault and at Comstock, there is clear evidence of faulting along the line of the contact, probably but not definitely of transcurrent type. Movement in schist adjacent to the contact is taken up along cleavage planes and is indicated by steep to vertical rodding and striae; the movement is generally horizontal and parallels the contact or any local important fault lines.

At a recent symposium on the Lyell Schists held in Queenstown, many objections were raised to alteration of the siliceous Owen formation, mainly on chemical grounds. Objections from a chemical point of view are strong but they have to be weighed against the field evidence. Schwartz (1947) states that quartz may be replaced somewhat by sericite and suggestions of sericitisation of quartz have been observed under the microscope in several slides. Again, Pettijohn (1949, p.248) suggests that replacement of quartz by sericite and chlorite takes place on low grade metamorphism of greywackes. Admittedly this is no proof that siliceous sandstones can undergo sericitisation but it does indicate that quartz, usually regarded as very stable, can undergo alteration. Replacement of quartz by felspar is illustrated by several examples in Reynold's paper on the chemical changes leading to granitisation (1946), and Leedal (1952) refers to albitisation of quartz in the Cluanie igneous intrusion. The writer considers it possible that alteration of quartz to sericite in preference to felspar might well take place under conditions of localised stress such as are likely to occur at the contact of schist and conglomerate.

Perrin and Rohbault (1942) describe a rather similar change from conglomerate to schist in the valley of L'Arly, though a careful study of the evidence they present in support of metasomatism of the conglomerate failed to reveal complete proof that the writers were not describing facies changes.

Considerable chemical mobility of elements at Lyell is indicated by the host-rock alteration associated with many of the orebodies, with the production of batchelorite, etc., and also by the distribution of hematite and silica, to be described shortly.

HEMATISATION AT LYELL

Much of the schist contact zone is characterised by the presence of hematite, either disseminated in the conglomerates and sandstones near the contact, or as massive lenses at the contact showing relict sedimentary structures. General dissemination is seen near the Blow and massive hematite bodies occur at the northern end of the Tharsis Ridge and near the North Lyell Open Cut. Detailed mapping has shown that where the Schists occupy the stratigraphical position of the upper Middle Owen Conglomerate, the contact is hematite-rich, but where they replace other horizons there is no sign of hematisation; for instance, there is no hematite at the contact along the west flank of the Tharsis Ridge, where schists are in the Lower Owen Conglomerate position.

As has already been explained when describing the Owen sediments the upper Middle Owen beds at Lyell represent a facies variation in that they are poorly sorted and contain angular fragments. Again in the chapter on the schist-conglomerate contact, the possibility of rejuvenation of the Dundas Ridge at this stage was suggested to explain the schists at this horizon. That the greywacke conglomerates which gave rise to these schists were rich in hematite is very probable, for the unaltered siliceous beds of this horizon are rich in detrital hematite pebbles, presumably derived from the Dundas rocks. It is concluded that the hematite in these beds was expelled during hydrothermal alteration and deposited at or near the conglomerate contact.

It should be mentioned here that Bradley (1954) regards this hematite as of "hypothetical" origin and linked with metasomatism; he regards pebbles of hematite as due to selective replacement of original quartz schist pebbles. His theory for the origin of hematite is based on the following "facts" (p.230):

"1. The pebbles are clean cut.

2. The pebbles are mixed with quartz pebbles over some 50 ft. from contacts, but are most numerous and almost exclusive near the contacts.

3. Pebbles occur to a depth of six inches alongside sericite veins which cut the bedding of normal quartz conglomerate.

4. The contact and hematite pebble zones run vertically through the 1200 ft. of the conglomerates.
5. Despite 4, no hematite pebbles occur elsewhere as bands in the conglomerates."

Examining these "facts" in the light of the more recent work:

1. Away from the contact hematite pebbles are clear cut but near the contact, pebbles and matrix are less easy to separate due to the general hematisation.

2. Hematite pebbles are not exclusive to contacts; on the Tharsis Ridge they are prominent throughout the Middle Owen beds, which are up to 200 ft. from the contact.

3. This has not been verified by detailed mapping.

4. There is no hematisation where beds other than Middle Owen are replaced.

5. The implication here is that there is no detrital hematite, yet it is clear from the regional work that parts of the Cambrian sequence were hematised in the Jukesian movement, particularly along the Lyell Shear. This is proved by hematite pebbles in the Jukes Conglomerate on Mt. Lyell and elsewhere.

With these criticisms and the results of the regional mapping in mind, it seems clear that the contact hematite has been derived by leaching of detrital hematite in the Middle Owen beds during the phase of hydrothermal alteration accompanying ore deposition.

SILICIFICATION AT LYELL

Silicification is widespread in the Lyell mine area and is particularly associated with major orebodies. Masses of buff-coloured chert are developed along the North Lyell fault zone, at North Lyell, and at Comstock, and are a phase of mineralisation. Similarly the formation of the previously mentioned grey quartzite accompanies mineralisation. Such wholesale introduction of silica into the ore zone is typical of many hydrothermal sulphide deposits and doubtless much of the silica is of deep-seated origin. Possibly also some of the quartz masses result from circulation of pre-existing silica as a result of hydrothermal activity, in the same way as the hematite enrichment.

The silicification of the Owen Conglomerate has been already attributed (p.59) to Devonian tectonism and is in no way related to the mineralisation. Proof of this is provided by the fact that the Owen Conglomerate in other areas well away from any mineralisation shows the same grade of silicification. Once again, these views are contradictory to those put forward in Bradley's papers.

DISTRIBUTION OF SCHIST TYPES IN RELATION TO MINERALISATION

As the distribution and nature of the Lyell Schists are closely controlled by the intensity and type of sulphide mineralisation, examination of schist-types in unexplored or unprospected areas can be a useful exploration guide.

Of first importance is the recognition of a mineralised zone containing the true Lyell Schists, and the presence of a flanking lightly mineralised marginal zone in which the original material has undergone propylitic alteration (Fig. 20).

Within the mineralised zone it is possible to sub-divide into sericitic, chloritic, and argillic zones but these are particularly irregular and often difficult to trace. Anomalies are frequent within this grouping; thus sericitic schists are found within the chlorite zone and minor zones of mineralisation with quartz-chlorite and quartz-sericite schists occur in the marginal schists. Such irregularity and vagueness of boundaries appears to be typical of hydrothermal alteration in low-grade copper deposits (Schwartz, 1947).

The marginal zone is interpreted as a "front" of propylitic alteration which precedes the main mineralisation and which is therefore earlier in time that the formation of the true Lyell Schists. As the mineralisation spreads and develops, so the marginal zone is extended and the original marginal schists converted to Lyell Schists. This dynamic concept of alteration is in agreement with views expressed by Sales and Meyer (1948).

Alteration in the marginal zone is controlled by original differences in rock composition and texture and is at a low "grade".

<u>The Lyell Schists</u> are direct indicators of the presence of sulphides, formation of which has been accompanied by hydrothermal alteration.

The schist types of this zone are related to a combination of two factors: (a) the original composition, and (b) the type and intensity of the sulphides. The importance of each factor varies within the ore zone, but generally (b) is dominant.

<u>Sericitic schists</u> are generally associated with high pyrite values, the higher the pyrite the greater the percentage of sericite as a general rule. When the pyrite content is less than about 10% the schists are generally of chloritic or intermediate type. This general observation is shown in Fig. 23, which is a plan of the West Lyell area. It may also be seen in detail at a number of points, e.g. on the 1850 ft. bench in the Comstock quarry, where a 2-3 ft. lode of pyrite following schistosity is flanked by a zone up to 4 or 5 ft. wide of pyritic quartz sericite schist, which in turn is flanked by lightly pyritic dark green chloritic schist.

Copper sulphides are closely associated with pyrite as can be seen from Fig. 23, but the cores of copper and iron mineralisation by no means coincide. The copper values of the Prince Lyell orebody, for instance, extend well into the chloritic and intermediate schists where there is little pyrite. Edwards (1939) has shown that pyrite was the first sulphide to be deposited, and this phase was apparently accompanied by sericitisation. Chalcopyrite forming at a later stage, and probably at a lower temperature, had little influence over the distribution of schist types established in the pyrite phase.

<u>Chloritic and intermediate schists</u> are generally associated with low pyrite and variable copper values and their relationships to the sericitic zones have already been described. The concentration of the bigger orebodies near the contact results in a predominance of sericitic schists near the contact, with an adjoining zone of mainly chloritic schists, which is in turn flanked by the marginal schists (Fig.22).

The zones of most intense rock alteration are closely associated with the richer orebodies such as the Blow, North Lyell, and Comstock. Here, hydrated aluminium silicates are common, generally flanking the orebodies in relatively thin lenses and bands; in the Comstock open cut for instance, the main ore lens on the 1850 bench has an associated band of batchelorite (?) no greater than 20 ft. wide.

Similar minerals also develop along zones of shearing within the mineralised zone at Lyell and they are therefore not always indicators of ore.

These silicates appear to represent the highest degree of rock alteration at Lyell. Another phase of intense rock alteration is the formation of grey quartzites and buff chert associated with ore occurrence.

In summary, it is possible to recognise in the Lyell area a zone of mineralised schists with an outer zone of marginal schists. The mineralised schists, known as the Lyell Schists, may be subdivided into sericitic and chloritic zones, with locally an additional "argillic" zone. Until the minerals developed in the latter zone are properly identified, it is perhaps unwise to refer to the "argillic" zone, but the available information suggests the characteristic minerals of this phase have, at least in part, strong affinities with clay minerals. In any case, the minerals form a characteristic phase of intense rock alteration.

The importance of clay minerals as a result of hydrothermal alteration has been repeatedly emphasised by Schwartz (1947, 1953, 1955) and many others, particularly as a result of work by Lovering (1941) on the tungsten ores of Boulder County, Colorado, and by Peterson, Gilbert, and Quick (1951) at Castle Dome, Arizona.

The zones outlined at Lyell are, in many respects, similar to alteration zones described by other writers working on low grade copper deposits. For example, Schwartz (1953) describes four zones of hydrothermal host-rock alteration at San Manuel, Arizona. They are:-

(a) A zone of intense alteration, with the rock composed mainly of hydrothermal clay minerals, especially kaolinite and alunite.

(b) Similar, but hydromuscovite is more common than kaolinite. The mineralisation is low copper and high pyrite.

(c) A sericitic zone associated with "important" amounts of chalcopyrite and pyrite. This zone is found in most disseminated copper deposits.

(d) A marginal zone involving slight alteration of the monzonite with production of secondary biotite, epidote, zoisite, and chlorite.

Again, Peterson, Gilbert, and Quick (1951) describe three phases of alteration in the Castle Dome copper deposit, viz., a clay alteration zone close to ore, flanked by a propylitic (marginal) phase, both zones being cut by later quartz - sericite alteration.

MINERALOGICAL AND CHEMICAL CHANGES ASSOCIATED WITH HYDROTHERMAL ALTERATION

A considerable amount of information is available on the chemical composition of the Lyell Schists, but discussion of chemical changes is hampered by difficulties in ascertaining the original nature of particular rock types. It has been shown that the lithologies of the Dundas Group vary rapidly both horizontally and vertically and doubtless the variations of schist types in the mine area are to some extent related to this. The proximity of acid and basic volcanics in the Dundas Group, and of basalts and sandstones, results in wide and rapid variations of chemical composition.

A feature that has to be taken into account at Lyell is the concentration of potash-rich, siliceous volcanics and granite along the Lyell Shear, as already described. If such rocks occurred in the Lyell area prior to mineralisation, then schists of similar composition might be expected.

Again, the Jukes Conglomerate is likely to be derived from an extremely variable set of sedimentary and igneous rocks and therefore can be expected to show similar variations in composition in even more detail, varying from pebble to pebble.

Marginal Schists

The schists exposed in the first few hundred feet of the West Lyell Tunnel are clearly derived from volcanics and greywackes that have undergone alteration involving the formation of chlorite, calcite, sericite, and probably paragonite, etc. Felspars of the original soda-rich volcanics may be seen in all stages of alteration to these minerals.

Chemically, hydration is ubiquitous, available analyses showing an increase in percentage of combined water of 2-3%. Iron also appears to have been introduced, both combined in chlorite and also as fine hematite. Whether there has been transference of other material from outside sources is impossible to tell from available information, but it is very likely that localised re-distribution has taken place. Schwartz (1952) suggests that much of the material introduced into the marginal zone is derived from the mineralised areas.

Lyell Schists

Quartz-chlorite schists are more intensely chloritised than the marginal schists, are generally more acid with a quartz content, are coarser in grain, and show few relict structures. The occasional felspar outlines and embayed quartz crystals suggest derivation from volcanics.

Chemically, they have a similar combined water content, tend to be more acid, and have a much lower alkali content with potash and soda in more or less equal amounts. They could well be derived from a volcanic sequence.

Quartz sericite schists are characterised by a high quartz and sericite content. Now if these rocks are derived from original rhyolites or even granites such as typify the Lyell Shear zone further south, then little chemical alteration is required (see Tables 3, 4 and 6) but if they are derived from the soda-rich, acid and basic volcanics, then considerable introduction of potash and probably silica is required. The lack of granitic and other potash-rich rock pebbles in the Jukes Conglomerate near Lyell suggest that no such material was formed in the mine area and was confined to the southern part of the Shear zone.

The relationship between high pyrite content and sericite is so well established that even if the original rocks were in part potash-rich, then considerable movement and re-arrangement of material must have taken place.

Original felspars have been almost entirely obliterated or at least reduced to sericitic material and the original quartz has undergone re-crystallisation along with silica freed by breakdown of felspars.

Considerable alteration must have taken place to produce the hydrated aluminium silicates of the rich orebodies. Alteration must have involved loss of silica and addition of alumina and water in all varieties, and in some, removal or re-arrangement of alkalies.

Expulsion of hematite from the Middle Owen horizon and silicification have already been described and testify to the considerable re-arrangement and introduction of material that accompanied Lyell Shear mineralisation.

Alteration of the Owen Conglomerate formation calls for removal of silica (up to 30% of the original total) and introduction of alumina, alkalies, and water.

HYDROTHERMAL ALTERATION ALONG THE LYELL SHEAR AWAY FROM MT. LYELL

At several points along the Lyell Shear zone there occur Lyell-like schists associated with sulphide mineralisation and it is possible to relate the schist types to the nature of the mineralisation.

The conclusions made at Lyell are borne out by the observations made outside the mine area.

The chief areas of interest, from north to south, are as follows:

Great Lyell - along the South Owen fault zone, a major NW fault showing transcurrent movement, there is a development of chloritic and sericitic schists that are clearly derived from alteration of Dundas Group rocks. Conolly originally described the schists as sheared porphyry that had been intruded along the fault zone, but regional mapping gives conclusive proof as to their true origin.

The schists here are largely marginal type and show relicts of original texture and mineral content. A typical example is a sheared reddish-brown felspar porphyry, the phenocrysts averaging 1 or 2 m.m. diameter. Under the microscope, the felspars, some of which are euhedral, appear to be albite undergoing alteration to sericite, chlorite, and calcite. The carbonation is interesting in that the calcite develops as rhombs in the altered felspars and the rhombs all show parallel orientation. The final stage of alteration is to reniform masses of calcite with rims of iron oxide. Many of the felspars are rounded off to conform with the dominant shearing direction.

The Great Lyell adits expose chloritic schists that resemble pyroclastics or coarse greywackes.

It is interesting to note that an electromagnetic anomaly near the Great Lyell shaft more or less coincides with a development of quartz sericite schists. This indicates pyritic but not necessarily copper mineralisation.

Quartz sericite schists with pyrite may be seen on the northern slopes of Mt. Huxley; they are typical of the pyritic alteration but contain little copper.

The ore host at Jukes Proprietary, on the northern slopes of Mt. Jukes, varies from dark green chloritic schist to dense "felsite". There is only limited development of sericitic schists and the pyrite mineralisation is weak. The granophyric felsite of the Lake Jukes mine is veined by bornite and hematite but the slight degree of silicification is not significant.

The only large development of Lyell Schists away from Lyell is at East Darwin, where chloritic and sericitic schists flank the Owen beds on Conglomerate Spur. Mineralisation consists of rather ill-defined, fairly narrow pyrite zones containing patchy chalcopyrite. The host rocks and mineralisation are a small scale, low grade, version of the West Lyell type of orebodies.

Findon's Show and Hal Jukes are similar to Jukes Proprietary in that weak pyrite and chalcopyrite mineralisation occurs in dark chlorite schists and more or less unaltered dense "felsite" (rhyolite flows and breccias). There is only minor development of sericitic material which is in keeping with the type of mineralisation. The development of chloritic schists from these host rocks must involve introduction of water, iron, and magnesia, and probably loss of silica.

TEMPERATURE OF FORMATION

The study of the temperature of formation of the Lyell Schists requires detailed laboratory work and positive mineral identification, particularly of the fine grained types. Unfortunately the commonest minerals, chlorite and sericite, form over a wide temperature range with changes in acidity, and cannot be used as temperature indicators (see Stringham, 1952). The more useful minerals have not been definitely identified and temperature determination by this method must await further work.

The highest temperature of deposition indicated by the sulphides is 475° C. Edwards (1939) has noted intergrowth textures between chalcopyrite and bornite that resemble those formed experimentally by Schwartz (1931) on heating the two minerals to 475° C. However, some doubt is cast on this figure by Filimonova (1952) who states that her experiments show that similar intergrowths can be produced by heating bornite and pyrite to 240° C. Other lines of evidence, such as bornite-chalcocite intergrowths, show a gradually falling temperature, and no higher than 175° C.

Wall rock temperatures would be considerably lower than that of the ore solutions, and the temperature ~~away~~ fall from the orebodies probably fairly steep. Thus the temperature through most of the Lyell Schists probably never rose higher than a few hundred degrees Centigrade. Pyrite was the earliest sulphide and was probably deposited at the highest temperature, succeeding phases of deposition taking place with falling temperature. The associated sericite may therefore be taken as the highest temperature mineral, schists developed at a later stage, or further from the orebodies, being formed at a temperature several degrees lower.

The few temperature indicators suggest a mesothermal type of ore deposition, using Lindgren's classification (1933). This is confirmed by the Schwartz's observation (1939) that mesothermal alteration almost invariably results in relatively large gains of water and potash while the epi- and hypo-thermal types show small gain or losses of water and potash. Increase in the potash and particularly the water contents are particular features of the Lyell Schists.

SCHISTOSITY

The development of schistosity in the incompetent rocks was a feature of the Tabberabberan Orogeny. The predominant strike in the Lyell Schists lies between 300 and 330° E of N and schistosity generally dips steeply south west. Near the contact, the strike and dip are controlled by the form of the contact and the schists tend to "mould" themselves upon the competent material. Evidence of horizontal movement along schistosity planes is given by lineation running steeply down the dip. The schistosity was developed prior to ore deposition for it exerts a strong control over the strike and dip of many of the orebodies, particularly near West Lyell. Edwards (1939) states that the hydration of the original rocks, and the consequent increase in volume, is the cause of the schistosity at Lyell. Bateman (1954), however, insists that hydrothermal replacement is a volume-for-volume change. From the regional tectonic study it is apparent that the schistosity at Lyell with its dominant NW trend, is merely a feature of the overall stress pattern and is a reflection of high stress along the Lyell Shear rather than localised volume increases.

That conditions of stress were maintained after development of schistosity and ore deposition is indicated by shears and thrusts distorting and offsetting the schistosity. On smaller scale, post-ore shearing may be seen in hand specimen in striated and polished pyrite and chalcopyrite, and occasionally under the microscope by the development of micaceous "tails" in the "shadows" of pyrite cubes in chloritic and sericitic schists.

LATE-STAGE PHENOMENA

Quartz, quartz-chlorite, and quartz-chlorite-siderite-chalcopyrite-albite veins and lenses are common throughout the Lyell and marginal schists. They distort schistosity and are of post-ore deposition, and much of the contained minerals and sulphides are probably "picked up" from surrounding rocks during their "intrusion". Chlorite veins often cause a general chlorite enrichment in the local host rocks and further complicate Lyell Schist distribution.

ORIGIN AND ECONOMIC SIGNIFICANCE OF THE LYELL SCHISTS: A SUMMARY

As a result of reconnaissance and detailed mapping, it has been possible to prove that the Lyell Schists are derived from Dundas Group rocks, the Jukes Conglomerate, and the Owen formation, by hydrothermal alteration accompanying sulphide mineralisation. Proof is provided by elucidation of the history of sedimentation and tectonics in the Lyell area and by study of the nature of the Schists.

The Lyell Schists have been found useful pointers in exploration work in that their occurrence is a result of mineralisation, and different types of schist reflect differing forms of metallisation. Thus in new areas, study of structure and schist type together provide an initial indication of the likelihood of the presence of economic deposits. Application of the detailed work at Lyell to other centres of mineralisation along the Lyell Shear has proved useful and findings have been confirmed by recent exploratory work.

TABLE 2.

	I	IIa	IIb	III	IV
S_1O_2	46.72	47.4	47.6	50.6	45.78
T_1O_2	0.48			0.5	2.63
Al_2O_3	18.25	16.1	17.7	20.3	14.64
Fe_2O_3	2.38	11.9	13.7	10.7	3.16
FeO	7.73	n.dt.	n.dt.	n.dt.	8.73
MnO	0.07	n.dt.	n.dt.	n.dt.	0.20
MgO	7.81	9.5	6.55	4.4	9.39
CaO	7.86	10.0	8.2	6.6	10.74
Na_2O	2.64	2.3	2.0	2.3	2.63
K_2O	1.32	0.2	1.3	1.8	0.95
H_2O+	0.11	(2.5	(1.5	(1.9	(0.76
H_2O-	4.43	(	(	(	(
P_2O_5	n.dt.				
CO_2	-	0.4	0.6	0.4	-
S	-	-	-	-	-
SO_3	-	1.05	1.1	1.0	-
	99.80	101.35	101.25	100.5	99.51

I Porphyritic (augite) basic lava, Lynch Creek, South Queenstown.
Analyst - B. Scott.

IIa, b. Pyroxene lavas from Lynch Creek
Analyst - Mt. Lyell Co.

III Lava near Miners Ridge, east of Lynchford.
Analyst - Mt. Lyell Co.

IV Normal alkali basalt, average of many analyses.
(Nockolds, S.R., Bull. Geol. Soc. Amer. 54. 10. 1954).

TABLE 3

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
SiO_2	56.80	56.2	72.88	70.60	58.08	61.58	58.6	73.44	73.76	61.2	46.4	50.4
TiO_2	0.35	1.0	0.37	0.40	0.42	0.49		0.33	0.12	15.5	22.1	26.0
Al_2O_3	17.11	17.4	13.76	13.31	16.32	16.96	15.7	14.18	11.98			
Fe_2O_3	2.12	3.7	0.89	1.54	2.00	1.75	8.9	1.46	1.14			
FeO	5.26	3.4	3.44	2.36	5.53	2.85	n.dt.	0.55	2.40			
MnO	0.28	0.2	0.02	0.05	0.12		n.dt.	Tr.				
MgO	3.61	2.5	0.94	1.75	3.98	3.67	3.6	0.43	0.76			
CaO	4.20	5.2	0.16	1.68	7.32	6.28	2.8	-	0.32			
Na_2O	4.47	5.0	2.86	4.44	2.16	3.94	5.8	0.16	0.53			
K_2O	2.75	3.6	2.63	2.03	1.30	1.28	1.8	8.05	7.38			
H_2O+	2.58	} 1.3	2.04	1.46	2.74	} 1.30	} 1.0	1.38	} 1.75			
H_2O-	0.04		0.06	0.06	Nil			0.08				
P_2O_5	0.33	0.5	0.09	0.08	0.18		n.dt.	0.10				
CO_2	0.44	-	0.31	0.73	0.38	0.25	0.7	0.38				
S	Nil	-	Tr.	0.07	Nil		n.dt.	Tr.				
Other Consts.									0.34			
Total:	100.37	100.0	100.45	100.56	100.53	100.35	98.9	100.54	100.48			

TABLE 3 Cont'd.

I	Felspar porphyry, Lake Margaret tram line. Analyst: Tasmanian Mines Dept. 1956.
II	Trachyandesite, mean of 19 analyses. Osann - Rosenbusch, Gesleinslehre, 1923, p. 378 as quoted in Tyrell (1930, p.126).
III	Sodi - potassic rhyolite, Comstock tram line. Analyst: Tasmanian Mines Dept. 1956.
IV	Quartz felspar porphyry, West Queen river. Analyst: Tasmanian Mines Dept. 1956.
V	Hornblende andesite, Crown Hill. Analyst: Tasmanian Mines Dept. 1956.
VI	Hornblende andesite, Mount Shasta, California (H.N. Stokes), as quoted in Hatch, Wells, and Wells, 1952, p.271.
VII	Pyroxene-felspar porphyry, near Lynchford. Analyst: Mt. Lyell Co. Assay office, 1954.
VIII	"Felsite" of Intercolonial Spur, near Mt. Jukes. Analyst: Tasmanian Mines Dept. 1956.
IX	Potassic rhyolite, Cwm Caregog, Snowdon. (Anal. R.J.C. Fabry) Q.J.G.S., 1927, p.368
X, XI, XII	Partial analyses of albite basalts, Spero River to High Rocky Point. Analyst: Mt. Lyell Assay Office, 1957.

TABLE 4

	I	II	III
SiO_2	74.96	71.9	76.92
TiO_2	0.13	n.dt.	0.19
Al_2O_3	13.55	14.7	14.07
Fe_2O_3	0.79	3.6	0.43
FeO	0.71	n.dt.	0.64
MnO	0.01	n.dt.	Tr.
MgO	0.48	0.6	0.25
CaO	0.16	0.5	0.16
Na_2O	2.33	1.9	3.24
K_2O	5.57	4.7	2.61
H_2O+	0.86	0.6	1.84
H_2O-	0.16		nil
P_2O_5	0.05	n.dt.	Tr.
CO_2	0.30	0.4	0.06
Total:	100.06	98.9	100.41

I Pink granite, South Darwin. Analyst: Tasmanian Mines Dept., 1956.

II Pink granite, South Darwin. Analyst: Mt. Lyell Co, Assay Office, 1955.

III White granite, South Darwin. Analyst: Tasmanian Mines Dept., 1956.

TABLE 5

The Owen Conglomerate on Mt. Owen

Central part of Owen Spur

Upper Owen:	20 ft.	Alternating shaley sandstone, tubicolar sandstone, and granule conglomerate.
	40 ft.	Fine yellowish conglomerate, hematitic at base, with many pebbles brown iron exide. Matrix rich in alluvial chromite.
	60 ft.	Dark hematitic tubicolar sandstone showing current disturbances.
	250 ft.	Pink, grey or purple thin-bedded sandstones with shale and hematitic bands.
	140 ft.	Grey fine breccia conglomerate with a few quartzite beds.
	110 ft.	Purplish thin-bedded sandstones, red-pink pebbly sandstone and shaley beds.
	100 ft.	Alternating grey quartzite, fine yellowish conglomerate and green-grey shales.
Total:	720 ft.	
Middle Owen:	40 ft.	Yellow, medium grained, thick bedded siliceous conglomerate.
	200 ft.	Red sandstone.
Total:	240 ft.	

TABLE 5 cont'd.

Below Summit of Mt. Owen

Middle Owen:	160 ft.	Red sandstone, cross bedded and with pebble bands, becoming increasingly conglomeratic upwards.
	40 ft.	Dark medium grained conglomerate, mainly yellow siliceous pebbles in hematite matrix.
	50 ft.	Red sandstone.
Total:	250 ft.	
Lower Owen:	340 ft.	Coarse grey siliceous conglomerate with red sandstone beds usually less than 2 ft. thick. Sandstones more frequent upwards. Pebbles are mainly banded quartzite, vein quartz, quartzite, chert, etc.
	40 ft.	Very coarse conglomerate and boulders up to 2 ft. in diameter.
	350 ft.	Yellow-grey coarse siliceous conglomerate with lenticular sandy beds.
	200 ft.	Pink-grey very coarse siliceous conglomerate with thin sandstone beds; pink sandy matrix.
Total:	930 ft.	

TABLE 6

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
SiO_2	67.52	60.44	42.2	51.64	22.12	55.60	49.4	45.04	46.28	46.60	50.0
TiO_2	0.28	0.60	n.dt.	0.56	0.45	0.56		0.07	0.13		
Al_2O_3	11.99	27.01	31.3	17.32	21.35	17.41	45.1	36.68	37.75	39.70	17.6
Fe_2O_3	1.77	0.86	4.3	5.18	4.74	3.07		0.53	0.5		11.4
FeO	6.81	0.26	n.dt.	11.09	32.69	12.28		0.23	0.13		n.dt.
MnO	0.16	Tr.	n.dt.	0.12	1.24	0.34		Tr.	0.05		
MgO	1.22	0.42	0.9	2.56	6.45	2.84		1.91	0.14		4.7
CaO	0.12	0.80	1.0	0.28	nil	nil		0.48	0.12		4.4
Na_2O	0.59	1.51	4.8	1.02	0.14	0.04		4.40	1.36	5.52	6.3
K_2O	2.73	4.35	10.2	2.79	nil	1.95		4.18	6.79	1.87	1.8
H_2O+	1.95	3.98	5.4 (H₂O+ and H₂O- together)	3.90	9.74	5.52	5.6 (H₂O+ and H₂O- together)	4.32	5.64	5.40 (H₂O+ and H₂O- together)	4.2 (H₂O+ and H₂O- together)
H_2O-	0.02	0.26		0.06	0.36	0.14		0.32	0.42		
P_2O_5	0.06	0.05	n.dt.	0.16	Tr.	0.20		0.18	0.30		
CO_2	-	-	n.dt.	3.27	0.28	0.13		nil	nil		
S	-	0.03		0.03	nil			0.04	0.05		
BaO								1.13			
Total:	99.57	100.57	100.1	99.98	99.36	100.08	100.1	99.51	99.66	99.09	100.4

TABLE 6 Cont'd.

I	Pink, rather hematitic sericitic schist, West Lyell. Analyst: Tasmanian Mines Dept., 1956.
II	Very sericitic schist, West Lyell. Analyst: Tasmanian Mines Dept., 1956.
III	Sericite separated from schist during flotation process. Analyst: Mt. Lyell. Co., Assay Office, 1955.
IV	Quartz-chlorite schist, West Lyell. Analyst: Tasmanian Mines Dept., 1956.
V	Chloritic "bed", south of West Lyell Open Cut. Analyst: Tasmanian Mines Dept., 1956.
VI	Sericite-fleck schist, North Lyell. Analyst: Tasmanian Mines Dept., 1956.
VII	So-called batchelorite, North Lyell Mine. Analyst: Mt. Lyell Co. Assay Office, 1905.
VIII	Green "schist", North Lyell Mine. Analyst: Tasmanian Mines Dept., 1956.
IX	Grey-brown "schist", North Lyell Mine. Analyst: Tasmanian Mines Dept., 1956.
X	Pale green "schist", North Lyell Mine. Analyst: Mt. Lyell Co. Assay Office, 1909.
XI	Typical marginal chlorite schist, 50 ft., from portal of West Lyell Tunnel. Analyst: Mt. Lyell Co. Assay Office, 1957.

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