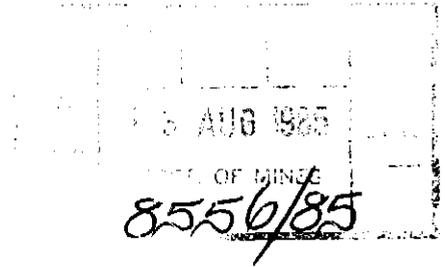


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**GOLD FIELDS EXPLORATION PTY. LIMITED**

Mt Lyell 1985:

an exploration perspective



**G.O. Arnold**  
June, 1985.

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SUMMARY AND CONCLUSIONS

Two phases of mineralization are present in the Lyell field: early volcanogenic Cambrian mineralization, and later (possibly Devonian metamorphogenic) mineralization spatially associated with the earlier phase.

Host rocks of the Lyell mineralization, schistose and altered Mt Read Volcanics, can be subdivided into two main rock types: schist entirely (or with a major component) derived from felsic volcanics, and schist derived from andesitic to basaltic volcanics and dykes. The former tend to be siliceous and sericitic, the latter chloritic, but present assemblages are the result of alteration and metamorphism as well as primary rock type. Early volcanogenic Cambrian mineralization is present as beds and/or boudins of massive pyrite and silica-pyrite, in some cases with or without Cu-Pb-Zn sulphides. This mineralization is hosted exclusively by schist derived from felsic volcanics.

Widespread disseminated and stringer pyrite and chalcopyrite mineralization could be partly Cambrian volcanogenic in origin but much is likely to be the result of the second phase mineralizing event.

Structural development in the Lyell area can be seen initially in the location of a north-south trending depositional hinge-line or basin margin during sedimentation of the Owen Conglomerate. Thrusting of the Mt Read Volcanics over the Owen Conglomerate along this hinge-line followed. Thrusting was accompanied by imbrication and folding of the Mt Read/Owen contact and by large-scale recumbent folding in the Owen Conglomerate. Strong deformation of altered Mt Read Volcanics in the overthrust slab almost certainly accompanied such a deformation. The 'Haulage' unconformity resulted from this thrusting deformation in the early Ordovician.

Subsequent deformation was Devonian in age and included a phase of north-south trending folding ( $D_1$ ) and a phase of northwest trending folding ( $D_2$ ). Syn- $D_2$  fabric modification, during strain and metamorphism, has obliterated many earlier textures. The extent of  $D_1$  deformation in the altered Mt Read Volcanics is uncertain but there is evidence for at least one phase of strong deformation pre-dating  $D_2$ , related either to  $D_1$  and/or the thrusting phase associated with the 'Haulage' unconformity.

The second phase of mineralization pre-dated D<sub>2</sub> but post-dated the 'Haulage' thrusting deformation and subsequent sedimentation of the Pioneer Beds and Gordon Limestone. While not proven, a syn-D<sub>1</sub> metamorphogenic origin seems likely.

The second phase of mineralization is particularly evident along the schist/conglomerate contact. High-grade shoots were deposited where zones of earlier volcanogenic pyritic mineralization are in contact with steep to overhanging (ie east dipping) parts of the schist/conglomerate contact. The schist/conglomerate contact appears to have coincided with a chemical contact, a redox front. Metamorphogenic fluids in the Owen Conglomerate were oxidizing, buffered by primary or diagenetic hematite in the sequence. Metamorphogenic fluids in the Mt Read Volcanics were buffered by pre-existing pyrite, and charged with copper, lead, zinc, gold, silver, and sulphur. Deposition of hematite, silica, and barite took place along zones of mixing on the schist/conglomerate contact, with shoots of high grade base and precious metals adjacent, mostly in the Mt Read Volcanics.

Two kinds of mineralization are of exploration interest in the present economic context. The first is not known with certainty to be present at Lyell in economic tonnages : massive volcanogenic sulphides. However the presence of high grade deposits in other parts of the Mt Read Volcanics and the high grades of Pb-Zn-Cu-Ag at Tasman Crown, albeit in small tonnages, suggests that such mineralization could be present. Low-grade disseminated pyrite-chalcopyrite mineralization may have been a major distraction for earlier exploration directed towards volcanogenic targets at Lyell, and incorrect assumptions of undisturbed stratigraphy a cause of unwarranted discouragement.

The second kind of mineralization of immediate exploration interest is the high grade shoots on the schist/conglomerate contact, as exploited in the North Lyell area and at the Blow.

Exploration at Lyell is at a mature stage and there seems little hope of finding more ore-bodies except by the expensive and difficult measure of drilling for blind targets. Recent sampling has given no great hope for the presence of gold mineralization other than that associated with the two styles of mineralization outlined above. Sub-surface data on drill-hole

locations and geology, and on the location of old workings, are inadequately compiled for an exploration overview. Two attractive areas for further exploration are at depth beneath The Blow and South Lyell ore-bodies, and in the Comstock area.

RECOMMENDATIONS

1. A systematic compilation should be made of drill-hole positions and geology, and the location of old workings. Geological data required are outlined in 3) below.
2. Surface mapping of the kind carried out in this study should be continued to both north and south, extending over all the Mt Read Volcanics affected by feldspar-destructive alteration, and the schist/conglomerate contact bounding them. Geological data required are outlined in 3) below.
3. Geological data of immediate exploration significance at Lyell are:
  - a) zones of primary volcanogenic mineralization, particularly beds and boudins of massive laminated pyrite (+ Cu-Pb-Zn sulphides) and boudins of silica-pyrite;
  - b) position and orientation of the schist/conglomerate contact;
  - c) Alteration along the schist/conglomerate contact, particularly hematite, barite, and silica.
4. Targets of immediate interest are:
  - a) High grade shoots such as those in the Blow and in the North Lyell area. These are expected where zones of volcanogenic mineralization intersect steep to overhanging east dipping sections of the schist/conglomerate contact. Silica-hematite-barite alteration of the conglomerate should be associated.
  - b) High grade massive sulphides. Prediction of the location of such mineralization is difficult if not impossible. The most promising possibilities are at Comstock and the Blow, and any exploration in these areas could lead to encouragement for this target type.
5. Preliminary data suggest two areas of immediate interest:
  - a) The Comstock area, which has all the components of the North Lyell area, but is apparently less intensively explored, and is less understood geologically.

- b) Beneath the Blow and South Lyell orebodies, down-dip on the schist/conglomerate contact, between depths about equivalent to 11 level and 17 level in the present West Lyell development. (This area is located approximately under Philosopher's Ridge, about 200m to 650m below the surface. I am not aware of any previous systematic drilling there. The target is a repeat of the Blow high grade mineralization. Any deep mineralization there could be accessed from existing development. Exploration would be much easier if down-hole E.M. could be used, requiring geophysical work to be done when power transmission in the area is minimized.)

## 1. INTRODUCTION

This report outlines the results of a study begun in February, 1985, after an introductory visit. A total of 8 weeks were subsequently spent on field work at Mt Lyell, over a period of 4 months.

The Mt Lyell mineralization was discovered in 1883 and subsequent geological investigations have occupied many man-years, consequently with distressingly large amounts of geological reporting.

The first major period of geological work can be regarded as extending to the 1960's, culminating in the landmark descriptions of Mt Lyell geology by Wade & Solomon (1958) and Solomons's (1957, 1964) Masters and Ph.D theses. A number of themes emerged in the early work (for example, in that of Conolly, 1940, 1947), which continue to have relevance. The nature of the 'Lyell Schists' hosting the copper ore-bodies, and the nature of their contact to the east with the Owen Conglomerate are problems which provoked a variety of imaginative responses including resort to spectacular fold and thrust-fault geometrical solutions. Majority opinion easily favoured structural control of mineralization (particularly by the schist/conglomerate contact) and an age for the mineralization younger than either the 'Lyell Schists' or the Owen Conglomerate.

Subsequently, models of massive volcanogenic sulphide mineralization gained popularity amongst geologists working on Mt Lyell. Solomon (1967) first argued that the mineralization was part of the deformed and altered volcanic sequence represented by the 'Lyell Schists', and so of Cambrian age. Markham (1968) provided documentation of deformation textures in the ores and possible evidence for primary exhalative sedimentary-type textures in some of the ore-bodies.

The attention of most workers at Lyell then shifted to the volcanics, their stratigraphy, and the relationship of the Lyell ore-bodies to the spectrum of emerging volcanogenic mineralization styles (eg Reid, 1975).

McDonald (1968) produced a very useful study of the West Lyell mineralization, strongly influencing a number of later authors. A substantial body of subsequent work at Mt Lyell was done as postgraduate

research from a number of universities, much by students of Solomon at the University of Tasmania. Notable results of such work were the honours theses of Bryant (1975), (documenting the geology of the North Lyell group of ore-bodies), and Green (1971), (dealing with the Cape Horn to Comstock area); the Ph.D. theses dealing with the geochemistry of Mt Lyell by Hendry (1972) and Walshe (1977); and the Ph.D Thesis of Cox (1979) dealing with structural and microstructural aspects of the field. A feature of this work and follow-up publications has been unqualified support for the massive volcanogenic sulphide model, and increasingly sophisticated particular models for the Mt Lyell mineralization, as exemplified by the recent publications of Hendry (1981) and Walshe & Solomon (1981).

To judge from exploration direction at least, a third phase of Mt Lyell geological investigations has become evident in the last two years. Driven by the unprofitability of low grade disseminated copper mineralisation exploration geologists took particular interest in the high grade ore-bodies in the North Lyell area and rediscovered some of the peculiarities of the schist/conglomerate contact and its apparent control on mineralization. Three geologists in particular were responsible for advocating a revolutionary change to Mt Lyell genetic theories: Bird (1984a, 1984b, 1985), Brook (1984a, 1984b), and Sillitoe (1984, 1985).

Bird, Brook and Sillitoe concluded that mineralization in the Lyell Field is not Cambrian and volcanogenic in origin, but structurally controlled and younger than the Owen Conglomerate. This swing of the pendulum back to earlier ideas contradicts most recent research at Mt Lyell. Exploration decisions now need to be made in an uncomfortable climate of financial and time pressures related to the projected closure of the mine, and of uncertainties related to geological controversy.

The study reported here was optimistically undertaken to help resolve the problem of the timing of mineralization. My colleague, Mel Jones, had already begun a sampling program (mostly of core) to test the possibility of gold-only mineralization in the area. I undertook surface mapping and sampling of the main mineralized zone from Gormanston to North Lyell,

paying particular attention to structures, alteration, and mineralisation. Results of the mapping are shown in Plates 1, 2 and 3. Sample results are tabulated in the appendix; sample localities are indicated in Plate 4.

#### 1.1 Acknowledgements

My thanks are due to the Gold Fields Exploration managers who employed me on such a challenging job and to particular individuals who contributed to this study: to Jeff Beddows who assisted throughout and took most of the samples; to Mike Bird and Mel Jones who introduced me to Lyell geology; to Richard Sillitoe with whom one week was spent in collaborative work; to John Carswell for his advice on West Lyell and help in accessing the Blow open pit; to Steve Cox for comments on Mt Lyell structural geology; and to Emyr Williams for his corrections to my mapping of the Pioneer spur.

## 2. STRATIGRAPHY AND ROCK TYPES

The regional setting of the Lyell Field has been discussed by numerous authors, for example by Wade & Solomon (1958), Corbett et al (1974), Williams et al (1975), and Corbett (1981).

The Mt Read Volcanics are a belt of Middle to Late Cambrian volcanics about 10km wide and 90km long. They host not only the Lyell copper mineralisation but a number of famous volcanic-hosted deposits including Rosebery, Que River, and Hellyer. This volcanic belt occupies a rift-like setting, abutting Precambrian basement to the east and superimposed on or interfingering with Cambrian marine sequences to the west. The Mt Read volcanics comprise mostly subaerial rhyolitic and dacitic volcanics, including rhyolite domes and thick ash-flows, subordinate andesitic and mafic volcanics, and minor intercalations of possibly marine sediments. Just north of the Mt Lyell area, mineralized parts of the Mt Read Volcanics are unconformably overlain by the Tyndall Group of late Middle Cambrian age - tuff, volcanoclastic conglomerate, and intercalated marine sediments. The unconformity is believed to be erosional and without major angular discordance.

The Mt Read Volcanics (including the Tyndall Group) are overlain by the Owen Conglomerate and its correlates, of Late Cambrian to Early Ordovician age. These rocks comprise mostly coarse terrestrial siliciclastics fining upwards to a hematitic red-bed style sequence which becomes marine towards the top. In the Mt Lyell area a graben-like basin was filled by over 1000m of siliceous detritus shed from the Precambrian basement to the east. The contact zone between Mt Read Volcanics and Owen Conglomerate, exposed near the Lyell ore-bodies, is assumed to approximate to the graben-margin of this basin.

An angular unconformity, the 'Haulage' unconformity, is locally present along this contact zone in the Mt Lyell area, separating most of the Owen Conglomerate from a thin overlying sequence of Owen-style siliciclastics - the Pioneer Beds. These in turn are overlain by regionally extensive marine limestones of Ordovician age - The Gordon Limestone

## 2.1 The 'Lyell Schists'

The term 'Lyell Schists' is an old, non-stratigraphic, but useful and evocative term referring to the mineralized belt of Mt Read Volcanics in the Lyell area.

Perhaps the most straightforward description of the 'Lyell Schists' is that contained in Wade & Solomon (1958) and Solomon's (1957, 1964) theses. A point made by this description is that the 'Lyell Schists' contain a few main rock types, severely modified by alteration; these altered rocks make up a very large belt extending from Comstock to south of Philosopher's Ridge; they pass transitionally (through 'marginal schists') into less altered Mt Read Volcanics to the west, south and north.

The area mapped during this study lies entirely within the 'Lyell Schists' as recognized by Wade and Solomon. Cox (1979, 1981), Walshe (1971), and Green (1971) discuss details of the transition into less altered parts of the Mt Read Volcanics; Cox suggests that the alteration contact is partly conformable.

The present mineralogy of the 'Lyell Schists' is the result not only of alteration but also of low greenschist facies metamorphism accompanied by deformation. Most of the 'Lyell Schists' now consists mainly of quartz, chlorite, and sericite, in various proportions. The microtextural study of Cox (1979) indicates that most if not all the micas are metamorphic in origin as is much of the quartz, with quite major fabric modification resulting from solution transfer mechanisms during deformation and metamorphism.

The mineralogy of the 'Lyell Schists', before metamorphism but after alteration, is a matter for conjecture. There has been a tendency to assume that present mineralogy is both metamorphic assemblage and alteration assemblage. Walshe & Solomon (1981) discuss this problem and come to the conclusion that if the temperature of formation of the mineralization and the peak metamorphic temperatures were similar, then phases formed during mineralization should be stable during metamorphism. Such an argument seems doubtful if applied to the entirety

of the 'Lyell Schists'. What can be concluded with reasonable certainty is that the 'Lyell Schists' were subjected to pre-metamorphic alteration which was strongly feldspar-destructive, created abundant clays and/or micas, and strongly depleted sodium contents.

For the identification of major primary rock types, surface textures etched on outcrop by weathering seem to me the most reliable criteria. Proportions of quartz, chlorite, and sericite reflect primary rock types in many cases but almost certainly also reflect variations in hydrothermal activity. In this context the comment of Solomon (1957) seems entirely sensible: "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."

On the basis, then, mostly of surface etched textures and partly of mineralogy, I have identified what appears to be two grossly different rock types throughout the 'Lyell Schists'. In parts of the mapped area, these two rock types have been mapped out; other parts remain unsubdivided usually because incompleteness of exposure and complex intercalation and folding have made mapping-out at 1:5,000 scale a time-consuming task. Results are shown in Plates 1 and 3.

The dominant rock type is schist with siliceous pods and bands of felsic volcanic derivation. In many cases quartz and sericite are the most abundant minerals but in places the matrix can be strongly chloritic. On Philosopher's Ridge where primary textures are often well developed, many of the 'pods' clearly reflect primary fragmental textures; some of the 'bands' there also clearly reflect a primary banding such as flow layering (Fig. 1). In many places, however, the origin of the podded and banded textures is less clear-cut. In particular, multiple deformation has obscured these textures, for example by creating small pods from boudinage of layers.



Fig. 1. Example of a major rock type within the Mt Read Volcanics: schist with siliceous pods and bands of felsic volcanic derivation. Fragmental textures in this case are likely to be volcanoclastic in origin. Banding in the fragments is possibly flow banding. The  $S_2$  schistosity is vertical, subparallel to the short dimension of the frame.

The common presence of quartz phenocrysts, and the characteristic quartz-sericite assemblages, suggest this rock type was derived from altered felsic volcanics, probably a complex of lavas and tuffs. More chloritic varieties may reflect intermixing with mafic volcanics, but at least the abundant siliceous pods and bands are of felsic volcanic derivation.

The other major rock type in the 'Lyell Schists' is chloritic mafic schist. Although much of this rock type is strongly chloritic, it can be strongly silicified or strongly sericitized locally, and the most distinctive feature is a fine, often pocked, surface etch texture without silicious pods and bands (Fig. 2). Coarse fragmental textures are present in places but clasts are mostly of chloritic mafic rock, though occasional siliceous clasts and pebbly layers of siliceous rock of felsic volcanic derivation are also present. A rather subtle primary layering, possibly bedding, is present in a number of places. Flecking by sericite clusters after primary feldspar phenocrysts and by chlorite clusters after primary ferromagnesian phenocrysts is also sometimes evident. Much of the chloritic mafic schist is likely to be lava and volcanoclastics of basaltic to andesitic composition. Some dykes and sills could also be present.

To some extent these rock types have been observed and recorded by numerous workers at Lyell. However, the major difference between my results and those of other workers is the emphasis on texture rather than composition, and the perspective that two grossly different rock types may be identified and mapped throughout the 'Lyell Schists'. Irrespective of local variations within each rock type or the occasional place where differences are indistinct or obscured, most outcrops of the 'Lyell Schists' can be readily identified as belonging to one or the other major rock type; however, this distinction is not so readily achieved underground, or in cuttings, or in core.

Wade & Solomon (1958) and Solomon (1957, 1964) describe the 'Lyell Schists' in quite similar fashion, though the rock types were mapped out in only a few places on the 1 inch to 100 foot maps of Wade and Solomon. Their quartz-sericite schists are mostly schist with siliceous pods and

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Fig.2 Outcrop of chloritic mafic schist, a major rock type within the Mt Read Volcanics. Coarse fragmental textures are possibly volcaniclastic in origin. Clasts are mostly (though not entirely) of chloritic mafic volcanics similar to the matrix, contrasting with the siliceous fragments shown in Fig.1. Surface textures etched by weathering are most diagnostic in distinguishing the two rock types.

bands of felsic volcanic derivation and their quartz-chlorite schists and quartz-sericite-chlorite schists have descriptions similar to the chloritic mafic schist type.

McDonald (1968) had rather more subdivisions of the 'Lyell Schists' in the West Lyell area, but these may be translatable to the two major types described above. McDonald also mapped outcrop on Philosopher's Ridge and arrived at a map pattern very similar to that shown in Plates 1 and 3 for this area. This mapping is figured by Walshe (1971) and shows that the chloritic mafic schist rock type recognized here includes a number of categories recognized by McDonald : fine grained quartz chlorite schists, medium grained quartz chlorite schists, medium grained sericite flecked quartz chlorite schists, and agglomerates of basic composition. Cox (1979) also mapped out similar rock types in the Philosopher's Ridge and Glen Lyell areas. Other workers such as Bryant (1975) distinguished so many units locally within the 'Lyell Schists' that it is difficult to identify the main types.

Not surprisingly there has been some uncertainty about the primary nature of the 'Lyell Schists'. Some of the most specific and well founded identifications are those of Cox (1981) who recognizes volcanic breccias, vitric tuff, spherulitic lava or ash-flow, flow banded lava, and lapilli tuff - probably all variants of the schist with pods and bands of felsic volcanic derivation. Cox suggests that the rock type I have identified as chloritic mafic schist may include vitric-crystal tuff but may also include abundant dykes and sills. I would question his identification of dykes and sills in some specific instances in the Philosopher's Ridge and Glen Lyell area, where pebbly layers have been identified in recent mapping and also on the 1 inch to 100 foot maps of Wade and Solomon.

Finally, another subdivision of the 'Lyell Schists' is shown on Plates 1 and 3 : a zone in the North Lyell area characterized by the presence of large and small boudins ('heads') of silica and silica-pyrite. This zone otherwise comprises the two major rock types identified in other parts of the 'Lyell Schists'. The significance of the siliceous boudins is discussed in more detail in later sections : they could be a combination of alteration and recrystallized primary cherty rocks.



Fig. 3 North face of the Crown 3 open cut showing the zone of Mt Read Volcanics characterized by the presence of large and small boudins of silica-pyrite. The blue-grey mass in the centre of the photograph is one such large boudin. Dark schist to the left and above this 'silica head' is chloritic mafic schist. More smaller 'silica heads' are present to the left of this dark zone, hosted by schist with siliceous pods and bands derived from felsic volcanics.

## 2.2 Owen Conglomerate

The distribution of rock types within the Owen Conglomerate, and their rather intricate contacts with the 'Lyell Schists', are shown in Plates 1 and 3. My recent mapping of these features virtually reproduced the excellent 1 inch to 100 foot mapping of Wade and Solomon. Some of the extrapolation beneath cover shown in Plate 1 was taken from their mapping of areas not then covered by dumps.

Distinctive coarse massive conglomerate is present on the western side of Tharsis Ridge. Poorly sorted clasts range up to boulder size and are mostly siliceous. Some of this conglomerate is shown in Fig. 8.

Interbedded finer conglomerate, quartzite and slate are present on the remainder of Tharsis Ridge, on Razorback Ridge, and on the upper western sides of the Pioneer, Linda, and Whaleback spurs. This unit is more hematitic than the coarse conglomerates, but intensity of red coloration varies widely.

Fine hematitic quartzite and interbedded slate forms the easternmost outcrops of Owen Conglomerate on the Pioneer, Linda, and Whaleback spurs, and east of the North Lyell area. Similar rocks are present on the north end of the Razorback Ridge. An example of these rocks is shown in Fig. 21(a). The pervasive red coloration of these rocks is suggestive of red-beds, with fine dispersed hematite as a primary or early diagenetic feature. As noted by Wade & Solomon (1958) beds of nearly massive hematite are present in one part of the sequence and appear to be a primary feature, generally unlike the massive hematite along the schist/conglomerate contact discussed in more detail below.

Hematitic siliceous conglomerate and sandstone on the slopes of Mt Owen, across the North Lyell Fault, were not looked at in sufficient detail to warrant sub-division in this study.

Because of the structural complications apparent in the area, I have been cautious about assigning to these groupings of rocks any stratigraphic significance. However, it is interesting to note that these have

traditionally been correlated with major stratigraphic subdivisions of the Owen Conglomerate based on what I trust are less disturbed sections. The coarse conglomerate on the western side of Tharsis Ridge has been identified as "Lower Owen Conglomerate"; the interbedded finer conglomerate, quartzite and slate as "Middle Owen Conglomerate"; and the hematitic quartzite and slate as "Upper Owen Conglomerate" (except the small area on Razorback Ridge which has been included in the "Middle Owen Conglomerate") (Wade & Solomon, 1958; Solomon, 1964). Indeed it is possible that the groupings of the Owen Conglomerate described above are in gross west to east sequence as suggested, though it is hardly possible to be certain from this area alone.

### 2.3 Pioneer Beds

A spectacular angular unconformity, the 'Haulage' unconformity, separates the Owen Conglomerate from the Pioneer Beds (Fig. 4). The Pioneer Beds are generally no more than about 10m thick, apparently thickening somewhat and becoming more pebbly to the southwest in comparison to the section figured from Batchelor's Quarry (Fig. 4). Chromite-bearing quartzite and pebbly quartzite are typical, interbedded with shale and some pelitic horizons with similarities to parts of the Gordon Limestone.

In the mill area to the west of the mapped area, the Pioneer Beds rest directly on Mt Read Volcanics. At the eastern ends of the Pioneer, Linda, and Whaleback spurs, the Pioneer Beds appear to be essentially conformable with the Owen Conglomerate. Indeed, away from the Lyell area the Pioneer Beds are not distinct from the main part of the Owen Conglomerate. Thus the disturbance responsible for the 'Haulage' unconformity is associated with a spectacular wedging out of the Owen Conglomerate sequence, and is spatially approximately coincident with the schist/conglomerate contact in the Lyell area. This coincidence can be reasonably assumed to relate to deformation of a graben or basin margin. However, the relative importance of non-deposition versus erosion in the wedging out of the Owen Conglomerate beneath the unconformity is not apparent from the geology of the mapped area.



Fig. 4. Exposure of the 'Haulage' unconformity in Batchelor's Quarry. Beneath the angular unconformity is hematitic sandstone and slate of the Owen Conglomerate. A full section of the Pioneer Beds is exposed above the unconformity comprising mostly quartzite and shale. On the far right of the frame, dark 'pug' derived from Gordon Limestone overlies the Pioneer Beds. The lowermost bed above the unconformity is a hematitic sandstone, overlain by the prominent greenish pelitic horizon. The green coloration is from chrome and copper staining.

Native copper

Distinction of the Pioneer Beds from the Owen Conglomerate is not always straightforward, particularly in the area between the Whaleback spur and North Lyell. After agonizing over particular outcrops, I concluded that recent interpretations there by Sillitoe (1984) and Bird (1985) showed mistakenly exaggerated thicknesses of Pioneer Beds. For example, the hematite-barite replacement body intersected in the recent North Lyell DDH's 1101 and 1102 is likely to be in the Owen Conglomerate rather than Pioneer Beds as shown by Bird (1985). The distribution of Pioneer Beds shown on Plates 1 and 3 is not identical to that on the 1 inch to 100 foot maps of Wade and Solomon, but very similar.

#### 2.4 Gordon Limestone

Outcrops of Gordon Limestone in the mapped area are mostly of black greasy puggy clay, variably bleached and limonitic in some areas - particularly those with 'copper-clay' mineralisation. These are clearly much modified from Paleozoic precursor limestones, so little can be said of the primary rock type in the mapped area. The processes which modified the limestone to its present condition are referred to in the following section.

#### 2.5 Pleistocene glaciation and an earlier weathering regime

Pre-glacial and glacial surficial processes resulted in some problems of significance to recent exploration at Lyell. These problems were confronted during the joint work with Richard Sillitoe in March, and conclusions were reported by Sillitoe (1985).

Pre-glacial supergene leaching under very low pH conditions has affected the Lyell area. This acid leaching has produced friable, bleached, pale brown to white rocks from 'Lyell Schists' as well as from quartzite and conglomerate of the Owen Conglomerate and Pioneer Beds. Sulphides are removed, micas converted to clay, and silica partially dissolved. Sillitoe suggested that the supergene fluids were of low pH because of the marked lack of limonite : bleached rocks pass transitionally into fresh pyritic rocks without any intermediate zone of Fe oxide precipitation. Glacial erosion completely modified the weathering surface, leaving remnants of the supergene leaching scattered about

amongst outcrop of fresh sulphide-bearing rock on the high ridges; lower outcrops such as near Gormanston are entirely supergene leached. The end result is a pattern of weathered rocks quite unusual in the Australian context but familiar to Sillitoe from parts of the high Andes.

Another unusual effect of this weathering phase is the production of 'black pug' from the Gordon Limestone. The transition from the 'pug' to normal limestone can be seen in the quarry between the town and the mine. Schistosity is generally obliterated and bedding features retained in part, but often brecciated and disturbed. Much of the black pug has abundant fine pyrite; indeed the pug is often apparently more pyritic than the admittedly rare examples of fresh limestone sighted. Much of this fine pyrite may have developed in the supergene environment subsequent to carbonate dissolution, as a response to the high levels of carbonaceous residue in the pug.

A Pleistocene glacier apparently occupied the Linda Valley, at some stage possibly breaching the watershed between North Lyell and Gormanston. Glacier-related sediments include a variety of coarse chaotic deposits, possibly of periglacial and fluvio-glacial origin, as well as varved sediments formed in the lake caused as the glacier receded and blocked the eastern end of the Linda Valley.

Steep-sided deep depositories of glacial sediments have been intersected by drilling at Gormanston and the McDowell area. A number of earlier holes, as well as the recent hole G13, have intersected poorly consolidated glacial sediments at Gormanston. Bird (1985) interpreted them as landslide blocks of volcanics, and volcanic debris, infilling a Paleozoic hydrothermal explosion crater. Prior to this interpretation, attempts had been made to correlate them with Paleozoic rocks (Campbell, 1969). Similarly at the McDowell area, the recent hole G14 seems to have intersected only poorly consolidated colluvium and glacial sediments. Bird (1985) interpreted the McDowell P.A. workings as being present in a slide block, and the lithologies in G14 as representing fill of a Paleozoic explosion crater. The slide block interpretation seems correct but the explosion crater is more probably a steep sided glacial sediment depository. In retrospect, Bird's interpretations correctly confront the

problem and are geometrically sensible; a hydrothermal interpretation seemed the only one possible before identification of the combination of pre-glacial supergene leaching and unexpectedly steep topography beneath glacial sediments in the Linda Valley.

Examination of core from recent drilling of the Gordon Limestone in the North Lyell-Blocks area also prompted some agonizing over the inter-relationship of glacial processes and the 'black pug'. Details of the Blocks drilling are discussed further in the section dealing with copper-clay mineralization. However, in these recent drillholes as well as in many outcrops of the 'black pug' there is evidence of slumping, mixing, and re-sedimentation with the glacial sediments. The picture is further confused by some similarity between the 'black pug' and the Pleistocene varved clays. I have little doubt that most outcrops of black pug are weathered Gordon Limestone but the significance of some particular outcrops is certainly in doubt.

### 3. STRUCTURAL GEOLOGY

#### 3.1 Some previous interpretations

Perhaps the most important structural problem in the Lyell area is the nature of the schist/conglomerate contact.

One of the prevailing interpretations of the schist/conglomerate contact, reproduced for example by Walshe & Solomon (1981), has direct links with some of the more picturesque structural interpretations from the early phase of Mt Lyell geology.

Early workers at Lyell were perplexed by the 'Lyell Schists'; the intricacies of the schist/conglomerate contact and the locally transitional appearance of the schist and conglomerate played a major part in their interpretation of the origin of the schist. Many geologists could see good field evidence for the conglomerate passing along strike into the schist.

Nye et al (1934) and subsequently Conolly (1940, 1947) resolved the problem by assuming that the schist was derived from an intrusive porphyry which possessed the remarkable ability to replace the sediments in-situ without greatly disturbing their structure. Bradley (1954, 1956) advocated a variation on this theme: he envisaged the schist as the result of complete metasomatic replacement of the Owen Conglomerate.

Wade & Solomon (1958), agreeing with a number of other earlier workers, realised that the 'Lyell Schists' were derived from volcanics. They resolved the schist/conglomerate contact problem by assuming that the conglomerate and the volcanics, from which the schist was derived, are partly facies equivalents. They proposed that islands of volcanics remained elevated and shed detritus around their margins as the Owen Conglomerate was deposited. Continuing sedimentation progressively over-stepped and buried the islands. Thus Wade and Solomon's detailed mapping of the schist/ conglomerate contact was done at a time when they were spared the embarrassment of finding a structural explanation for it. By the time Solomon's (1964) thesis was written the theory of facies equivalence was abandoned for one of slumping. He suggested that the present schist/ conglomerate contact represents a steep basin or graben margin, active during sedimentation, with major subaqueous slumping of volcanics into the basin in which the Owen Conglomerate was depositing. Subsequent folding of the slump mass and enclosing sediments produced the complex schist/conglomerate contact. This model has been reiterated in subsequent publications, for example by Walshe & Solomon (1981).

Solomon's interpretation has one important similarity to an earlier structural interpretation documented by Conolly (1947). Conolly interpreted a giant recumbent fold, the 'Razorback Fold', in the area of the schist/conglomerate contact. By implication, the steep dipping conglomerate of the Tharsis and Razorback Ridges continues downwards to a fold hinge, rolls under, then dips gently east. A similar 'roll-under' is indicated for the schist/conglomerate contact in Solomon's interpretation. In this, the schist/conglomerate contact west of the Tharsis and Razorback Ridges represents the Owen Conglomerate basin margin or bottom, locally overturned, dipping down to a 'roll-under', then dipping gently east.

The identification of separate overprinting phases of deformation associated with folding was successfully achieved by Solomon (1964). He identified a local phase of folding responsible for the 'Haulage' unconformity and two subsequent regional deformations of Devonian age. The 'Haulage' folds were related to the major subaqueous slumping of the volcanics, as discussed above. The first phase of Devonian folding (Tabberabberan phase 1,  $TF_1$ ) was identified as responsible for major north-south trending folds, and the second phase of Devonian Folding ( $TF_2$ ) as responsible for NW-SE trending cross-folds and associated faults. Subsequent structural studies in the Lyell area have confirmed Solomon's sequence of deformations. Williams (1978) discussed regional folding in Tasmania and confirmed the presence, regionally, of two such fold phases of Middle Devonian age.

Cox (1979, 1981) recorded the results of a major structural and microstructural study of rocks in the Lyell area. His study greatly added to knowledge of the structure of the Mt Read Volcanics, particularly details of the second Devonian folding deformation. The structure of the Owen Conglomerate and the schist/conglomerate contact received much less attention, however.

Cox (1981) produced an alternative interpretation of the schist/conglomerate contact. He visualized the contact as a steeply dipping reverse fault (the Great Lyell Fault). The North Lyell Corridor and Tharsis Ridge and Trough structures he explained by a series of interfering fault displacements : normal faulting oblique to the Great Lyell Fault, subvertical faulting with a strike subparallel to the Great Lyell Fault, reverse faulting, and finally movement on the North Lyell fault. Because of the scale at which Cox mapped the Lyell area, much of the complexity of the schist/conglomerate contact was overlooked.

Cox recognized the early 'Haulage' deformation and two subsequent phases of Devonian age folding,  $D_1$  and  $D_2$ , equivalent to Solomon's  $TF_1$ , and  $TF_2$ . Following Solomon, he regarded the 'Haulage' deformation as penecontemporaneous.

008

Cox suggested that the first Devonian deformation ( $D_1$ ) produced large-scale upright north trending regional folding, but did not identify outcrop-scale  $D_1$  folding, and found an associated  $S_1$  cleavage developed in only one localized part of the area. The  $D_2$  deformation was recognized as responsible for northwest trending folding as well as the prominent schistosity and lineation within the 'Lyell Schists'. Strain associated with  $D_2$  was found to involve 30% to 60% shortening and subvertical elongation of up to 150%. This syn-metamorphic strain was accompanied by extensive fabric modification, mostly from solution transfer processes.

### 3.2 Structure of the Owen Conglomerate and Pioneer Beds

Three phases of deformation can be identified in the Owen Conglomerate; the first is related to the 'Haulage' unconformity, and the second and third are the Devonian  $D_1$  and  $D_2$  phases of Cox (or the  $TF_1$  and  $TF_2$  of Solomon).

Details of structure within the Owen Conglomerate are shown in Plates 2 and 3. Fig. 5 shows an area southwest of Batchelor's Quarry where evidence for the three phases may be seen.

As shown on Plate 2, the effects of the 'Haulage' deformation are apparent on the Pioneer, Linda and Whaleback spurs. Complete exposures of the hinge zones of 'Haulage' folds are not common but have been observed on the Pioneer spur and in two places in the area southwest of Batchelor's Quarry (Fig. 5). One of these exposures of the hinge of a 'Haulage' fold is shown in Fig. 6. The approximate position of the hinge zones can be traced for about 100m in a number of places (Plate 2).

Where the hinge zones of 'Haulage' folds are directly overlain by the 'Haulage' unconformity on the Pioneer spur (Plate 2), relationships between the folding and the then horizontal surface can be seen. The 'Haulage' folds were (and still are in many cases) recumbent folds, with axial surfaces orientated at low angles (eg  $30^\circ$  to  $40^\circ$ ) to the unconformity surface. These folds have one limb with bedding orientation

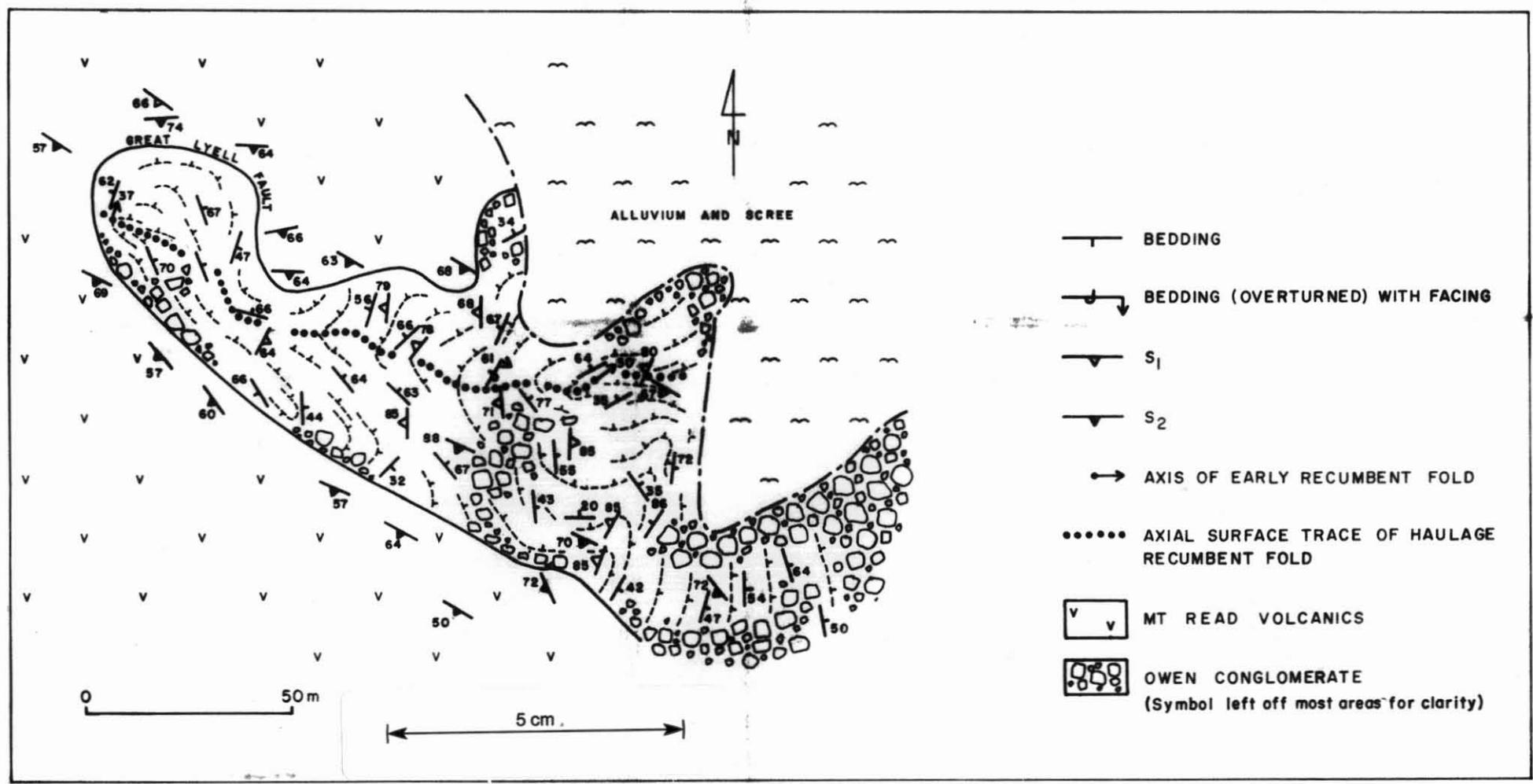


FIGURE 5. FIELD SKETCH MAP: EXPOSURE OF THE SCHIST/CONGLOMERATE CONTACT SOUTHWEST OF BATCHELOR'S QUARRY



Fig. 6. 'Haulage'-age recumbent fold in Owen Conglomerate from locality shown in Fig. 5. Folds of this age were associated with the thrusting which produced the Great Lyell Fault, and are overprinted by two phases of Devonian-age folding.

conformable or near conformable with the unconformity surface and one limb steeply dipping with respect to the unconformity surface. This sharp change in bedding orientation has resulted in prominent nick points on the Pioneer and Linda spurs where the Owen Conglomerate outcrops.

The general pattern of bedding orientations and facing directions resulting from the 'Haulage' folding can be seen from the mapping on the Pioneer spur (Plates 2, 3). There, all facings are to the east. The steep fold limbs mostly dip west and are overturned. The shallow fold limbs dip gently east and are right way up. Near conformity of dips above and below the unconformity is present at the eastern end of all the spurs: the effects of the 'Haulage' folding do seem to be confined to within a few hundred metres of the schist/conglomerate contact. 'Haulage' folding also appears to be present just east of the Blow open cut. Here the folds are associated with facing changes; in all likelihood the 'near-conformable' limb (which dips gently east on the Pioneer spur) has been affected by subsequent folding near the Blow, where it dips and faces westward.

Solomon (1964) investigated and discussed the 'Haulage' folding in some detail. He recognized that this folding affected a north-south strip of rocks along the schist/conglomerate contact. Solomon attempted to reconstruct bedding orientations by unfolding the 'Haulage' unconformity; however, he apparently failed to recognize the pattern of large-scale recumbent folding.

Solomon (1964) explained the 'Haulage' folding as penecontemporaneous, related to slumping of the 'Lyell Schists' into the Owen Conglomerate basin. No support for this theory can be found either from facies in the Owen Conglomerate or from the style of 'Haulage' folding. There are no intraformational slumps or breccias which can be traced along bedding in the Owen Conglomerate. (The hematite-barite breccias in the North Lyell area are discussed in detail in a later section dealing with mineralization and alteration.) There is no coarse talus derived from fallen and slumped volcanics at the base of the Pioneer Beds. The 'Haulage' folding appears to have been a phase of systematic large-scale recumbent folding, confined to a few hundred metres from the schist/conglomerate contact.

A far more likely interpretation of the 'Haulage' folding is that it is associated with reverse or thrust faulting along the schist/conglomerate contact, as shown in Fig. 9.

Devonian  $D_1$  deformation is suspected to have affected the Owen Conglomerate on the Tharsis and Razorback Ridges and on the western edge of the Linda and Whaleback spurs. The deformation was generally weak and because of overprinting by the much stronger  $D_2$  deformation, there is much difficulty and ambiguity in identifying mesoscopic effects. Some suspected  $S_1$  cleavage is shown in Tharsis Ridge on Plates 2 and 3, but  $D_1$  mesoscopic folds, as well as  $S_1$  cleavage, have been identified on the western sides of the Linda and Whaleback spurs.

These  $D_1$  mesoscopic folds are north-south trending with subvertical axial surfaces. In the area southwest of Batchelor's Quarry (Fig. 5),  $D_1$  folds overprint the limbs of a large-scale 'Haulage' fold, and are associated with a subvertical cleavage. This cleavage looks like a slaty cleavage and is sometimes recognizable in finer pelitic horizons; it is orientated about orthogonally to the dominant  $S_2$  cleavage in this area, so there is little chance of confusion between the two.

Further east from these exposures of  $D_1$  mesoscopic folds, the effects of  $D_1$  deformation seem to be virtually non-existent at outcrop scale. The 'Haulage' unconformity and Pioneer Beds are little affected by  $D_1$  folding, except perhaps for possible open folding on the north side of Linda spur, and east of Lyell Tharsis.

Large-scale  $D_2$  folds are the main control on bedding attitudes and rock unit distributions on the spurs plunging towards the Linda Valley. An axial plane cleavage is commonly developed: generally only a spaced cleavage in sandstone and conglomerate, and a slaty cleavage in pelitic horizons (Fig. 21 a). Highly strained pebbles in conglomerate are mostly absent except locally along some parts of the schist/conglomerate contact.



*Fig. 7. The vertical cleavage in this outcrop of Owen Conglomerate is  $S_1$  associated with the first phase of Devonian-age folding.  $S_1$  in this locality (part of the area shown in Fig. 5) is at a high angle to  $S_2$ , the generally dominant schistosity.*

Abundant quartz veins accompanied the  $D_2$  deformation. The syn-tectonic timing of quartz veining is demonstrated by the common presence of fibrous quartz in the veins, orientated (where undeformed) parallel to the extension lineation associated with  $S_2$ . The fibres are the result of progressive growth during incremental extension throughout the deformation (eg Durney & Ramsay, 1973). As noted by Cox (1979), many of the veins have systematic orientations: subhorizontal and in sigmoidal en echelon arrays associated with low-angle reverse faults. Owen Conglomerate on Tharsis Ridge is cross-cut by an abundance of such veins (Fig. 8); quartz veins are also common in many other parts of this unit. I am suspicious that some of the quartz veining on Tharsis Ridge was associated with  $D_1$  as well as  $D_2$ , though most are surely syn- $D_2$ .

Some faulting in the Owen Conglomerate is likely to be syn- $D_2$  as well. The low-angle reverse faults with fibrous en echelon sigmoidal quartz veins, clearly syn- $D_2$ , are rather common but never appear to have major displacements. A series of steep dipping faults trending northwest (parallel to  $S_2$ ) have segmented the outcrop pattern of Owen Conglomerate and overlying units (Plate 2). These are also likely to be syn- $D_2$  as they cannot be traced as discrete surfaces within the 'Lyell Schists' but terminate into zones of high  $D_2$  ductile strain associated with abundant deformed quartz veins.

Rather minor deformation of a fourth phase may also be present in the Lyell area. East of Lyell Tharsis and east of the Blow are two localities where the Owen Conglomerate has been affected by broad, very open folds with subvertical northeast trending axial surfaces.

### 3.3 Structure of the schist/conglomerate contact

Except for the few places where the contact is offset by a straight northwest trending cross-fault, the schist/conglomerate contact in outcrop is a complex irregular surface, albeit with some sections straighter than others, and is overprinted by the  $S_2$  schistosity (Plates 2 & 3). Anomalous  $S_2$  orientations and 'mylonitic looking' schistosity

a)



b)



Fig. 8 Quartz-veined massive conglomerate of the Owen Conglomerate on Tharsis Ridge. a) Near vertical face looking north with  $S_1$  and  $S_2$  trending at a high angle into the face. b) Close-up of part of the same view.

associated with the contact seem to be related to  $D_2$  strain heterogeneities along an irregular interface between rock types of greatly contrasting ductility. Or to restate this another way: the anomalous  $S_2$  orientations appear to be the result of refraction of the  $S_2$  cleavage in schist near irregular shoulders and embayments of the contact with the much more competent Owen Conglomerate.

Some of the irregularities in the schist/conglomerate contact are likely to be the result of  $D_2$  folding and have  $S_2$  situated in an axial plane orientation. Numerous other embayments in the contact pre-date  $S_2$  from the evidence of unchanged vergence between  $S_2$  and the 'limbs' of the embayment : these are likely to be the result of earlier deformation either associated with  $D_1$  or the 'Haulage' event. The intricacies of the schist/conglomerate contact are the result of superimposed multiple deformation.

Although the irregularities and embayments in the schist/conglomerate contact were well known to some of the early geologists at Lyell and were accurately portrayed on the 1 inch to 100 foot maps of Wade and Solomon, they have been ignored or forgotten since. Subsurface data on the contact position has been treated as relating to a straight fault offset by cross-faults. The contact on the eastern side of Tharsis Ridge has been designated the 'Tharsis Fault' and the contact on the eastern side of Razorback Ridge as the 'Razorback Fault'. These contacts are no more obviously faulted than any other part of the schist/conglomerate contact.

The map compiled by Brook (1984) and the maps of Cox (1979) and Sillitoe (1984) all treat the contact as essentially straight segments separated by crossfaults. Many of the crossfaults on these maps are actually folds. Some of these crossfaults figured prominently in the theories of ore genesis proposed by Brook, Bird, and Sillitoe. An example is the 'Blow Cross Fault' which proved, on more detailed examination, to be a fold of the schist/conglomerate contact, as previously shown by the 1 inch to 100 foot mapping of Wade & Solomon. Sillitoe (1985) acknowledged that his previous conclusions regarding crossfaults as localizers of ore at Mt Lyell were ill-founded.

In order to understand the genesis of the schist/conglomerate contact, it is necessary to look carefully at a number of its geometrical aspects.

### 3.3.1 Involvement of $D_1$ and 'Haulage' deformation in contact geometry

Some embayments and protrusions shown in the map pattern of the schist/conglomerate contact have an orientation which is compatible with (though does not prove)  $D_1$  folding. These include the embayment at the north end of Tharsis Ridge and the protrusion at the north end of Razorback Ridge. Both are crosscut by and so pre-date  $S_2$ , and both have a vergence compatible with approximately north-south trending folding about a sub-vertical axial surface. Other embayments and protrusions have a vergence incompatible with  $D_1$  or  $D_2$  and are possibly 'Haulage' deformation effects. These include the embayment on the western side of Razorback Ridge, and the protrusion southwest of Batchelor's Quarry, as shown in Fig. 5. It is difficult to estimate how much the  $D_1$  deformation has affected the schist/conglomerate contact, as most irregularities can be explained by a combination of the 'Haulage' and  $D_2$  deformations. Even though  $D_1$  effects on the Owen Conglomerate are mostly weak to non-existent, they do appear to be strongest near the schist/conglomerate contact and  $D_1$  was probably associated with significant strain effects within the 'Lyell Schists'. I suspect that both  $D_1$  and 'Haulage' folding have affected the contact geometry prior to the  $D_2$  event.

Mining operations and diamond drilling have shown the Tharsis and Razorback Ridges to be connected by a subsurface conglomerate ridge. The gross geometry of the conglomerate contact is west dipping with a large-scale pre- $D_2$  anticline and syncline represented by the Tharsis/Razorback structure and the Tharsis Trough and its southward continuation, respectively. This large-scale anticlinal/synclinal couple could be a  $D_1$  fold or a 'Haulage' fold, but is probably a combination of both. Rather than the simple planar thrust structure illustrated in Fig. 9, which may apply to some parts of the contact, the gross

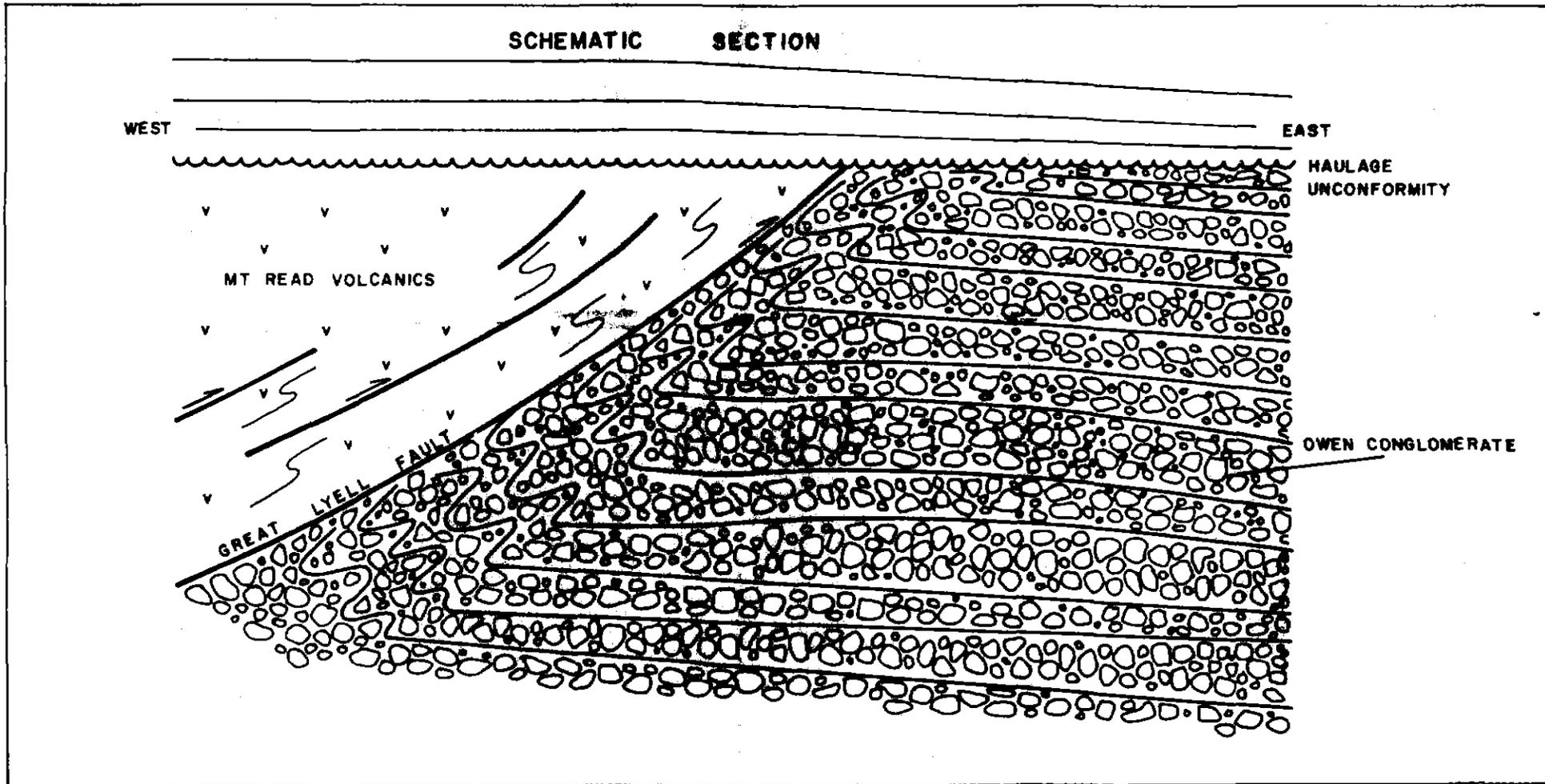


FIGURE 9. OVERTHRUSTING OF MT READ VOLCANICS; PRODUCING LOCALIZED RECUMBENT FOLDING IN OWEN CONGLOMERATE

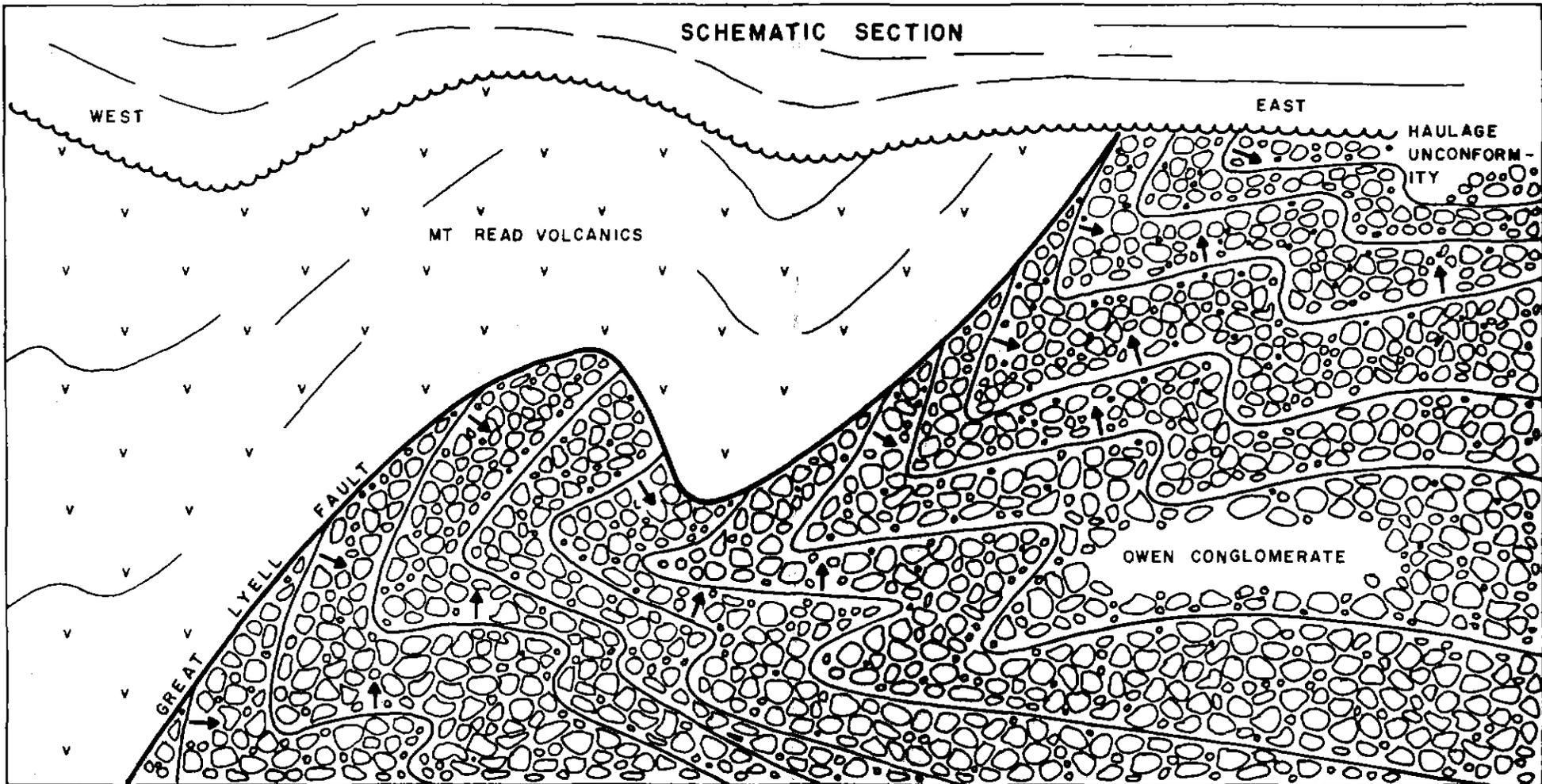


FIGURE 10. FOLDING OF THRUST SURFACE TO PRODUCE THARSIS RIDGE AND TROUGH  
(Arrows emphasize facing)

geometry across (for example) the Tharsis Ridge and Trough structures is illustrated in Fig 10. In this illustration, attention has been paid to the orientation and facing sense of bedding in the large-scale "Haulage" folds in the Owen Conglomerate. It is apparent that the consistently east facing orientation of bedding near the schist/conglomerate contact, even on Tharsis Ridge, is consistent with such a gross structure. Also the apparent sequence from west to east in the Owen Conglomerate, as discussed previously and as recognised by many earlier geologists such as Conolly and Wade & Solomon, may well be the original sequence, somewhat disturbed but still grossly ordered.

### 3.3.2 Abrupt northern truncation of Tharsis Ridge and Trough structures

At the northern end of the Tharsis Ridge, the anticlinal/synclinal couple comes to an abrupt termination. The conglomerate contact falls abruptly to a flattish bottom; recognition of this distinct break in the arrangement of the schist/conglomerate contact in the North Lyell area is implicit in the definition of the North Lyell Corridor, shown in Plate 2. The rather complex three-dimensional geometry of the North Lyell area is illustrated on level plans in Plate 8.

As a possible (though certainly not proven) explanation of the sharp northern termination of the Tharsis Ridge structure, I have proposed in Fig. 11 an explanation related to typical patterns of structures in thrust terrains as (for example) documented by Dahlstrom (1970). There is commonly a close inter-relationship between folds and imbrications of thrusts, apparently more or less contemporaneous in origin. It is common for an anticline to pass along strike into an imbricate thrust, as shown in Fig. 11. It is also common for thrusts to terminate abruptly along strike against transverse tear faults. The transverse tear faults produce sharp corners in plan view, as shown in Fig. 11, and are analogous to the transform faults of sea-floor spreading in that they separate parts of a thrust sheet with different magnitudes of lateral displacement.

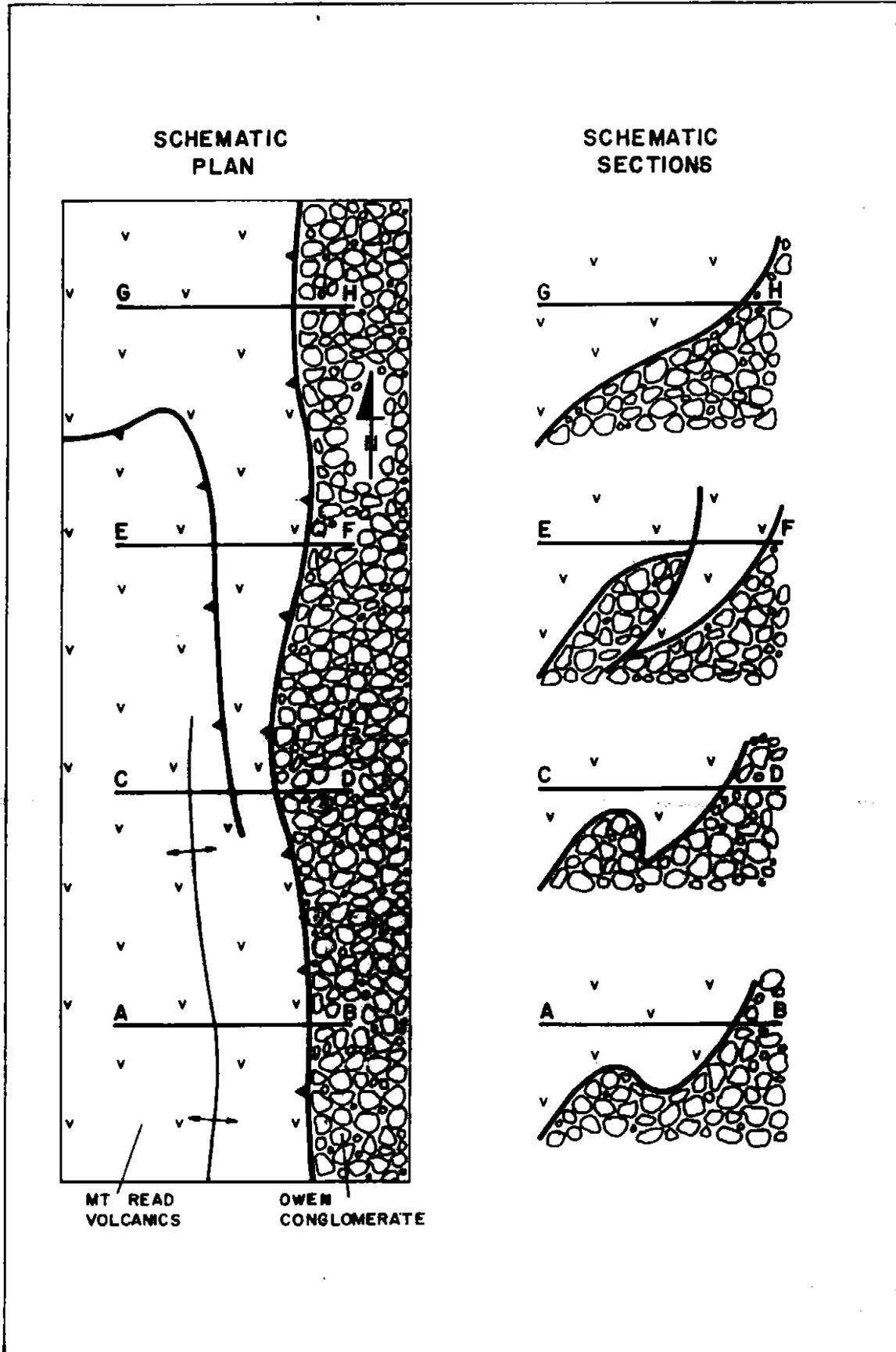


FIGURE II. ILLUSTRATION OF GEOMETRY OF FOLDED IMBRICATED THRUST. THE NORTHERN TERMINATION OF THE THARSIS RIDGE AND TROUGH STRUCTURES MAY HAVE ORIGINATED IN ANALOGOUS FASHION.

### 3.3.3. The schist/conglomerate 'overhangs'

Another puzzling problem of the geometry of the schist/conglomerate contact is that parts of it have 'overhangs'. This is illustrated for example at the Blow. Here the contact is known to be grossly west-dipping (Plate 7) but vergence relationships between  $S_2$  and the contact at the southern end of the open-cut imply that the contact is locally east-dipping (ie overhanging). Other major overhangs have been revealed by mining operations at North Lyell. In these examples, there is a vergence change between  $S_2$  and the different orientations of the contact, so the overhangs pre-dated the  $D_2$  deformation. The  $D_1$  folding is assumed to have sub-vertical axial surfaces and so could hardly be responsible for such overhangs. Indeed the two Devonian deformations should have tended to flatten out any such variations in attitude of the contact across verticality. So what kind of early perturbations of the schist/conglomerate contact do the overhangs represent?

Of several possibilities, perhaps the likeliest is that the overhangs represent segments of the basin or graben margin which originally formed the volcanic/conglomerate contact prior to the 'Haulage' deformation. This proposition is illustrated in Fig. 12 : segments of the pre-existing contact are ideally orientated to form overhangs separated by the more normal westerly dipping sections of the schist/conglomerate contact which are imbricate thrust surfaces.

Such a proposal has another corollary, as illustrated in Fig. 13. Parts of the pre-existing schist/conglomerate contact should become involved in the large-scale 'Haulage' recumbent folds which affect the Owen Conglomerate. Indeed just such geometry seems to be implied by the area shown in Fig. 5, southwest of Batchelor's Quarry. Here, a 'Haulage' recumbent fold forms the hinge zone of a major fold-like protruberance of the schist/conglomerate contact, somewhat modified by subsequent  $D_1$  and  $D_2$  deformation.

The complex geometry of the North Lyell area can be explained by a combination of 'Haulage' folding, imbricate thrusting, transverse tear

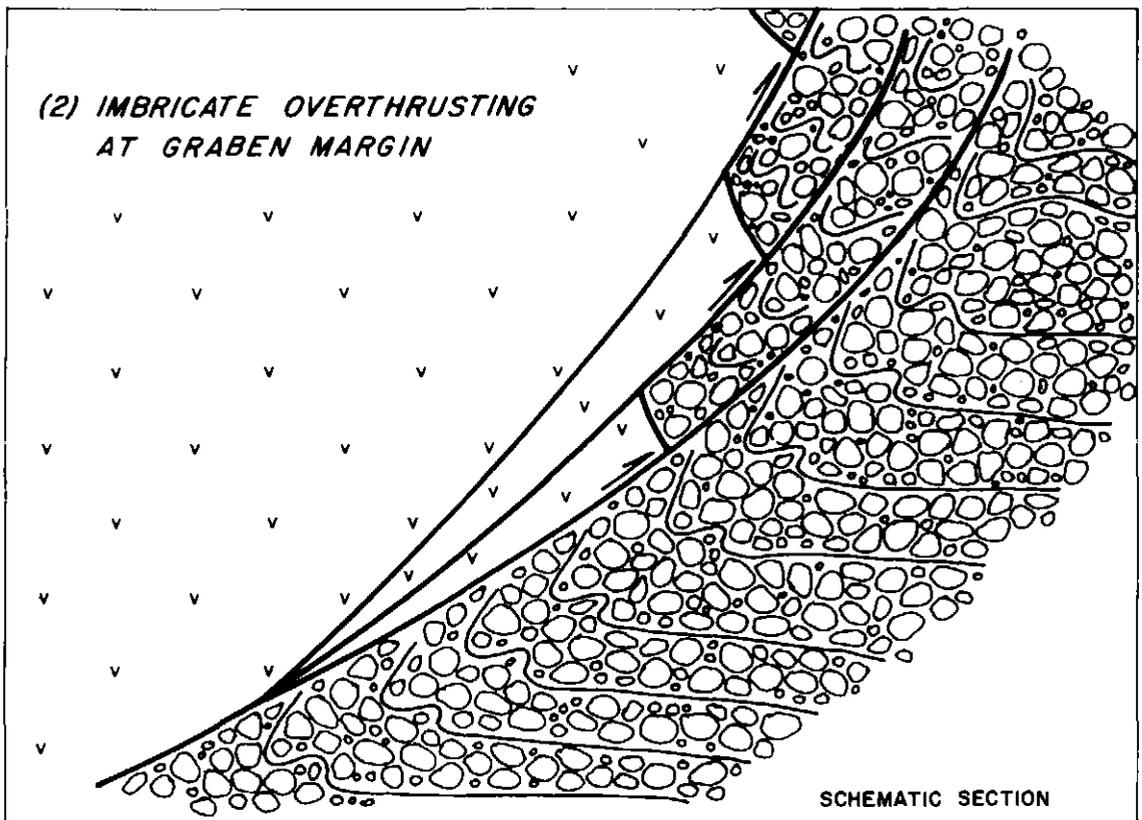
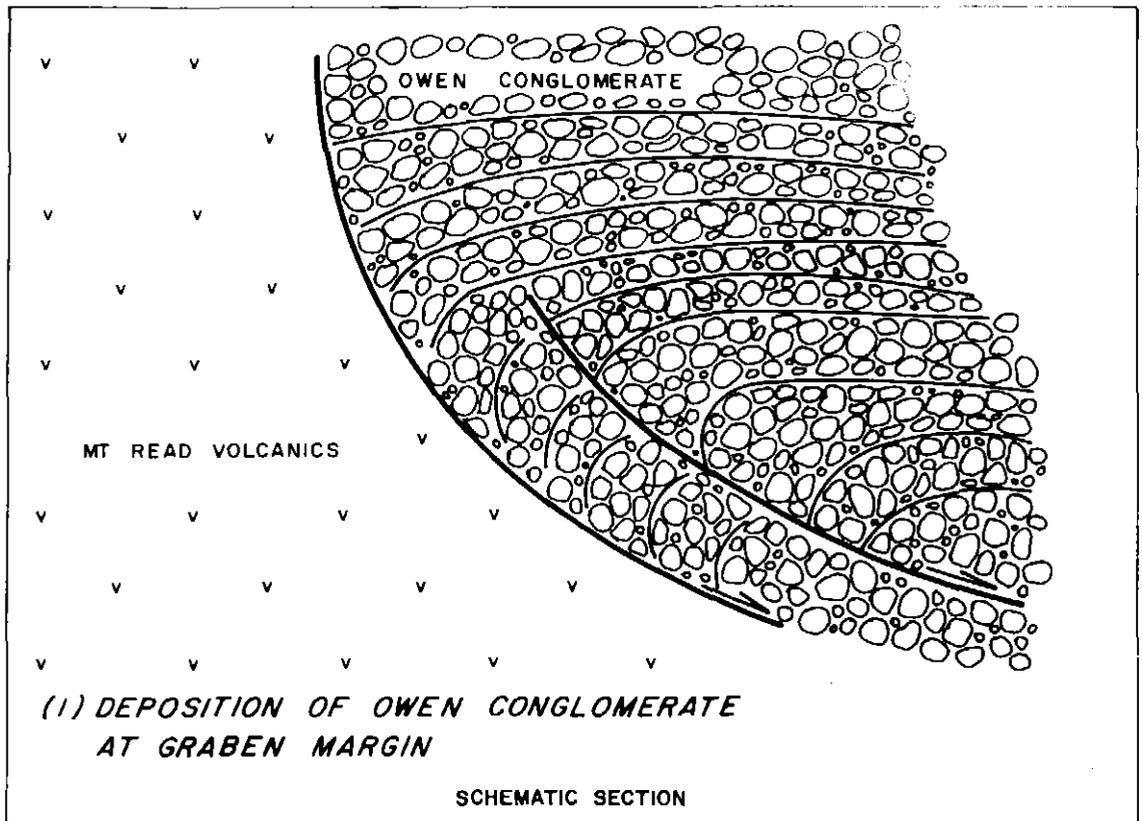


FIGURE 12. ILLUSTRATION OF GRABEN-MARGIN INVOLVED IN IMBRICATE THRUSTING, POTENTIALLY FORMING OVERHANGS OF THE SCHIST/CONGLOMERATE CONTACT.

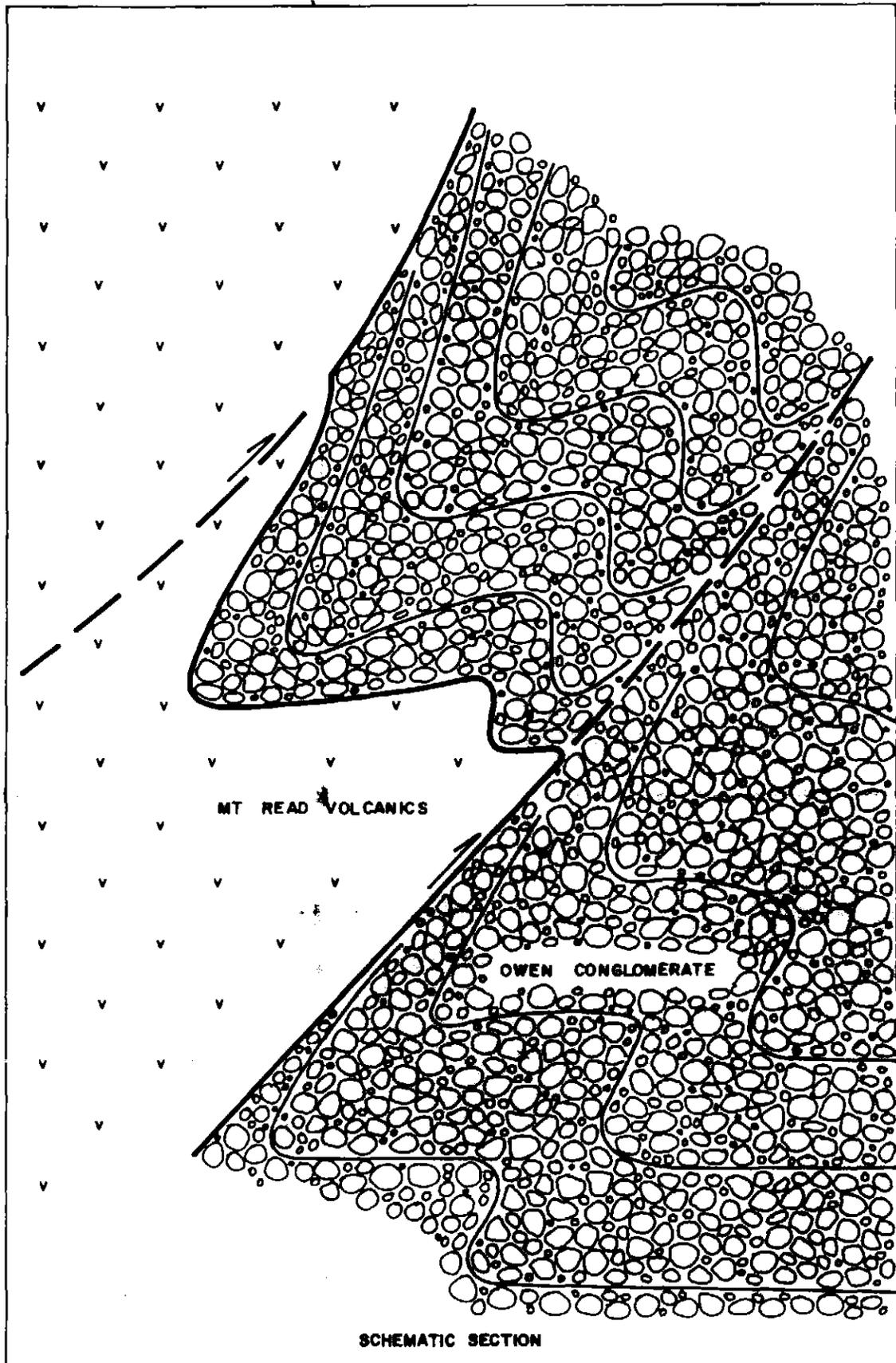


FIGURE 13. ILLUSTRATION OF HOW GRABEN-MARGIN PARTS OF THE SCHIST/CONGLOMERATE CONTACT MAY BE INVOLVED IN RECUMBENT FOLDING CONTEMPORANEOUS WITH OVERTHRUSTING.

faulting, and involvement of segments of pre-existing schist/conglomerate contact. Such an origin is illustrated in Fig. 14. However, it should be emphasized that these proposals are an explanation for the complex three-dimensional geometry of this area, but are not proven.

#### 3.3.4 Sandstone dykes

Another peculiarity of the schist/conglomerate contact is that dykes of sandstone from the Owen Conglomerate have been injected into the 'Lyell Schists' adjacent to the schist/conglomerate contact near the Blow open cut and along the west side of the Razorback Ridge. Dykes of sandstone have also been mobilized within the Owen Conglomerate itself. The sandstone dykes in the volcanics are reasonably explained by injection of sand into adjacent rock fractures under high pore fluid pressures, either penecontemporaneously at the original graben or basin margin, or subsequently during the 'Haulage' thrusting and folding. A 'run' of sandstone dykes is present from the Blow open cut south through the 'Lyell Schists' apparently some distance from the schist/conglomerate contact. This may be an indication of subsurface proximity of a ridge of the schist/conglomerate contact, though there is no outstanding reason why the dykes could not be injected into fractures some distance from the conglomerate, laterally or even downwards as well as upwards. Sillitoe (1984) used the 'run' of sandstone dykes south of the Blow to indicate the presence of a structure he identified as the 'Tharsis Fault'.

#### 3.3.5 Summary comments

The schist/conglomerate contact appears to be mainly a west dipping folded thrust surface, possibly with imbrications separating some segments of the pre-existing contact of the graben or basin margin; some modification has probably occurred in the Devonian D<sub>1</sub> deformation, and some certainly in the Devonian D<sub>2</sub>; the intricacies of the schist/conglomerate contact are the result of superimposed multiple deformation. One major difference between this version and that advocated by Solomon is that no 'roll under' is expected down dip of

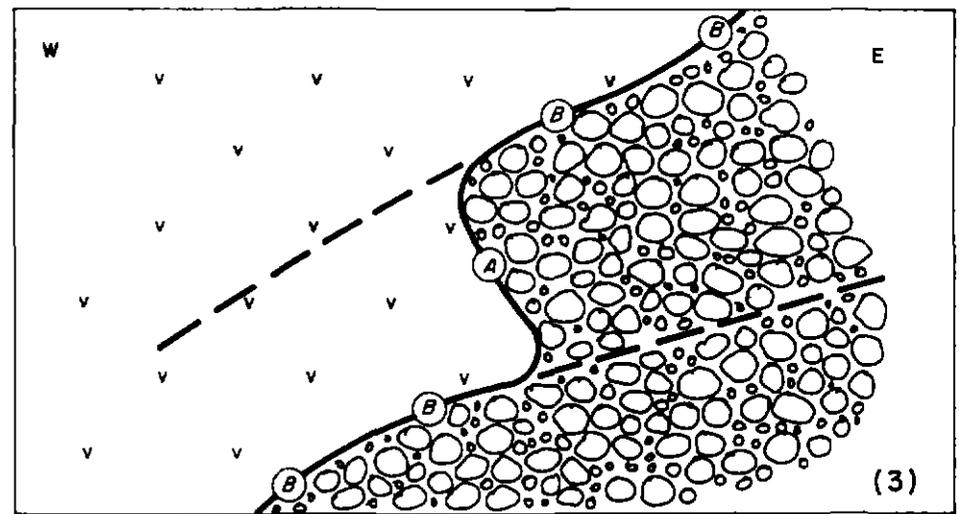
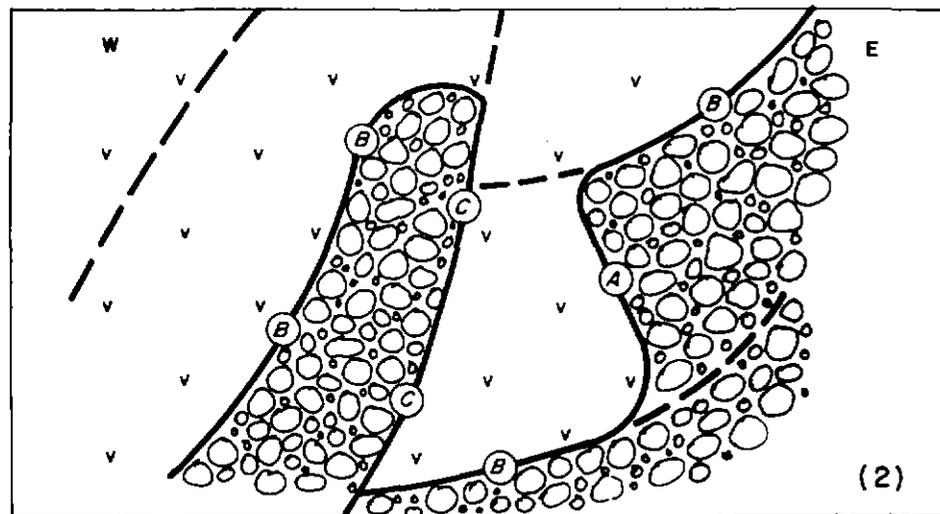
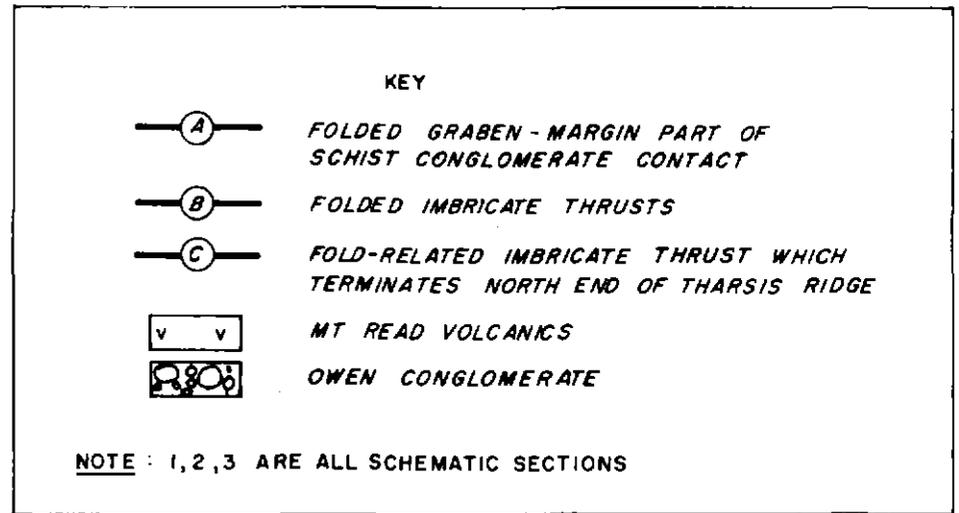
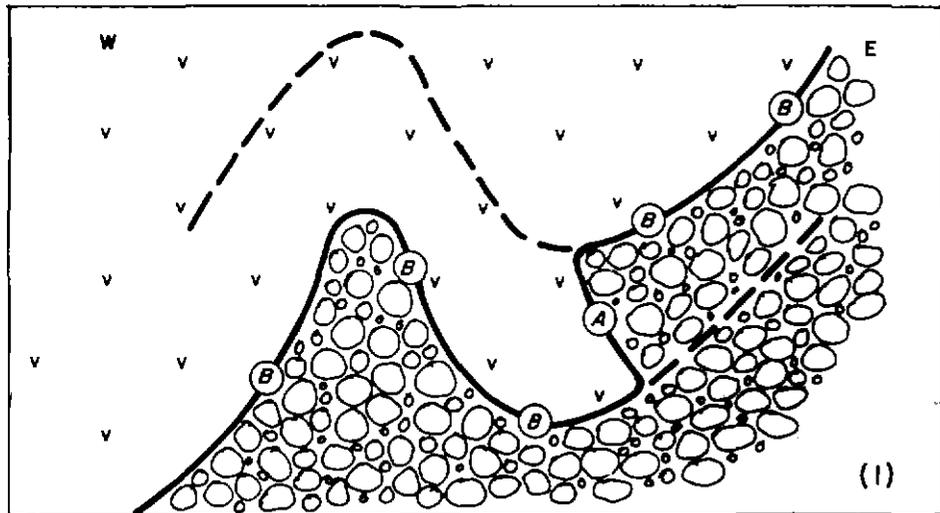


FIGURE 14. POSSIBLE EXPLANATION OF SCHIST CONGLOMERATE CONTACT GEOMETRY IN THE NORTH LYELL AREA (CF PLATE 8)

the schist/conglomerate contact on the western side of the Tharsis/Razorback antiform. Mineralized parts of the 'Lyell Schists' need not directly underlie the Owen Conglomerate of the Tharsis Ridge. Although equivalents of the mineralized parts of Mt Read Volcanics should be represented somewhere in the section below the Owen Conglomerate on Tharsis Ridge, deep exploration for them cannot be recommended.

The entire schist/conglomerate contact (except for the few obvious crossfaults) can reasonably be designated the 'Great Lyell Fault'. Identification of the significance of particular parts of the contact is problematical and the old term introduced by Gregory (1905) serves as well as another.

#### 3.4 Structure of the 'Lyell Schists'

Throughout the 'Lyell Schists', the most apparent structures are strong  $S_2$  schistosity and a steeply dipping extension lineation. Generalized  $S_2$  trends are indicated in Plate 2 : These are mostly subparallel, steep, and northwest trending except for refraction effects near the schist/conglomerate contact and a tendency to dip southwest which becomes particularly pronounced in some northern parts of the mapped area.

Pre- $D_2$  structures are mostly obliterated and the question of the effects of  $D_1$  and 'Haulage' deformations on the 'Lyell Schists' is fraught with problems.

Cox (1979, 1981) took the view that there is little or no  $D_1$  folding or cleavage development in the 'Lyell Schists'. His interpretation is that these rocks are in essentially undisturbed sequence from oldest in the west to youngest in the east. Such an assumption is also implicit in reconstructions of the mine area geology by, for example, Green (1971) and Walshe & Solomon (1981).

The mapping out of primary rock types in the 'Lyell Schists' is of particular significance to this question (Plates 1 and 3). The map patterns which emerged from this mapping suggest that  $D_2$  folds are

superimposed on at least one earlier phase of intense folding. Objections might be raised along the lines that irregular intrusive margins and facies interfingering may be creating pseudo-closures, giving a false impression of an earlier deformation. However, some of the bodies of chloritic mafic schist in question - for example the large body in the Glen Lyell area - contain pebble layers and have contacts which are knife sharp. Such contacts were probably neither intrusive nor facies boundaries but were subhorizontal originally. Given the presence of two earlier deformation phases in the Owen Conglomerate adjacent to the 'Lyell Schists', there is every likelihood that similar or stronger deformation affected the more easily deformable altered volcanics.

I have tentatively identified an  $S_1$  cleavage in a number of parts of the 'Lyell Schists' with weathered surface-etched exposures. Both Steven Cox and Emyr Williams have objected to this identification on the grounds that the apparent rhomboidal intersection pattern could be the result of a single deformation,  $D_2$ . Certainly there is no microtextural evidence for overprinting, such as crenulation cleavage. My suspicion, however, is that the Devonian  $D_1$  deformation was accompanied by widespread hydrothermal effects (discussed in a later section) which may have obliterated deformation fabrics to the extent of largely destroying mica preferred orientations. However, compositional variation related to earlier cleavage may have influenced the subsequent  $D_2$ -related fabric to the extent of an inherited 'ghost' cleavage.

As shown on Plate 2, the interpreted  $S_1$  trends are at a more acute angle to  $S_2$  than are those from the Owen Conglomerate. This may reflect greater  $D_2$  strain in the 'Lyell Schists' related to higher ductility.

There is every likelihood that a large slab of altered volcanics involved in a deformation such as the 'Haulage' thrusting and folding will have suffered more than just decollement on the basal thrust surface. My conclusion is that the story of undisturbed primary sequence is wishful thinking. However it is possible that some form of gross sequence, with repetitions, can survive imbricate thrusting and related folding. The most likely pattern, so far as primary mineralization is concerned, seems to be one of large-scale en echelon repetition of sequence pre-dating the  $D_2$  deformation.

Syn-D<sub>2</sub> faulting and quartz veining in the 'Lyell Schists' are similar to the patterns in the Owen Conglomerate, except that the sharp northwest trending faults tend to be replaced by zones of ductile D<sub>2</sub> strain with abundant deformed syn-D<sub>2</sub> quartz veins.

The chloritic mafic schist tends to form boudins within the more ductile podded and banded felsic schist. Silica and silica-pyrite 'heads' form large and small boudins wrapped about by the S<sub>2</sub> cleavage. Pyritic lenses at the Blow and South Lyell have shapes similarly suggestive of boudins within S<sub>2</sub>.

Carbonate, pyrite, chlorite, chalcopyrite, and hematite are present in syn-D<sub>2</sub> quartz veins but the distribution of these components is closely controlled by host-rock types. Thus chalcopyrite and pyrite in the quartz veins are generally only present in mineralized parts of the 'Lyell Schists'. Galena, bornite, and barite are also present locally in syn-D<sub>2</sub> quartz veins cross-cutting mineralization. Chlorite in quartz veins is particularly prominent in the chloritic mafic schists, and specular hematite in syn-D<sub>2</sub> quartz veins is spectacularly present in the vicinity of massive hematite-barite alteration.

Parts of the 'Lyell Schists' appear to be affected by weak kinking or crenulation with sub-horizontal attitudes. This may be genetically related to the low angle thrusts with sigmoidal en echelon arrays of quartz veins. Quartz veins associated with these thrusts are fibrous and apparently syn-D<sub>2</sub>, but S<sub>2</sub> is bent or kinked near the fault surfaces suggesting much of the movement was post-cleavage.

#### 4. MINERALIZATION AND ALTERATION

##### 4.1 The West Lyell Ore-bodies

Plate 6 summarizes some aspects of the West Lyell mineralization. The 11 level plan and the section are taken from McDonald (1968). On these, an attempt has been made to translate McDonald's rock types into the two-fold subdivision recognized in the surface mapping. The resulting geology is comparable to the picture derived from the surface and bench mapping, except that I would expect the chloritic mafic schists to be more boudinaged parallel to  $S_2$ , to have contacts folded about  $S_2$  axial planes, and to be more discontinuous. McDonald's geology was derived from core logging, which may explain some of the differences. The 14-level plan of the Prince orebody was provided by courtesy of mine geologist John Carswell. Again the geology has been simplified to allow comparison with the surface mapping. Copper mineralization seems to be particularly controlled by schist with pods and bands of felsic volcanic derivation but with an anomalously chloritic matrix. Whether the anomalously chloritic matrix reflects alteration or primary rock type is problematical, but the distribution of the unit seemed worth showing.

One interesting point that emerges from casual inspection of Plate 6 is that zones of greater than 10% pyrite, zones of greater than 1% Cu, and the primary rock types bear some consistent mutual relationships but also display considerable independence. Most copper and pyrite mineralization resides within schist with pods and bands of felsic volcanic derivation. Copper mineralization is grossly associated with abundant pyrite but the association is very loose indeed when examined in detail. Both copper and pyrite zones defined using these particular cutoffs are elongate subparallel to geological contacts (though cutting them in places) and are at an angle to  $S_2$  trends.

Pyrite occurs as disseminations, as stringers and veins, in fine laminated beds with variable proportions of silica (Fig. 15), and as coarsely crystalline masses in segregations and veins associated with quartz (Fig. 16). All are clearly pre- $D_2$ , except the latter coarse grained variety which is syn- $D_2$ . Chalcopyrite occurs as disseminations,



*Fig. 15* Beds of massive pyrite and silica exposed on the face of the open cut south-west of the Royal Tharsis ore-body. Parts of the beds are re-crystallized to coarse pyrite and quartz but remnants are retained of fine laminated cherty silica and pyrite. Enclosing rocks are quartz-sericite schist with variable high proportions of disseminated and banded pyrite.



Fig.16 Coarsely crystalline remobilized pyrite and quartz exposed on the face of the open cut west of the Royal Tharsis ore-body. Pyrite of this variety is interpreted to be syn-D<sub>2</sub>.

stringers and veinlets, and in syn-D<sub>2</sub> quartz veins. Some pre-D<sub>2</sub> micro-structures are preserved in pyrite, but much pyrite and all the chalcopyrite are extensively modified by syn-D<sub>2</sub> deformation, recrystallization, and grain growth (Cox, 1979). Much chalcopyrite has been redeposited in syn-D<sub>2</sub> extensional microfracture sites.

Mapping of the benches on the western and northern end of the open pit indicated that though disseminated pyrite is pervasive through rocks there, beds of laminated pyrite and silica appear to be restricted to two main zones (Plate 1). Recent work on 14-level of the Prince mineralization has identified a disrupted bed of laminated pyrite with some sphalerite (Carswell, pers. comm.) and the approximate distribution of this bed is indicated in Plate 6. Walshe & Solomon (1981) recorded the presence of small, discontinuous lenses of massive magnetite with subordinate apatite, and the presence of possibly equivalent magnetite-apatite rock containing spectacular large fragments of apatite.

Disseminated hematite, magnetite and apatite are distributed through specific parts of the mineralized area hosting the Prince orebody (McDonald, 1968; Walshe & Solomon, 1981; Hendry, 1981). Disseminated magnetite is commonly present in the chloritic mafic schist lenses, and hematite is particularly prominent in upper and eastern parts of the Prince mineralized zone. Barite in veinlets and thin bands with pyrite is also present in parts of the mineralized area.

Hendry (1972) suggested that the geochemistry of the Prince mineralisation indicated a two-phase genesis, with pyrite and magnetite precipitated in the first phase, and chalcopyrite, hematite, and barite in the second. Subsequently, Hendry (1981) has contended that the present assemblages in the Prince body closely reflect an essentially undisturbed primary sequence with early diagenetic/syngenetic alteration formed on or close to the sea floor. Solomon (1976), Walshe (1977) and Walshe & Solomon (1981) prefer an epigenetic hydrothermal origin for the West Lyell and other bodies of disseminated mineralization: formation within a sequence beneath consanguinous exhalites by percolation of fluids laterally within permeable horizons.

Some points of apparent significance:

- a) There are exhalite-like beds of pyrite and magnetite (-apatite) in parts of the mineralized area; Hendry (1981) may well be correct in attributing some variations in assemblages and mineralogy to syngenetic/early diagenetic alteration on or near the sea-floor.
- b) Although there are considerable local mobilization and textural modification in the D<sub>2</sub> deformation and metamorphism, these have probably not grossly changed the distribution of sulphides or of the elements determining silicate assemblages.
- c) The diffuse zones of disseminated and stringer pyrite and chalcopyrite have neither textures nor distributions specific to an exhalite origin but rather the reverse : the epigenetic origin preferred by Walshe and Solomon reflects such a view.
- d) There is a spectre of multiphase mineralization irrespective of the conclusions based on other areas discussed in later parts of this report. Copper distribution does appear to be independent of pyrite distribution in detail. Hendry appears to have substantially modified his views between writing his 1972 thesis and 1981 paper, but continued to doubt that mineralization originated in a single stage event. Walshe & Solomon (1981) assumed single stage mineralization, but noted evidence for a two-stage origin for hematite. Hematite commonly occurs as replacement of magnetite but in some instances is replaced by pyrite. The magnetite has been assumed by them to be of comparable age to the pyrite, and the hematite in part an early phase (where replaced by pyrite) and in part a post-mineralization phase. Such textures could just as well result from late-stage mineralization in which both hematite (and subsequently) pyrite formed.

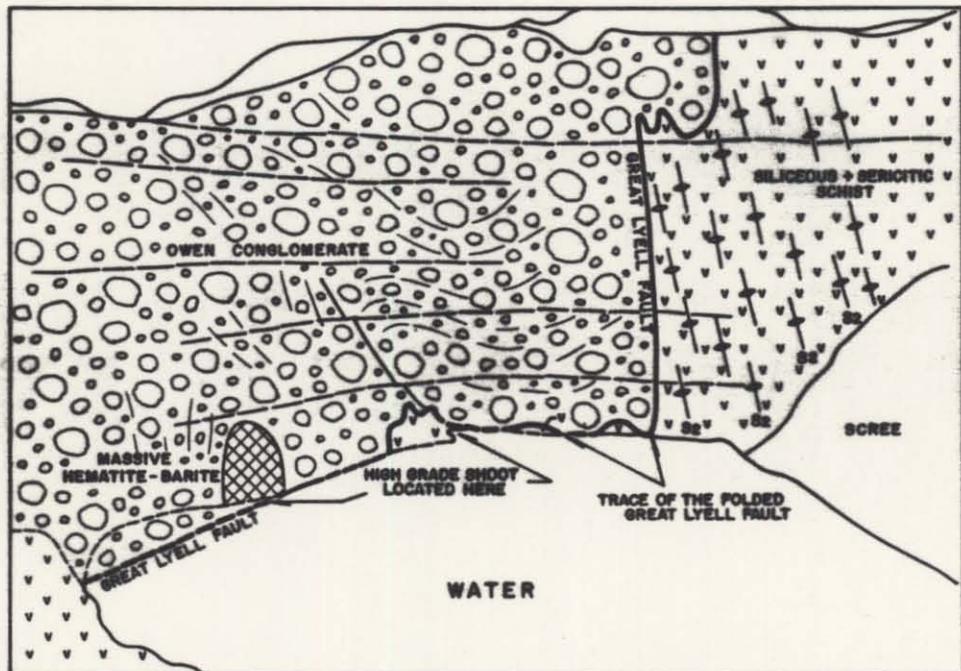
#### 4.2 The Blow and South Lyell ore-bodies

Apart from the brief and largely repetitive descriptions of this mineralization by Wade & Solomon (1958), Solomon (1962), Solomon & Elms (1965), Reid (1975), and Walshe & Solomon (1981), some additional information has been gathered by Bird (1984a,b) from old mine records. Additionally, I was able to access some of the Blow open cut benches, and otherwise inaccessible exposures at water level were examined from a rubber raft. From this work and a series of old level plans (anonymous) held by the mine office, the reconstruction of the Blow geology shown in Plate 7 was compiled.

As shown on the one inch to 100 foot map of Wade and Solomon, the schist/conglomerate contact exposed in the Blow open-pit is folded (Fig. 17) and can be traced round near the present water-level and up the benches. The massive pyrite lens which trends at a low angle into and along the schist/conglomerate contact has largely been removed by mining, though a remnant remains untouched at the north end of the pit (Fig. 18). The  $S_2$  schistosity refracts around the end of this remnant where chaotic intermixing of fine laminated pyrite, schist, and coarsely crystalline pyrite suggest syn- $D_2$  brecciation and local remobilisation.

The massive pyrite lens resembled a large boudin of primary exhalative laminated pyrite wrapped around by the  $S_2$  schistosity. At depth, two similar boudins are present on a separate line of strike (Plate 7, level 8) and are known as the South Lyell 'Main Lens' and 'North Lens'. The South Lyell lenses are so similar to the Blow pyritic lens that all three are likely to be boudinaged parts of the same horizon. The transposition of the South Lyell lenses to a separate line of strike is probably the result of pre- $D_2$  ('Haulage') deformation.

Cox (1979) discussed microtextures of dump samples from the Blow massive pyrite lens. He found mostly fine grained pyrite together with lesser quartz, barite, chalcopyrite, sphalerite, galena, and tetrahedrite. Some fine grained pyrite samples contain relict colloform, rosette, and framboidal microstructures which Cox interpreted as virtually undeformed depositional or diagenetic fabrics. Cox suggested that the framboidal pyrite textures are characteristic of deposits known to have formed at or near the sediment/water interface.



*Fig.17* The Blow open-cut looking south. Much of the area filled by water was originally occupied by a lens of massive pyrite. Hematite-barite alteration and high grade Cu-Au-Ag shoots were located on the folded schist/conglomerate contact - the Great Lyell Fault Vergence of  $S_2$  and the schist/conglomerate contact indicates an overhang on the generally west-dipping Great Lyell fault.



Fig. 18 Part of the Blow massive pyrite lens : a remnant exposed at the north end of the open-pit. Schistosity ( $S_2$ ) deflects around the end of the massive pyrite lens, and marginal breccia containing mixed clasts of pyrite and schist is interpreted as syn- $D_2$ . The end of the lens (a large competent boudin of massive pyrite) has been the site of anomalous syn- $D_2$  strain.

Fine laminated pyrite textures can be seen in remnants of the main lens, and in a narrow boudinaged subparallel bed near the present water level (Fig. 19). These closely resemble the beds of fine laminated pyrite and silica exposed on the benches on the western side of the West Lyell open cut. Some disseminated pyrite surrounds the Blow massive pyrite lens, apparently confined to a narrow envelope (Plate 7). This disseminated pyrite is identical in appearance to that, for example, in the West Lyell area but is notably different in the aspect of its restricted distribution. Although some chalcopyrite is present in the Blow mineralization, much of the copper is in the form of tetrahedrite (or tennantite according to Bird, 1984a). Cox recorded layering not only of pyrite but also of chalcopyrite, sphalerite, galena, barite, and quartz. Much of the chalcopyrite and tetrahedrite seen during my examination of the open cut seems to be occupying D<sub>2</sub> extensional sites.

Most of the Blow massive pyrite lens was actually mined as smelter flux rather than copper ore, as were the South Lyell lenses. Bird (1984 a) understood from his review of old records that grades were mostly about 0.4% Cu, 0.4 to 3.0 gms Au/t, and 30 to 100 gms Ag/t. Bird (1984 b) documents grades in the South Lyell bodies of 0.4% Cu, 1.1 gms Au/t, and 6 gms Ag/t.

The generally quoted production figures for the Blow ore-body are 5,586,000 tons of 1.29 % Cu, 1.99 gms Au/ton, and 61.22 gms Ag/ton (Reid, 1975). However, lost in this figure is: a 'bonanza' silver shoot totalling 840 tons of 21% Cu and 31,500 gms Ag/ton, comprising stromeyerite, tetrahedrite, chalcopyrite, bornite, and chalcocite; and 'high grade ore' totalling some  $1.5 \times 10^6$  tons of 2.8% Cu, 2.8 gms Au/ton, and 80 gms Ag/ton, comprising chalcopyrite, tetrahedrite, galena, pyrite and probably some bornite, enargite, and chalcocite.

Remnants of the high grade ores are still present at water-level, which is near 4-level as shown in Plate 7. They appear to have been worked from timbered and filled stopes, earlier than the open-cut. Available level plans outline 'high grade ore' from 4-level down. No details are available of the cut-off used to define this high grade ore, so it may



Fig. 19 Bed of fine laminated massive pyrite and lesser silica enclosed by sericitic schist and lying parallel to the Blow massive pyrite lens.

not coincide exactly with the tonnage and grade quoted above, but is nevertheless an indication of the pattern of distribution of the better grades. The high-grade ore on the old level plans is confined to shoots on the 4,5, and 6 levels, located on the contact between the massive pyrite lens and the Owen Conglomerate (Plate 7).

The 'bonanza' shoot is also shown as following the conglomerate contact between 4-level and 6-level. High grade mineralization was almost certainly present above 4-level but I have no details of its distribution. Much of the high grade ore was reputed to have been in upper parts of the ore-body.

Still exposed at water-level on the conglomerate contact, and adjacent to a zone where high grade ore was mined, is massive hematite-barite with minor pyrite (Plate 7). No indication of a precursor rock was seen in this exposure but farther round the conglomerate contact adjacent to another high grade shoot is weaker hematite-barite-pyrite alteration within the Owen Conglomerate. The old level plans show further details of the distribution of massive hematite below 4-level - generally minor and confined to the conglomerate contact. Zones of 'chert' are also recognized, lying partly along this contact between 4 and 6 level (Plate 7).

While no precise details are available on the outlines, massive hematite along the conglomerate contact wedged upwards and formed an impressive outcropping ironstone from which the 'Blow' derived its name. The cross-section of Solomon (1964) shows a massive hematite body nearly half as wide as the pyrite lens at the original surface, narrowing downwards. High grade ore in the upper part of the ore body was probably alongside this massive hematite body.

Another important aspect of the geology of the Blow, is that the high grade mineralisation and the hematite-barite are associated with an anomalously overhanging part of the schist/conglomerate contact (Fig. 17), where  $S_2$  and the contact have a reversed vergence sense compared to most of the west dipping contact.

The South Lyell pyritic lenses are not known to intersect the schist/conglomerate contact. According to Bird (1984b) some higher grades are present in the South Lyell bodies, but are volumetrically insignificant.

Some points of apparent significance:

- a) The pyritic lenses may be boudinaged parts of a single horizon of massive exhalative pyrite.
- b) Disseminated pyrite is present in a restricted envelope around the Blow massive pyrite lens, perhaps representing a remobilization halo.
- c) High grades were located where the massive pyrite was in contact with an overhanging part of the Great Lyell Fault, adjacent to massive hematite and 'chert' along the fault contact.

#### 4.3 The North Lyell Ore-Bodies

##### 4.3.1 Geological context

The position of the North Lyell group of ore-bodies is shown on the level plans in Plate 8 produced from the data of Bryant (1975) and level plans held by the mine office (anonymous). The North Lyell group of ore bodies includes, for the purposes of this report anyway, the Lyell Tharsis, Crown 1, Crown 2, Crown 3, Crown Extended, and North Lyell ore-bodies. All these lie within the 'Lyell Schists' in the rather complex structures discussed previously as the Tharsis Trough and North Lyell Corridor.

Bird (1981a, 1985) and Sillitoe (1984, 1985) interpreted rocks on the northeast side of the North Lyell (10-stope) open-cut as altered and mineralized Gordon Limestone. This interpretation strongly influenced their model for structural controls on North Lyell style mineralization: sections of the Great Lyell Fault just beneath where the 'Haulage' unconformity overlaps the fault (eg Fig. 1 of Sillitoe, 1985).

Plate 9 is a detailed map of geology around the North Lyell (10-stope) open cut. The geological picture is one of: competent siliceous 'heads' (or boudins), variably pyritic; similar competent boudins and irregular masses of siliceous breccia/conglomerate, variably hematitic; and strongly foliated schist surrounding and wrapping about the siliceous 'heads' and breccia/conglomerate masses. The  $S_2$  schistosity generally trends northwest and dips at about  $60^\circ$  to the southwest. However there is considerable variation in orientation, partly from refraction around siliceous boudins, but also from re-orientation related to post- $S_2$  fault movement. The post- $S_2$  faults are well exposed, trend in a number of directions, are associated with brecciation and bending of the schistosity, and appear to be late-stage adjustment faults. By late-stage adjustment faults, I mean structures associated with uplift and unroofing, perhaps even weathering and downslope movement. This conclusion reflects the observation of lack of continuity and apparent chaotic orientations of the zones of brecciation and faulting (Plate 9).

Particularly on the northeast side of the 10-stope open-cut some of the schist is quite anomalous in appearance. It is soft, dark, has pyrite and some bornite and chalcopyrite mineralization, and has anomalous orientation related to the late adjustment faults. Indeed, in many respects it resembles weathered Gordon Limestone. Furthermore, black pug of the Gordon Limestone with copper-clay style mineralization does outcrop further up the slope along the North Lyell Fault (Plates 1, 3).

This anomalous looking schist seems to be the product of ordinary 'Lyell Schists' particularly affected by low pH deep weathering because of enhanced permeability around the late adjustment faults. This weathering has transformed micas to soft clays, even in rock containing apparently fresh sulphides. The dark coloration seems to be related to the presence of secondary minerals such as Mn oxides and other more unusual species. Black earthy material veining one of the breccia zones was determined by A. Eggleton of the School of Geology, Australian National University, as possibly a beudantite group mineral (svanbergite) which could be of secondary origin -  $Sr Al_3 PO_4 SO_4 (OH)_6$  with some substitution of Pb for Sr.

Another major problem in interpreting the geology of the North Lyell area is location of the schist/conglomerate contact. As shown in Plate 3, the schist/conglomerate contact along the eastern side of the Tharsis Trough has a selvage of massive hematite-barite which widens northwards into a zone of massive silica with some barite and hematite, traditionally known as the 'North Lyell chert'. Where silica is a major component, breccia textures are common, with hematite between angular siliceous fragments (eg Fig. 22). Much of the hematite-barite and silica-hematite-barite is massive, with no sign of precursor rocks. However parts do have relict textures suggesting that precursor rocks were mainly Owen Conglomerate.

Such a suggestion is hardly new. Bird and Sillitoe were certainly convinced that the hematite-barite and silica-hematite-barite rocks are replacements of sandstone and conglomerate. Many earlier workers seem to have been as well. For example Nye et al (1934) stated"

"Hematite is plentiful around the North Lyell mine and to a less extent around the Mount Lyell. It is particularly developed along the schist-conglomerate contact to the south of the North Lyell mine, in a dense massive form. At the Mount Lyell mine it is associated with barite. The hard dense hematite possibly represents replacements of conglomerates and quartzites in some cases, and the softer hematite schists represent replaced schists and slates."

And Conolly (1940) noted:

"North Lyell and Comstock Silicified Breccia ("Buff quartzite")

These rock masses, walling the North Lyell orebody and forming the Comstock outlier, have been interpreted as silicified smashed beds of sandstone and conglomerate. A rude layering may be seen in places but otherwise the original character of the rock has been obscured by the brecciation and silicification."

As discussed later, there is good evidence that at least some of the hematization and silicification is replacement of Owen Conglomerate. In the area shown in Plate 9, the situation is particularly obscured because of the presence of boudins of silica-pyrite (some baritic) in the schist, as well as irregular masses of silica with breccia/conglomerate textures and variable amounts of hematite and barite. I have interpreted both the 'North Lyell chert' and the hematitic breccia/conglomerate textured silica masses northeast of the 10-stope opencut (Plate 9) as mostly Owen Conglomerate. The silica-pyrite boudins appear to be part of the 'Lyell Schists'. The consequent interpreted schist/conglomerate contact in the North Lyell area (Plate 1) has a rather bizarre shape, perhaps not an unexpected consequence of multiple deformations.

Another unusual feature which can be seen in the surface geology of the North Lyell area is the faulted wedge of Gordon Limestone and Pioneer Beds against the North Lyell Fault. The North Lyell Fault has breccias which suggest late (post-D<sub>2</sub>) movement, a timing preferred also by Cox (1981), although not precluding earlier movement. However the faulted contact on the southern side of the Pioneer/Gordon wedge appears to be an earlier, probably pre-D<sub>2</sub> fault. Where the schist is in contact with Gordon 'pug' nothing definitive can be seen except for a run of hematitic alteration in adjacent parts of the schist (Plate 1). However where the schist is in contact with Pioneer Beds, the west-dipping deformed contact surface is overprinted by S<sub>2</sub>.

The complex geometry of the schist/conglomerate contact surrounding the North Lyell group of ore-bodies is shown in Plate 8. Above 5-level, the contact swings down from the Tharsis Ridge into the Tharsis Trough, then round the eastern end of the North Lyell Corridor, then wedges out against the North Lyell Fault. From 5-level down, the Tharsis Ridge and Trough no longer exist - only the steep sided but rather flat bottomed North Lyell Corridor. Thick zones of massive hematite-barite or silica-hematite-barite run along the schist/conglomerate contact, the rule rather than the exception. Much of the schist/conglomerate contact forms overhangs, as illustrated in the stacked cross-sectional profiles

in Plate 8. In Fig. 14, I have attempted an explanation of this geometry based on interpretation of the schist/conglomerate contact in terms of a folded and imbricated thrust with segments of an earlier graben-margin contact. The shapes in the stacked cross-sectional profiles can be rationalized by such a scheme, but their origin is hardly proven.

As shown in Plates 1 and 3, the 'Lyell Schists' in the North Lyell area are distinctive in that they host large and small silica heads (or boudins), variably pyritic. These are cherty-looking masses with subordinate carbonate and barite, and pyrite contents locally ranging to about 40%, though generally less. The pyrite is present as disseminations, stringers, and possibly in conformable bands, though delicate continuous interlayering of silica and pyrite (such as in the 'exhalite' beds at the Blow and West Lyell) is rare or absent. Some of the silica heads have ghost fragmental textures within the silica and pyrite which must surely be replacive at least in these cases. Disseminated chalcopyrite within large silica heads formed the Crown 3 ore body (Plate 8 and Fig. 3).

Bryant (1975) made multiple subdivisions of the geology of the volcanics in the North Lyell area. Unfortunately these are difficult to relate to the rock types I have recognized in surface mapping. Besides the silica heads, the other rocks seem to fit into the major categories of chloritic mafic schist and schist with siliceous pods and bands of felsic volcanic derivation. From Bryant's descriptions I have interpreted as representing silica heads his categories: "siliceous lavas and pyroclastics," "siliceous lavas and pyroclastics - sheared and leached," "pink siliceous lavas", and "undifferentiated siliceous lavas and pyroclastics". In Plate 8, on cross-section and level plans, an enveloping surface has been drawn around these rock types recognized by Bryant, to outline the geometry of the zone containing silica heads.

While considerable uncertainty exists regarding details, the zone of silica heads seems to be independent of the schist conglomerate contact, but runs parallel to 'stratigraphy' in the volcanics. For example, the zone at depth appears to roll under in a large synformal structure, truncated by both the irregular Great Lyell Fault and the North Lyell Fault.

#### 4.3.2 The ore-bodies

The Crown 3 ore body (Bryant, 1975; Reid, 1975; Walshe & Solomon, 1981) was distinctive in containing low grade disseminated and veinlet chalcopryrite mineralization, with grades of 1.28% Cu, 0.31 gms Au/ton, and 4.13 gms Ag/ton, hosted by pyritic silica heads. Minor molybdenite, galena, sphalerite, magnetite and hematite are also present. Markham (1968) reported the presence of colloform pyrite.

The Crown Extended mineralisation (Bryant, 1975; Brownscombe, 1975) has grades in the order of 1.0% Cu, 0.3 gms Au/ton and 5 gms Ag/ton. Mineralization consists of disseminated and veinlet pyrite and disseminated chalcopryrite hosted, apparently, not by pyritic silica heads but by schist with siliceous pods and bands of felsic volcanic derivation. Brownscombe recorded the presence of a minor deformed massive magnetite lens. Disseminated magnetite and hematite are also present in places, as are veins and blebs of barite.

The Crown 1 ore-body and most of the Lyell Tharsis ore-body were similar to the Crown Extended mineralization, or for that matter to the West Lyell mineralization (Bryant, 1975; Reid, 1975; Walshe & Solomon, 1981.) Crown 1 had grades of 1.65% Cu, 0.42 gms Au/ton, and 7.93 gms Ag/ton; most of Lyell Tharsis had grades of about 1.2% Cu, 0.24 gms Au/ton, and 2.68 gms Ag/ton. Mineralization consisted of disseminated pyrite and chalcopryrite. Hematite is reportedly disseminated in both ore-bodies. Some disseminated bornite mineralization was exposed by recent surface workings at Crown 1. Mineralization in both ore-bodies was probably hosted mainly by schist with siliceous pods and bands of felsic volcanic derivation.

The North Lyell, Crown 2, and 12-west ore-bodies were very different to the low grade mineralization, in terms of grade, mineralogy and structural setting. Most of the mineralization was as coarse-grained masses of bornite in silica heads adjacent to overhanging or steep parts of the schist/conglomerate contact. The adjacent contact has massive hematite-barite or silica-hematite-barite alteration. The common setting for these ore-bodies is readily apparent in Plate 8, but does tend to be

obscure in the commonly reproduced cross-section published by Reid (1975). Besides these ore-bodies, bornite rich ore was mined from the northern end of the Lyell Tharsis ore-body, near where it abuts massive hematite-barite alteration on the schist/conglomerate contact; minor bornite mineralization can still be seen at the southern end of the Lyell Tharsis ore-body, also against hematite-barite alteration along the schist/conglomerate contact.

North Lyell ore-bodies yielded 4,567,000 tons of 5.49% Cu, 0.40 gms Au/ton, and 34.29 gms Ag/ton; the 12-west ore-body yielded 75,000 tons of 6.45% Cu, 0.37 gms Au/ton, and 39.48 gms Ag/ton; Crown 2 yielded 238,000 tons of 3.24% Cu, 0.42 gms Au/ton, and 22.40 gms Ag/ton; and the north end of Lyell Tharsis 61,000 tons of 4.64% Cu, trace Au, and 18.67 gms Ag/ton (Reid, 1975: figures to 1974 - some production since is not included).

Part of the North Lyell ore-body was recently mined in the 10-stope open cut shown in Plate 9. Bornite, chalcopyrite, pyrite, galena, barite, and carbonate are present in silica heads, and disseminated pyrite and chalcopyrite in adjacent quartz-sericite-pyrophyllite schist, often with abundant disseminated hematite. Reid (1975) and Bryant (1975) listed minerals identified in the North Lyell ore-bodies, including chalcocite, tennantite, enargite, mawsonite, molybdenite, and stromeyerite among others.

Some points of apparant significance:

- a) While there is no very good evidence for the presence of any exhalite mineralization, the silica-pyrite heads may well represent either exhalites or near-surface penecontemporaneous mineralization originally deposited in one or a number of primary horizons.
- b) Low grade disseminated copper mineralization away from the schist/conglomerate contact is grossly associated with pyrite and is in lenticular zones paralleling the stratigraphy; however, as in the West Lyell area, it shows little consistent correlation in detail with either pyrite content or rock type.

- c) The high grade ores all appear to be located on the intersection of the zone of silica-pyrite heads with steep to overhanging parts of the schist/conglomerate contact, and all have massive hematite-barite or massive silica-hematite-barite alteration adjacent to them along the contact. The analogy to the high grade mineralization at the Blow is striking. The high grade ore at the north end of Lyell Tharsis is exceptional in terms of its location outside the zone of silica-pyrite heads.

#### 4.4 Copper-clay mineralization

Zones of bleached limonitic Gordon pug or massive goethitic 'gossans', which appear to be surface expression of Cu-clay mineralization, are shown in Plate 3. Location of the three main areas of Cu-clay workings - the Blocks, Consols, and King Lyell mineralized zones - are indicated in Plate 5. Descriptions of the mineralization have been written by Wade & Solomon (1958), Markham (1968), Solomon (1969), and Reid (1975). Reid estimated that about 200,000 tons of ore had been mined, with grades of about 1.2% Cu. Much of this probably came from the Blocks workings.

Mineralization consists dominantly of native copper and cuprite in disseminations and irregular masses in the limonitic clay and associated goethite. Mining operations ceased by 1910 and all workings are now inaccessible. Knowledge of the mineralization is largely from diamond drill core. Markham (1968) examined concentrates from drill holes and found pyrite, chalcopryite, bornite, covellite, digenite, sphalerite, and galena, as well as the expected native copper, cuprite, and chalcocite. Reid (1975) noted that some of native copper occurred as concentrations of sub-rounded water-worn grains and pebbles.

Markham (1968) considered that the copper-clay mineralization may represent syngenetic sulphides within the Gordon Limestone (perhaps formed as a response to weathering of earlier Cambrian mineralization as the limestone was deposited), or might have formed much more recently as a response to weathering. Solomon (1969) suggested that much of the native copper was probably derived from copper sulphides by supergene

processes; he concluded that the deposits are a combination of indigenous and transported gossans, formed either during deposition of the Gordon Limestone or subsequently during the Tertiary. Solomon did note the possibility that mineralization had been introduced during Devonian hydrothermal remobilization from the volcanic rocks.

Bird's review of old mine records suggested that the Blocks mineralization was controlled by a steeply dipping structure perhaps in continuity with the North Lyell ore body. Bird, Brook, and Sillitoe regarded syngenetic deposition of sulphides during deposition of the Gordon Limestone as unlikely and favoured introduction of the copper-clay mineralization at the same time as all the Lyell mineralization. Structurally controlled mineralization may therefore have remained untested by drilling programs designed to intersect conformable syngenetic or blanket-like supergene mineralization. Drilling of inclined holes beneath the Blocks mineralization was thus recommended to test the possibility of a North Lyell ore-body downdip in the structure hosting the copper-clay deposit (Sillitoe, 1984). These holes, North Lyell DDH's 1101 and 1102, failed to intersect significant mineralization and an interpretation of the geology intersected in them is outlined by Bird (1985).

As Bird recognized, massive hematite-barite alteration replaces sandstone and conglomerate beneath the Blocks mineralization. Bird interpreted the altered sequence as Pioneer Beds but subsequent re-examination of the core by myself and Sillitoe suggested that the Pioneer Beds in this area were of the same restricted thickness as elsewhere, and the alteration is in Owen Conglomerate just beneath the 'Haulage' unconformity. The earlier work of Bird, Brook, and Sillitoe suggested that alteration might spread out beneath the 'Haulage' unconformity (Sillitoe, 1984) and this appears to be the case beneath the Blocks mineralization, as indicated by both available outcrop and the recent drilling. In both DDH 1101 and 1102 (cross-over holes drilled beneath the Blocks workings from each side) an interval of patchy hematization beneath the 'Haulage' unconformity is underlain by massive hematite-barite. This alteration is identical to that, for example, exposed at water-level in the Blow open-cut, or along the eastern side of the Lyell Tharsis ore-body.

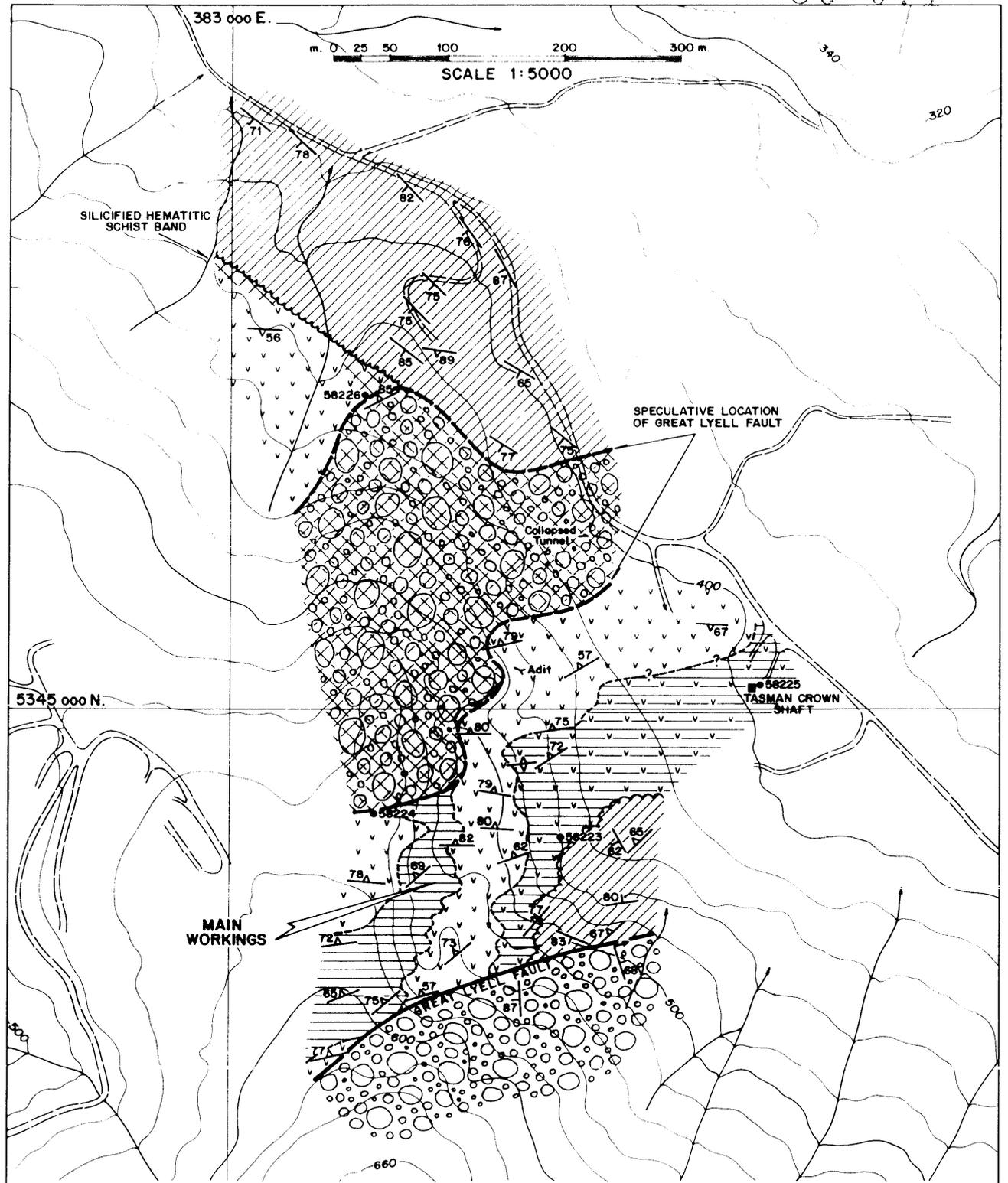
Bird (1985) also identified breccia dykes and acid leaching within the Gordon Limestone. Like the Gormanston and McDowell areas where Bird had made similar identifications, complication from glacial-related processes may be involved. The joint review by Sillitoe and myself of DDH 1101 and earlier drilling suggested the presence of recent sand and gravel mixed with 'pug'. Further review of outcropping black pug of the Gordon Limestone led us to the (then distressing) conclusion that this situation was widespread and suggested much slumping, sloughing, and mixing of unconsolidated pug with Pleistocene glacial-related sediments.

Ironically, such a conclusion has a corollary : the possibility of a previously unsuspected origin for sulphide minerals in copper-clay settings by erosion and mechanical intermixing with the clay of parts of the ore-bodies in the 'Lyell Schists'. However there is no certainty that this has happened, and no particular reason to doubt Bird's earlier assertion that the Block's mineralization was formed as a structurally controlled lode at the same time as at least some of the mineralization in the 'Lyell Schists'. Certainly the fault separating Gordon Limestone and 'Lyell Schists' in the North Lyell area appears to have been a pre-D<sub>2</sub> structure which exerted a control on hematitic alteration in the schist and has copper-clay style mineralization adjacent to it (Plate 1 and previous discussion in section 4.3.1).

#### 4.5 The Comstock area

This study was not originally intended to include the Comstock area; however two days field work were done there during which some preliminary conclusions were reached. A sketch map produced during this work is shown in Fig. 20.

Mineralisation in the Comstock area was described by Solomon (1964), Green (1971), and Reid (1975). The Lyell Comstock ore-bodies yielded 1,337,000 tons of 2.38% Cu, 0.67 gms Au/ton, and 5.23 gms Ag/ton. This mineralization was in four en echelon north-northeast trending lenses dipping steeply to the west. Part was mined by open cut, in the area labelled 'main workings' in Fig. 20. The main ore minerals were pyrite and disseminated chalcopyrite but bornite was an important component of part of the mineralization at depth and other minerals present include



- |   |                              |   |  |
|---|------------------------------|---|--|
|  | S2 SCHISTOSITY               |  | OWEN CONGLOMERATE  |
|  | BEDDING                      |  | TYNDALL GROUP. QUARTZ AND FELDSPAR PHYRIC FINE TUFF, CALCAREOUS SEDIMENT, MINOR COARSE FRAGMENTAL TUFF |
|  | BEDDING WITH FACING          |  | MT READ VOLCANICS<br>MAFIC CHLORITIC SCHIST WITH QUARTZ-FILLED<br>AMYGOALES ABUNDANT IN PLACES         |
|  | UNCONFORMITY                 |  | FELSIC QUARTZ-SERICITE SCHIST WITH BOUDINS OF<br>SILICA-PYRITE, SOME WITH CHALCOPYRITE                 |
|  | MASSIVE SILICEOUS ALTERATION |  | FELSIC QUARTZ-SERICITE SCHIST WITH BOUDINS OF<br>MASSIVE PYRITE-GALENA MINERALIZATION                  |
| ● 58225 SAMPLE LOCATION / SAMPLE No.  |                              |   |  |

FIGURE 20. SKETCH MAP OF THE COMSTOCK AREA

5 cm

magnetite, hematite, molybdenite, galena, sphalerite, chalcocite, covellite, digenite, tennantite, mawsonite, betechtinite, and stromeyerite. Massive banded fine grained galena-pyrite-sphalerite is exposed in the Lyell Comstock open cut to the east of the copper mineralization and similar mineralization was exploited in the Tasman Crown workings. These ores assayed 28.0% Pb, 20% Zn, 0.5% Cu, 490 gms Ag/ton, and 0.31 gms Au/ton. Cox (1979) recorded the presence of framboidal pyrite in this mineralization likely to be a primary texture formed at or near the sediment water interface.

As shown in Fig. 20, the two styles of mineralization appear to lie within two separate belts of felsic quartz sericite schist trending north-northeast and separated by chloritic mafic schist. In both belts there is disseminated pyrite in quartz-sericite schist, but most mineralization is in boudins wrapped about by the schist. The belt of felsic schist hosting the Lyell Comstock copper mineralization contains boudins of silica-pyrite, very similar to the silica-pyrite 'heads' in the North Lyell area, except that fine interlamination of silica and pyrite is preserved, perhaps more suggestive of exhalite-type textures than any in the North Lyell area. Exposure of the second belt in the open cut suggests that the massive banded pyrite-galena-sphalerite mineralization is also present in boudins surrounded by schist. The chloritic mafic schist in the Comstock area is very similar to that in the Lyell area except that parts of it contain abundant amygdules (or phenocrysts?) of quartz.

Adjacent to the mineralization in the open cut, and further north in a separate outcrop zone with northeast trends, are distinctly different rocks of the Tyndall Group: thin bedded quartz and feldsparphyric fine tuff, calcareous sediment, and minor coarse fragmental tuff. An unconformity between the Tyndall Group and the mineralized schists described above was proposed by Green (1971) and discussed in some detail by Corbett et al (1974).

Green first made the point, since reiterated by numerous authors, that the pervasive feldspar-destructive alteration present in the 'Lyell Schists' (including the mineralized schists at Comstock) has not affected the Tyndall Group sequence. Although some alteration and greenschist

facies metamorphism has affected the Tyndall Group rocks, I think Green's observation is right and represents a very strong argument for the presence of alteration and mineralization of Cambrian age in the underlying rocks.

On the southern side of the open-cut, both Tyndall Group and the underlying mineralized schists truncate against Owen Conglomerate on a part of the Great Lyell Fault without any apparent hematitic or siliceous alteration. However, on the northern edge of the open cut, massive silica of the 'Comstock chert' is present as a large discordant mass (Fig. 20). Parts of this silica body are hematitic, baritic, and pyritic. Parts appear to have breccia/conglomerate textures reflecting both a primary conglomerate texture and subsequent hydrothermal brecciation. Similarity to the 'North Lyell chert' has been apparent to virtually all geologists who have worked in both areas, though there do appear to be some differences in detail.

The Comstock silica body seems to be discordant to both the Tyndall Group and the underlying mineralized schist. Some silicification and hematization seems to have branched out along the unconformity surface to the northwest, just as it apparently branched out along the 'Haulage' unconformity in the North Lyell/Blocks area. Silicification has been intersected in drilling to the north, possibly also plunging down the unconformity surface,

Bird, Brook, and Sillitoe apparently regarded the Lyell Comstock mineralization and the silica body as all altered parts of the Tyndall Group; the compilation of Brook (1984a) shows the Tasman Crown mineralization in Gordon Limestone. I think their identification of the rock units is probably wrong and their interpretation of the mineralization thus substantially incorrect. However, Sillitoe (1984) noted evidence for some mineralization and alteration within drill-core intersections of the Tyndall Group: this observation is undoubtedly correct and has been side-stepped by previous authors claiming that the sulphides are clastic in origin. The answer to the apparently conflicting evidence for the timing of alteration and mineralization is

the same as for the Blow and North Lyell: some mineralization and alteration in the 'Lyell Schists' is at least partly syngenetic and Cambrian in age, whereas the silica body and the mineralization in the Tyndall Group are the result of subsequent hydrothermal activity.

Conolly (1940) had no hesitation in identifying the 'Comstock chert' as a probable outlier of intensely altered Owen Conglomerate, but subsequent geologists have been inhibited by the problem of acknowledging that the surrounding rocks are volcanics. My brief examination of this rock type suggests that the conglomerate textures there are real and likely to represent either the Owen Conglomerate (or possibly, though less probably, conglomeratic parts of the Tyndall Group). My inclination is to regard it as an intensely altered outlier of Owen Conglomerate, surrounded by the folded Great Lyell Fault. Perhaps the bornite mineralization in part of the Lyell Comstock ore-body was another high grade shoot of North Lyell type.

#### 4.6 The case for Cambrian Volcanogenic Mineralization

Until Bird, Brook and Sillitoe came to Lyell, few exploration geologists since the late 1960's lost any sleep worrying about whether volcanogenic mineralization is there.

But geological certainty depends on perspective. Once the possibility of late-stage, structurally controlled hydrothermal deposition of copper, gold, silver, silica, and hematite at Lyell is contemplated, and field evidence found to be overwhelming for its presence, then the question is asked, what are the limits of this mineralization? Isn't the run of silica heads between Crown 1 and North Lyell just another expression of the silicification in the 'North Lyell Chert? Doesn't all the mineralization intersect the Great Lyell Fault at some depth if the fault doesn't 'roll under' but is a west-dipping thrust? Looked at sceptically, the disseminated copper-pyrite ore-bodies at West Lyell have little to recommend them as obvious volcanogenic mineralization.

Neither Solomon's (1967) paper describing 'fossil gossans' at Mt Lyell (in which he argued for a pre-Ordovician age for the sulphides), nor Markham's (1968) identification of colloform textures and overprinting by the Devonian D<sub>2</sub> deformation can be used as strong evidence for Cambrian volcanogenic mineralization.

However three main lines of evidence from the Lyell area itself, as well as the regional association of volcanogenic mineralization with the Mt Read Volcanics, seem to indicate a first phase of Cambrian mineralization:

- a) Framboidal textures in finely laminated massive sulphides
- b) Beds of finely laminated massive pyrite with distributions surely unrelated to the position of the Great Lyell Fault
- c) The presence of pervasive feldspar-destructive alteration in mineralized schist in the Comstock area unconformably overlain by Cambrian Tyndall Group rocks unaffected by such alteration.

#### 4.7 The case for Devonian remobilization

Solomon (1967) suggested that the hematite bodies within the Owen Conglomerate and along the schist/conglomerate contact are gossans or limonitic scree developed during Ordovician weathering of the adjacent sulphides. He suggested that the Lyell area was exposed as the Owen Conglomerate was depositing alongside. In the North Lyell area, Solomon's reconstructions imply that the gossanous orebodies together with adjacent scree were slumped into the Owen basin and remained somehow in contact.

As recognised by Sillitoe (1984) and his coworkers, the hematite-barite bodies have all the ear-marks of hydrothermal alteration and are transitional to the silica-hematite-barite body known as the 'North Lyell chert'. The 'detrital pebbles' of hematite in the Owen Conglomerate appear to be in marginal parts of this alteration, where only parts of the conglomerate are selectively altered.

The transition from interbedded fine sandstone and slate of the Owen Conglomerate into silicified and hematitic rocks of the 'North Lyell chert' is well exposed along the main access road between Lyell Tharsis and North Lyell (Fig. 21). Relationships are unequivocal. Sandstone and slate passes transitionally into the 'North Lyell chert'. The silicification is a hydrothermal alteration phase post-dating the Owen Conglomerate but pre-dating the Devonian D<sub>2</sub> deformation.

Similar transitions between Owen Conglomerate and massive hematite-silica-barite breccia are exposed on Tharsis Ridge (Fig 22). Contacts are replacive between the sandstone and conglomerate and the hematite rocks. Textures within the hematite-silica-barite rocks strongly suggest hydrothermal brecciation (Fig.22 and 23).

Besides textural evidence, there is the problem of the gross geometry of the schist/conglomerate contact with hematite-barite alteration. Solomon's interpretations rely heavily on his theory of a slumped primary depositional contact and are impossible to rationalize with the folded and imbricated thrust interpretation proposed here (or the interpretation of Cox, 1981, either). Owen Conglomerate along the schist/conglomerate contact carrying some combination of hematite-silica-barite alteration surrounds the North Lyell Corridor and the north end of the Tharsis Trough (Plate 8). Such a geometry is difficult if not impossible to achieve along a slumped primary depositional contact - much more believable as hydrothermal alteration emplaced after the complex structure had formed.

Campbell (1968), no doubt somewhat bemused by the change of attention from the schist/conglomerate contact to stratigraphic features of the volcanic pile as the major control on mineralization at Lyell, was possibly the first to suggest that pre-existing Cambrian mineralization may have been remobilized into high grade ore-bodies along the conglomerate contact.

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Fig. 21 Transitional contact of Owen Conglomerate with 'North Lyell chert'. a) Unaltered fine sandstone and slate with  $S_2$  cleavage at a high angle to bedding surfaces. b) Pod of massive silica in pelitic horizon, overprinted by  $S_2$ . c) Remnant beds of hematitic sandstone in massive 'chert' and silica-hematite breccia.

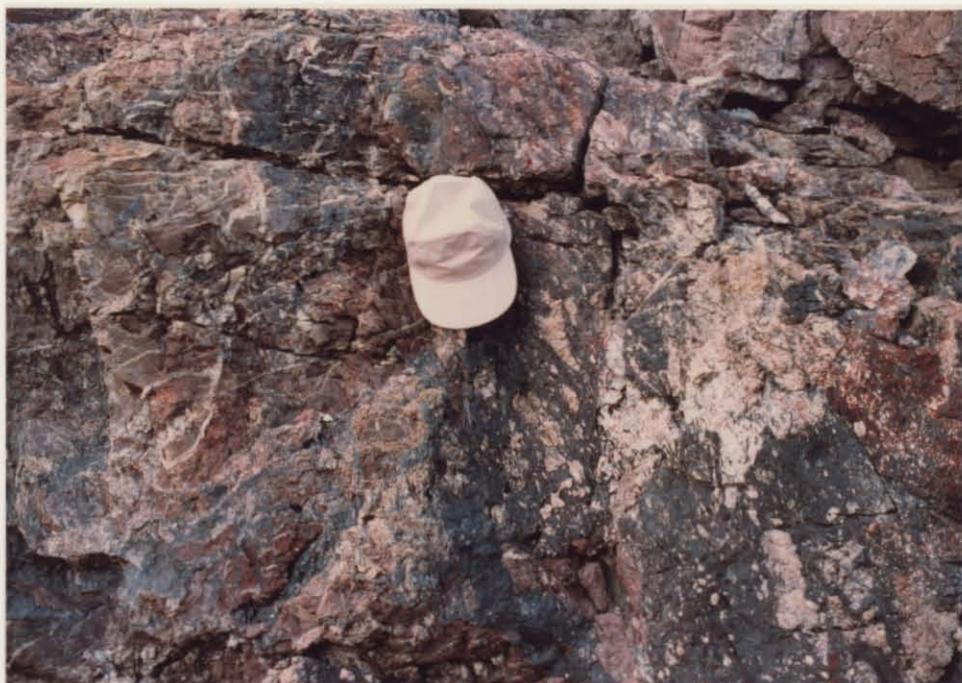


Fig. 22. Hematite-silica-barite breccia enclosing remnants of pink hematitic sandstone and conglomerate of the Owen Conglomerate, north end of Tharsis Ridge.



Fig. 23 Massive silica of the 'North Lyell chert' showing hydrothermal brecciation textures: pale cherty fragments are surrounded by massive hematite, and hematite invades irregular cracks within fragments. Precursor rocks have been entirely obliterated.

Bird, Brook and Sillitoe lost faith in Cambrian volcanogenic mineralization. Sillitoe (1985) reviewed a number of possibilities. He recognised that the schist/conglomerate contact behaved as an abrupt redox front during mineralization. Sillitoe noted that many aspects of the mineralization were compatible with an intrusive-related origin except that no suitable intrusions have been identified and the control by the schist/conglomerate contact of the redox front is an unusual and unexpected feature in such a system. Sillitoe doubted if metamorphogenic fluids (eg in D<sub>1</sub>) could provide all the sulphur in the Lyell system, though a metamorphogenic origin was compatible with the behaviour of the schist/conglomerate contact as a redox front. Derivation of mineralization from connate brines driven out of the Owen Conglomerate seems to be difficult to rationalize with the geometrical array of alteration and mineralization. Sillitoe (1985) did regard two-stage ore formation as a possibility but saw little supporting evidence: a volcanogenic origin for sericite-pyrite alteration (with or without some copper), followed by metamorphogenic or connate introduction of copper and silver.

Solomon (1984), perhaps partly prompted by some contact with Bird's theories, discussed possible remobilization of sulphides at Lyell. He acknowledged that some of the bornite-bearing assemblages were actually developed in silicified Owen Conglomerate - relationships recognized in the early phase of Lyell geology by his own publications and since ignored. Solomon noted that late-stage mineralization, of probable Devonian age, may be responsible for the high grade ore-bodies such as those at North Lyell together with the pyrophyllite-bearing assemblages associated with them.

Initially, I was dismayed by the lack of obvious spatial association between the low-grade disseminated copper mineralization and the high grade bodies with associated hematite-silica-barite alteration along the schist/conglomerate contact. Why aren't there high grade shoots along the contact between Royal Tharsis and the schist/conglomerate contact, for example? Where is the low-grade mineralization alongside the North Lyell ore-bodies? And as Sillitoe (1985) pointed out, the North Lyell ore-body contains the same order of magnitude of copper as the largest of the low grade ore-bodies. From this perspective, 'simple' remobilization seems an uninviting solution to the problem.

I think part of the answer is that pre-existing volcanogenic mineralization was much more limited than the wide zones of disseminated pyrite shown in Plate 1. While the Owen Conglomerate is rarely affected by sulphide-bearing alteration related to the late-stage mineralization, in a few places it is, as shown in Fig. 24, a feature first recognized during Sillitoe's first (1984) stint of Lyell geology. There can be little doubt that at least some disseminated pyrite and chalcopyrite mineralization was the result of the late phase, because it can be seen in the Owen Conglomerate.

How much of the low grade disseminated ore-bodies is the direct result of late-stage mineralization is difficult to establish. Certainly some is likely to be, and the widespread association of copper and disseminated hematite is particularly suspicious. Hematite exposed on the eastern side of the West Lyell open cut is associated with hydrothermal breccias in two localities - different from the hematite-silica-barite breccias along the schist/conglomerate contact in detail, but not too different.

Disseminated and stringer pyrite without accompanying beds of massive exhalite-type pyrite can be found in a variety of structural locations in the 'Lyell Schists' and much is likely to be second phase mineralization. In particular, disseminated pyrite extends along the Great Lyell Fault in a discontinuous narrow zone of 'mylonitic looking' schist. Disseminated and stringer pyrite is also preferentially located in discontinuous and partly discordant zones along the contacts of the mafic chloritic schist and the podded and banded felsic schist. The halo of disseminated pyrite around the Blow massive pyrite lens could also be a late-stage mineralization effect, as could much of the disseminated pyrite associated with beds of exhalite-type pyrite. There is generally no way this can be distinguished from disseminated and stringer mineralization formed in a 'Footwall' sequence contemporaneously with exhalative mineralization. However, the distribution of the disseminated and stringer mineralization is more often as haloes surrounding possible exhalites than confined to potential feeder zones or 'Footwall' rocks.

The best contenders for Cambrian volcanogenic mineralization are the beds and boudins of massive laminated pyrite (such as at the Blow and at West Lyell), in some cases with Cu-Pb-Zn sulphides. Also good contenders are the boudins of silica-pyrite at Comstock and in the North Lyell area.

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Fig. 24 Pyritic alteration within sandstone and slate of the Owen Conglomerate above Batchelor's Quarry. Disseminated pyrite, evident from the jarositic bloom in the central part of the photograph, is associated with a complete absence of the hematitic colouring typical of surrounding Owen Conglomerate. An envelope of dark hematization of anomalous intensity surrounds the tongue of disseminated pyrite.

Perhaps much of this was originally not strongly mineralized in base and precious metals but sufficient copper anomalism was present in the original 'foot-wall sequence' to be concentrated by subsequent remobilization. Viewed from this perspective, there is good spatial association of the high-grade mineralization with zones of earlier volcanogenic mineralization.

As to the timing and nature of the late-stage mineralization, the best guess seems to me to be metamorphogenic, possibly associated with  $D_1$ . Recent work at Mt Isa and Cobar suggests that metamorphogenic mobilization and emplacement of copper mineralization may be much more efficaceous than the wildest imaginings of a few years ago. Because of the overprint by  $D_2$ , demonstration of such origin has not been possible, only the presence of second stage mineralization predating this last Devonian deformation.

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APPENDIX: SAMPLE RESULTS

Sampling was undertaken to identify structures, alteration, veins, or primary rock types with anomalous precious metal content. Samples from the Blow open-cut, both strongly sulphide-mineralized examples and hematite-barite altered Owen Conglomerate, showed the strongest concentrations of gold and silver. Some silica-pyrite 'heads' in the North Lyell area, at the north end of the 10-stope open cut and at the north end of Crown 3, have anomalous gold and silver values. Some massive pyrite-silica bands on the west side of the West Lyell open-cut have anomalous gold. Schist with disseminated pyrite commonly has low levels of anomalous gold and some elevated isolated values where associated with baritic selvages and veins. Pyritic and gossanous Gordon 'pug' has elevated silver values in a few cases.

Some follow-up sampling may be warranted but I doubt if any significant precious metal mineralization has been identified in a workable locality. The main value of the sampling has been in demonstrating that both gold and silver enrichment in the area is present in the known styles of mineralization (Cambrian volcanogenic massive pyrite with Cu-Pb-Zn and the high grade Devonian shoots on the schist-conglomerate contact), and apparently not present to any extent in other settings. At one stage it was suspected that syn-D<sub>2</sub> quartz veins may have been enriched in gold but there is no consistent pattern developed: only very local anomalism in a few of the veins with abundant pyrite.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N57902	0.017	0.4	Silicified sericitic schist from the Blow open cut.
N57904	0.083	0.4	Pyritic 'mylonitic' sericitic schist from the Great Lyell Fault.
N57905	0.067	-	Massive fine grained chlorite in quartz vein.
N57906	0.367	1.8	Intensely foliated hematite-chlorite-pyrite breccia.
N57907	0.017	0.2	Massive, somewhat silicified pink felsic volcanic.
N57908	0.058	0.4	Pyritic, 'mylonitic' sericitic schist from the Razorback Fault.
N57909	0.032	0.3	Pyritic chloritic felsic schist associated with patchy hematization.
N57911	0.008	-	Sericitic felsic schist, intensely bleached, probably glacial-related colluvial breccia.
N57914	0.050	1.1	Sericitic pyrite 'mylonitic' schist from the Great Lyell Fault.
N57915	0.075	0.8	Sericitic pyritic 'mylonitic' schist in fold nose in the Great Lyell Fault.
N57916	0.217	1.8	Black pebbly gouge in joints in Owen Conglomerate from the Blow open cut.
N57917	0.008	0.2	Pebbly siliceous sandstone dykes crosscutting sericitic felsic schist.
N57918	0.017	1.1	Pyritic mylonitic schist associated

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N57919	0.117	2.0	Fault beccia with blocks of Gordon Limestone, Owen Conglomerate, felsic schist.
N57921	0.158	3.8	Siliceous, sericitic, pyritic, felsic schist.
N57922	0.050	1.0	Limonitic Gordon pug.
N57923	0.032	-	Bleached yellowish limonitic Gordon pug.
N57924	0.017	-	Geothitic zone in Gordon pug.
N57925	-	-	Geothitic sideritic Gordon pug.
N57926	-	1.4	Geothitic sideritic Gordon pug.
N57927	-	-	Foliated sericitic felsic schist, possibly a block in glacial colluvium.
N57928	0.058	0.4	Hematitic 'mylonitic 'schist from Great Lyell Fault.
N57929	-	-	Limonitic Gordon pug.
N57931	-	0.4	Limonitic Gordon pug.
N57932	-	0.6	Intensely hematized sandstone beds.
N57937	0.008	0.2	Barite vining in siliceous felsic schist.
N57939	0.040	0.5	Hematitic breccia.
N57943	0.100	-	Discordant hematitic alteration in schists.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N57945	0.008	-	Quartz-chlorite schist in fault zone.
N57948	0.117	1.5	Hematitic breccia in pyritic silicious schist.
N57951	0.750	0.8	Broken pyritic quartz in fault zone.
N57952	-	-	Quartz chlorite veining in chloritic schists.
N57954	0.182	12.1	Pyrite-quartz-sericite schist.
N57955	0.741	1.7	Hematite-barite selvedge in schist.
N57956	0.200	3.0	Quartz-sericite-pyrite alteration in chloritic schist.
N57957	-	-	Pyritic siliceous zone in podded and banded felsic schist.
N57959	0.075	8.0	Pyritic zone in chloritic mafic schist.
N57961	1.100	10.8	Silica-pyrite altered felsic schist.
N57963	0.017	-	Bleached chloritic schist near horizontal quartz veins.
N57964	0.050	0.3	Pyrite-silica-sericite altered schist.
N57965	0.032	0.5	Pyritic zone in chlorite schist.
N57966	0.142	0.8	Pebble layer in chloritic schist.
N57967	0.325	1.2	Silica-pyrite-sericite 'mylonite' in fault zone.
N57968	2.600	5.4	Barite-pyrite selvedge in pyritic

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N57971	0.217	3.8	Massive barite-pyrite-sericite-silica at adit.
N57972	0.017	-	Barite veins with minor hematite in chlorite schist.
N57973	0.350	0.5	Barite pyrite-hematite zone in schist.
N57975	-	0.4	Bleached pyritic podded and banded sericite schist.
N57976	-	-	Ferruginous interstitial material from breccia near Gormanston Oval (possible glacials).
N57977	-	-	Bleached schist near breccia above.
N57978	-	-	Goethitic, partly hematitic bleached chloritic schist.
N57979	-	2.6	Limonite, goethite zone in schist.
N57981	-	-	Pink quartz veined sandstone dyke.
N57982	-	-	Quartz chlorite vein in Pioneer Beds.
N57983	-	-	Limonitic clay and sand-possible Gordon Limestone.
N57984	-	-	Crush zone from fault separating Gordon Limestone and Pioneer Beds.
N57985	-	0.6	Green staining on fault zone.
N57986	-	-	Limonitic Gordon pug.
N57987	-	-	Limonitic Gordon pug.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N57988	-	-	Limonitic Gordon pug.
N57989	0.008	-	Limonitic Gordon pug.
N57991	-	-	Limonitic Gordon pug.
N57992	-	-	Limonitic Gordon pug.
N57993	-	0.3	Slickensided hematite vein in schist.
N57994	0.040	0.7	Pyritic siliceous schist.
N57995	0.032	0.6	Pyritic, silicified bleached schist.
N57996	-	-	'Mylonitic' schist from Great Lyell Fault, quartz veined.
N57997	0.032	0.2	Pyritic zone in schist.
N57998	-	8.6	Green chrome and copper stained layer at bottom of Pioneer Beds.
N57999	-	0.1	Quartz-hematite veins with pyrite and chalcopryrite in flat fault at Batchelor's Quarry.
N58001	-	0.4	Pyritic 'mylonitic' schist.
N58003	0.050	8.7	Fault zone material from Owen/schist contact.
N58004	0.040	4.0	Pyritic 'mylonitic' zone near Owen/schist contact.
N58005	-	0.8	Pyritic 'mylonitic' zone near Owen/schist contact.
N58006	-	0.3	Pyrite-sericitic 'mylonitic' schist.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58007	0.017	0.2	Gossanous and brecciated Gordon pug.
N58008	-	0.1	Green stained base of Pioneer Sst.
N58009	-	0.2	Possible fault zone, hematized and quartz veined.
N58011	0.008	0.6	Sheared and hematitic Owen sandstone beneath 'Haulage' unconformity.
N58012	-	0.2	Intensely sheared hematized conglomerate.
N58013	-	-	Limonitic Gordon pug.
N58014	0.017	18.6	White conglomerate and grit with copper stained hematite veins, possibly Pioneer Beds.
N58015	-	1.2	Gossanous hematitic Owen Conglomerate.
N58016	-	0.8	Bleached limonitic Gordon pug.
N58017	-	0.8	Pyritic-chloritic horizon in Owen Conglomerate overlain by very bleached quartzite.
N58018	0.025	-	Gossanous Gordon pug.
N58019	-	-	Copper stained gossanous material in Pioneer Beds.
N58021	-	0.2	Hematite veins in Owen Conglomerate at base of Pioneer Beds.
N58023	-	-	Limonitic Gordon pug.
N58024	-	0.8	Limonitic Gordon pug.

SAMPLE	Au(ppm)	Ag(ppm)	DESCRIPTION
N58025	-	0.2	Hematite-barite in Owen Conglomerate.
N58026	-	0.2	Hematitic 'mylonitic' schist.
N58028	-	1.9	Pyritic 'mylonitic' schist.
N58031	0.008	1.0	Pyritic mylonitic schist, possible derived from Owen Conglomerate.
N58032	-	-	Quartz veins with specular hematite.
N58033	-	1.2	Pyrite 'mylonitic' chloritic schist.
N58034	0.067	0.5	Hematitic, limonitic, strongly cleaved Owen Conglomerate.
N58035	-	0.7	Pyritic 'mylonitic' schist.
N58036	-	0.2	Hematite-barite on schist/conglomerate <i>contact</i> .
N58037	0.008	0.2	Hematized Owen Conglomerate on schist/conglomerate contact.
N58038	0.008	0.1	Massive hematite, possible <sup>y</sup> in Owen Conglomerate on schist/conglomerate contact.
N58042	0.050	0.6	Massive hematite with patches of barite.
N58043	-	0.1	Massive hematite.
N58045	0.167	2.4	Broken quartz veins with chlorite and pyrite, and fault pug, from reverse fault.
N58046	0.008	0.4	Quartz-chlorite-hematite veins and fault pug.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58047	0.032	0.4	Pyritic altered schist.
N58048	0.082	1.2	Pyritic schist with some barite.
N58049	0.017	0.3	Green chrome-stained beds on 'Haulage' unconformity.
N58051	0.150	1.2	Pyritic 'mylonitic' schist.
N58052	-	0.8	Bleached sericitic schist.
N58053	-	0.5	Quartz veins in thrust at Batchelor's Quarry with chlorite, specular hematite, malachite.
N58054	-	-	Limonitic Gordon pug.
N58055	-	0.1	Quartz chlorite veins.
N58056	1.500	1.8	Pyritic alteration zone in schist, some barite.
N58057	0.050	-	Pyritic alteration zone in schist, some quartz veins.
N58059	0.133	1.5	Pyritic alteration zone in schist, some quartz veins.
N58064	0.058	0.5	Pyritic siliceous alteration in schist.
N58065	0.082	1.0	Pyritic chloritic schist with pyritic quartz veins.
N58066	0.225	12.0	Pyritic alteration zone in sericitic schist.
N58067	0.025	0.5	Pyrite-silica altered zone in schist.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58068	0.040	0.5	Bleached pyritic silicified zone near quartz veining.
N58069	0.017	-	Gossanous material on pyritic schist.
N58071	0.900	3.5	Massive brecciated pyrite.
N58072	0.567	58.0	Finely laminated massive pyrite with minor chalcopyrite.
N58073	0.500	1.5	Clay, sericite, pyrophyllite schist.
N58074	3.250	20.0	Massive pyrite with minor tennantite.
N58075	0.032	2.0	Quartz veins associated with shallow reverse fault.
N58076	2.170	20.5	Massive pyrite.
N58079	0.683	27.0	Pyritic schist with minor quartz and barite.
N58081	7.670	6.0	Partially hematitic Owen Conglomerate with some barite.
N58082	1.600	130.0	Massive pyrite.
N58083	0.283	550.0	Massive pyrite and galena with quartz veining.
N58084	0.367	21.0	As above but with massive tetrahedrite.
N58087	0.750	20.0	Hematite-barite with some pyrite.
N58092	1.750	210.0	Massive sulphide with pyrite, chalcopyrite, tetrahedrite.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58094	0.233	12.5	Massive hematite replacement of Owen.
N58096	0.025	1.5	Siliceous weakly pyritic sericitic schist.
N58097	0.267	2.5	Siliceous pyritic schist.
N58098	0.032	2.0	Pyrite-sericite-silica schist with minor chalcopyrite.
N58099	0.050	3.5	Massive hematite alteration of Owen Conglomerate.
N58103	0.017	-	Pyritic hematitic schist near schist/conglomerate contact.
N58104	-	-	Hematitic Owen Conglomerate with minor barite.
N58105	0.008	0.5	Hematite-barite alteration possibly of Owen Conglomerate.
N58106	-	0.5	Massive hematite-barite on schist/conglomerate contact.
N58107	-	0.5	Hematite-barite alteration in conglomerate.
N58108	0.340	3.0	Pyrite-silica alteration in schist.
N58109	0.008	-	Quartz veining on Tharsis Ridge.
N58111	0.008	0.5	Pyrite-quartz-sericite schist.
N58114	-	0.5	Pyritic sandstone from the Owen Conglomerate.
N58115	-	1.5	Transported goethite at Lyell Blocks.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58116	0.008	-	Limonitic Gordon pug.
N58117	-	-	Transported goethite in Gordon pug.
N58118	0.032	2.9	Massive silicification
N58119	0.017	0.3	Quartz vein material with specular hematite.
N58121	0.467	2.1	Hematite-silica breccia.
N58122	0.200	3.7	Silica-pyrite altered sericitic schist.
N58123	0.050	2.8	Hematite-silica-barite alteration.
N58124	2.420	6.5	Veins of barite-chalcopyrite in chloritic schist.
N58125	0.233	4.3	Pyritic schist with chalcopyrite.
N58126	0.100	0.7	Hematitic schist.
N58127	0.040	0.2	Fibrous quartz veins with specular hematite.
N58128	0.283	5.4	Disseminated bornite, chalcopyrite, pyrite in felsic schist.
N58129	0.250	86.0	Quartz veining with bornite, chalcopyrite and chlorite.
N58131	0.017	0.5	Chloritic quartz veins.
N58132	0.025	0.2	Quartz-chlorite veins.
N58133	0.067	0.3	Specular hematite and barite in quartz veins.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58134	0.017	2.3	Hematite-silica-barite breccia.
N58135	0.225	0.6	Pyritic silica body with chalcopyrite.
N58136	0.025	-	Hematite-barite alteration on 'Haulage' unconformity.
N58137	0.008	73.0	Limonitic Gordon pug with blebs of native copper.
N58138	0.717	9.8	Massive silica-pyrite head with relict siliceous clasts.
N58139	0.140	1.3	Pyrite-sericite schist wrapping around silica head.
N48141	0.100	2.9	Quartz veining with chlorite and pyrite.
N58142	0.032	-	Chlorite-sericite schist with disseminated pyrite and hematite.
N58143	0.032	-	Disseminated hematite and pyrite in chlorite schist.
N58144	0.283	2.9	Massive hematite-barite alteration.
N58145	0.142	1.2	Quartz veining containing barite in hematite-barite alteration.
N58146	0.425	31.0	Silica body with pyrite, chalcopyrite and bornite.
N58147	0.083	6.8	Quartz vein containing pyrite, specular hematite, galena, chalcopyrite and bornite.

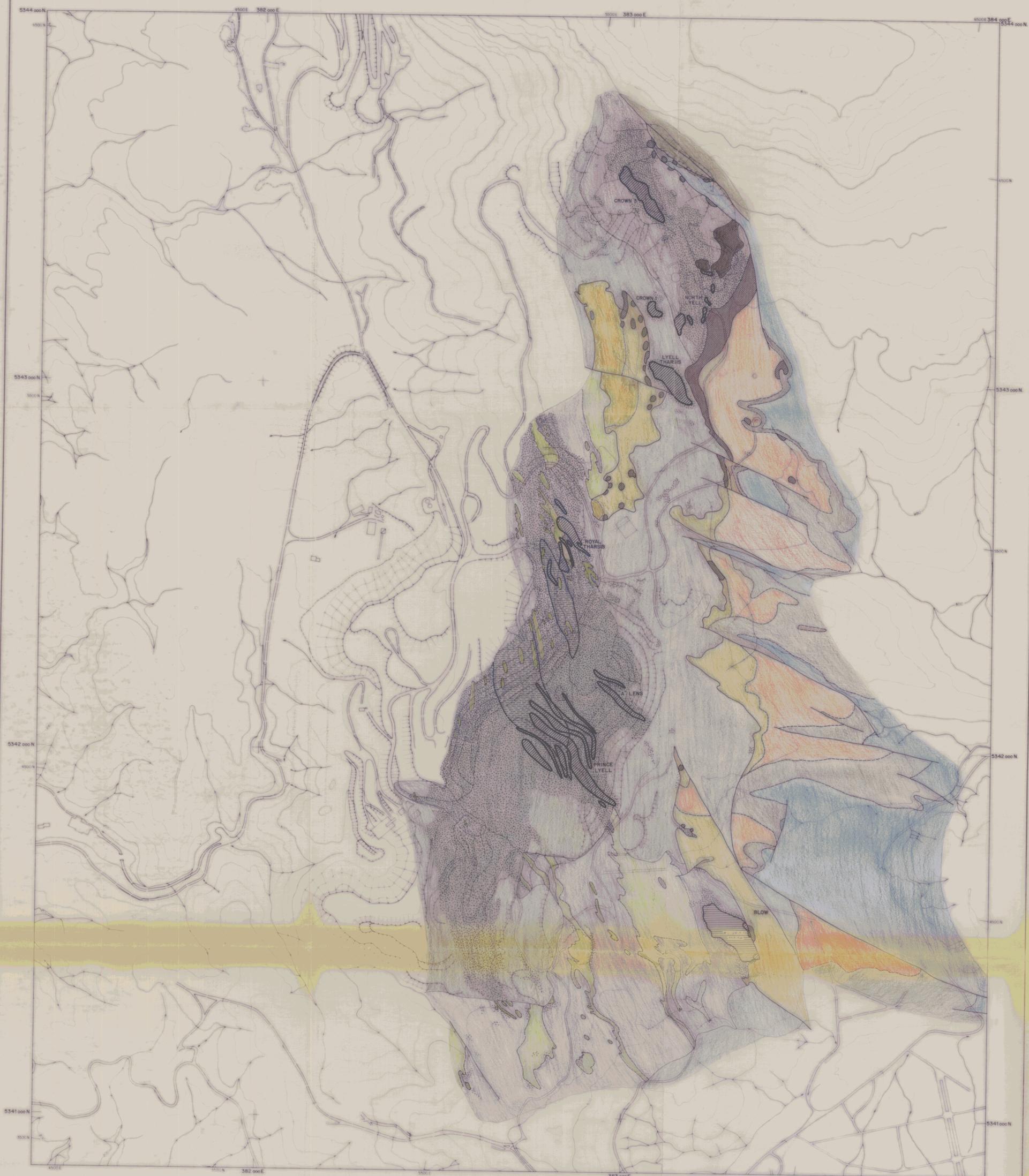
SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58149	0.150	7.6	Hematite-barite in silica body, breccia textured.
N58151	0.183	6.6	Massive pyrite and hematite in schist.
N58152	1.130	16.0	Silica-pyrite head.
N58153	0.040	7.8	Hematite-barite-silica.
N58154	0.050	1.1	Quartz veining with chlorite and barite.
N58155	1.280	38.0	Silica head with pyrite and chalcopryrite.
N58156	0.700	3.8	Quartz veins containing pyrite and chlorite.
N58157	0.208	1.3	Black soft material, possibly supergene manganese mineral.
N58158	0.032	1.0	Disaggregated blackish rock - possibly a silica body with intense supergene alteration.
N58159	0.133	6.4	Brecciated black dissaggregated rock containing chalcopryrite and pyrite.
N58161	0.083	8.0	Pyritic schist.
N58162	0.100	0.7	Silicified pyritic alteration in felsic schist.
N58163	0.025	0.3	Quartz veining in Owen Conglomerate.
N58164	0.032	-	Quartz veining with limonite.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58165	0.050	0.6	Pyritic schist.
N58166	0.275	0.4	Pyritic schist.
N58167	0.258	0.7	Pyritic schist.
N58168	4.830	56.0	Silica-pyrite 'head'.
N58169	0.067	-	Quartz-chlorite-pyrite veins in silica-pyrite body.
N58171	0.367	-	Silica-pyrite body.
N58172	0.167	8.2	Pyrite-silica 'head'.
N58173	0.117	-	Gordon pug with nodular goethite.
N58174	0.032	0.5	Hematitic chert.
N58175	0.100	9.0	Hematitic schist with silicified pods and some barite.
N58176	0.025	3.0	Hematitic siliceous breccia/conglomerate.
N58177	0.158	6.0	Silica-pyrite body near schist-Pioneer Beds contact.
N58178	0.283	80.0	Schist containing chalcocite, hematite, sericite, pyrite and small silica 'heads'.
N58179	0.032	0.4	Hematitic schist near schist-Gordon contact.
N58181	0.032	-	Intensely hematitic sandstone.
N58182	0.032	18.4	Pyritic Gordon pug on fault.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58183	0.025	0.5	Hematized sandstone.
N58184	-	-	Intensely hematized sandstone.
N58185	0.050	1.1	Goethitic Gordon pug.
N58186	0.017	-	Massive goethitic outcrop over Gordon pug.
N58187	0.032	-	Goethitic material in Gordon pug.
N58188	0.017	0.1	Quartz-chlorite veining.
N58189	0.117	0.6	Quartz-sericite-pyrite schist.
N58191	0.200	0.4	Quartz-sericite-pyrite schist.
N58192	0.050	-	Quartz-sericite-pyrite schist.
N58193	0.032	0.4	Quartz-chlorite veins.
N58194	1.000	5.4	Massive pyrite band.
N58195	0.567	2.3	Pyrite sericite schist with chalcopyrite.
N58196	0.717	5.5	Quartz veins with abundant pyrite.
N58197	0.350	2.2	Quartz veins with chalcopyrite.
N58198	0.017	-	Quartz veins.
N58199	0.150	1.7	Coarse grained pyrite in fault.
N58201	0.383	2.5	Coarse grained pyrite and quartz band.
N58202	0.550	1.6	Massive pyrite band.

SAMPLE NO.	Au(ppm)	Ag(ppm)	DESCRIPTION
N58203	0.108	5.6	Barite veins in sericitic material.
N58204	0.167	3.6	Fine grained massive pyrite.
N58205	0.100	0.6	Fine laminated pyrite-silica-sericite rock.
N58206	0.750	4.1	Banded massive pyrite-silica with some sericite.
N58207	0.008	-	Chloritic schist with disseminated pyrite and chalcopyrite.
N58208	0.133	2.3	Weathered gossanous massive silica.
N58209	0.100	0.5	Weathered gossanous massive silica.
N58211	0.850	10.5	Massive silica-pyrite body.
N58212	0.267	3.8	Massive silica body with limonite.
N58213	0.150	2.7	Small heads of massive silica-pyrite in sericite-pyrite-silica schist.
N58214	0.108	0.9	Small heads of massive silica pyrite in sericite-quartz-pyrite schist.
N58215	-	-	Massive silica body with very minor pyrite.
N58216	0.175	1.8	Massive silica body.
N58217	0.067	0.2	Massive silica body.
N58218	0.283	1.3	Massive silica-pyrite body containing barite.
N58219	0.350	8.8	Massive silica-pyrite body.

SAMPLE NO	Au(ppm)	Ag(ppm)	DESCRIPTION
N58221	0.040	-	Massive silica body with minor pyrite in parts.
N58222	-	-	Massive silica body.
N58223	-	134	Massive laminated silica-pyrite-galena.
N58224	-	7.7	Gossanous hematite-silica-barite breccia.
N58225	0.040	16.2	Massive galena-pyrite from the dump at Tasman Crown.
N58226	0.083	12.5	Silicified breccia-conglomerate with galena-pyrite mineralization.



- FAULTED CONTACT
- UNFAULTED CONTACT
- COPPER (GOLD, SILVER) OREBODY. OUTLINES OF NORTH LYELL GROUP OF OREBODIES PROJECTED FROM 1 & 2 LEVELS. OUTLINES OF WEST LYELL OREBODIES ARE PROJECTIONS OF >1% Cu FROM 11 LEVEL.
- DISSEMINATED SULPHIDES EXCEEDING ABOUT 5%; MOSTLY PYRITE; SOME CHALCOPYRITE AND BORNITE.
- ZONES WITH OBSERVED / SUSPECTED BOUDINAGED BEDS OF MASSIVE PYRITE; BOUNDARIES VERY APPROXIMATE.
- MASSIVE PYRITE WITH SILICA AND MINOR CHALCOPYRITE, TETRAHEDRITE.
- SILICA-BARITE AND/OR HEMATITE-BARITE ALTERATION COMMONLY WITH HYDROTHERMAL BRECCIA TEXTURES.
- GORDON LIMESTONE, BLACK CARBONACEOUS OR VARIABLY LIMONITIC PUGGY CLAY ASSUMED TO BE DERIVED FROM LIMESTONE.
- PIONEER BEDS, FINE CONGLOMERATE AND MEDIUM TO FINE SANDSTONE (INCLUDING CHROMITE-BEARING QUARTZITE).
- OWEN CONGLOMERATE  
MEDIUM TO FINE GRAINED SANDSTONE, SLATE, HEMATITIC.  
INTERBEDDED MEDIUM TO FINE CONGLOMERATE, COARSE TO FINE SANDSTONE, SLATE, HEMATITIC.  
COARSE CONGLOMERATE; ONLY MINOR SANDSTONE.  
UNDIVIDED; MAY INCLUDE ALL ROCK TYPES ABOVE.

- MT. READ VOLCANICS  
MAFIC SCHIST, GENERALLY CHLORITIC, WITHOUT SILICEOUS PODS AND BANDS, VARIABLY SERICITIC & SILICIFIED.  
SCHIST WITH SILICEOUS PODS AND BANDS OF FELSIC VOLCANIC DERIVATION; SERICITIC & VARIABLY CHLORITIC.  
UNDIVIDED MIXTURE OF MAFIC SCHIST AND SCHIST WITH SILICEOUS PODS AND BANDS (AS ABOVE).  
UNDIVIDED MIXTURE OF MAFIC SCHIST AND SCHIST WITH SILICEOUS PODS AND BANDS (AS ABOVE) BUT ALSO INCLUDING LARGE AND SMALL BOUDINS (HEADS) OF SILICA-PYRITE.

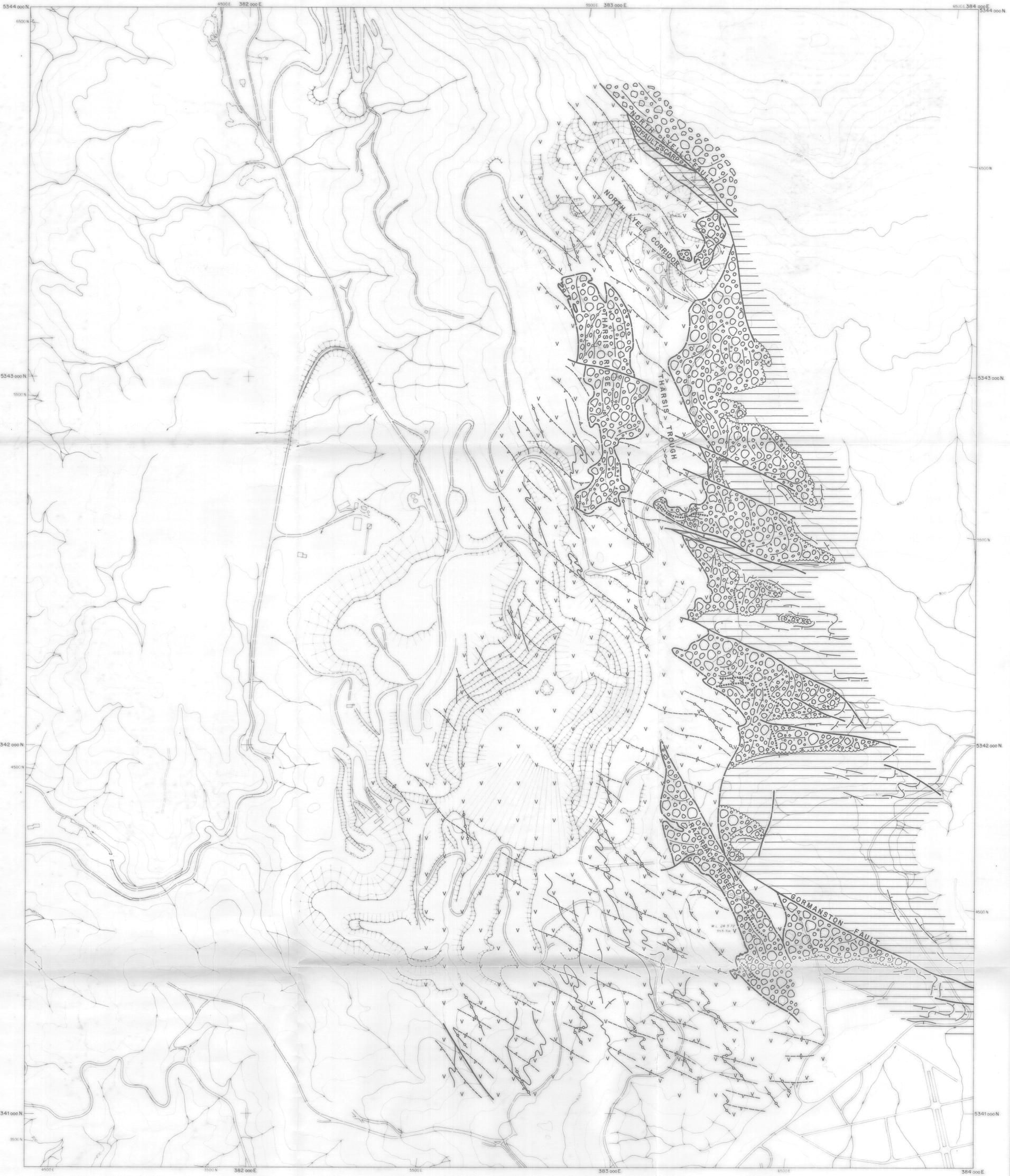
\* NOTE: INTERPRETATION BASED ON SURFACE GEOLOGY MAPPING, PLATE 3. ALL CONTACTS AND DISTRIBUTIONS OUTSIDE OUTCROP AREAS ARE SPECULATIVE.

5 cm

86 107 7276

REVISIONS		GOLD FIELDS EXPLORATION PTY. LIMITED	
DESIGNED BY	G. A.	<b>MT. LYELL - TASMANIA</b> <b>INTERPRETATION MAP</b> (GEOLOGY AND MINERALIZATION)	
DRAWN BY	D.E.K.A.		
DATE	JUNE, 1985		
CHECKED BY	G. A.		
APPROVED BY			
SCALE 1:5000			
		PLATE 1	

85-2474



- BEDDING
- BEDDING WITH DIP AND FACING
- OVERTURNED BEDDING
- S<sub>2</sub> WITH DIP
- S<sub>1</sub> (GENERALLY STEEPLY DIPPING) \*
- ..... AXIAL SURFACE TRACE OF "HAULAGE" RECURRENT FOLDS, DIPS VARIABLE \*
- FAULT (YOUNGER THAN GREAT LYELL FAULT)
- GREAT LYELL FAULT
- ~~~~~ HAULAGE UNCONFORMITY

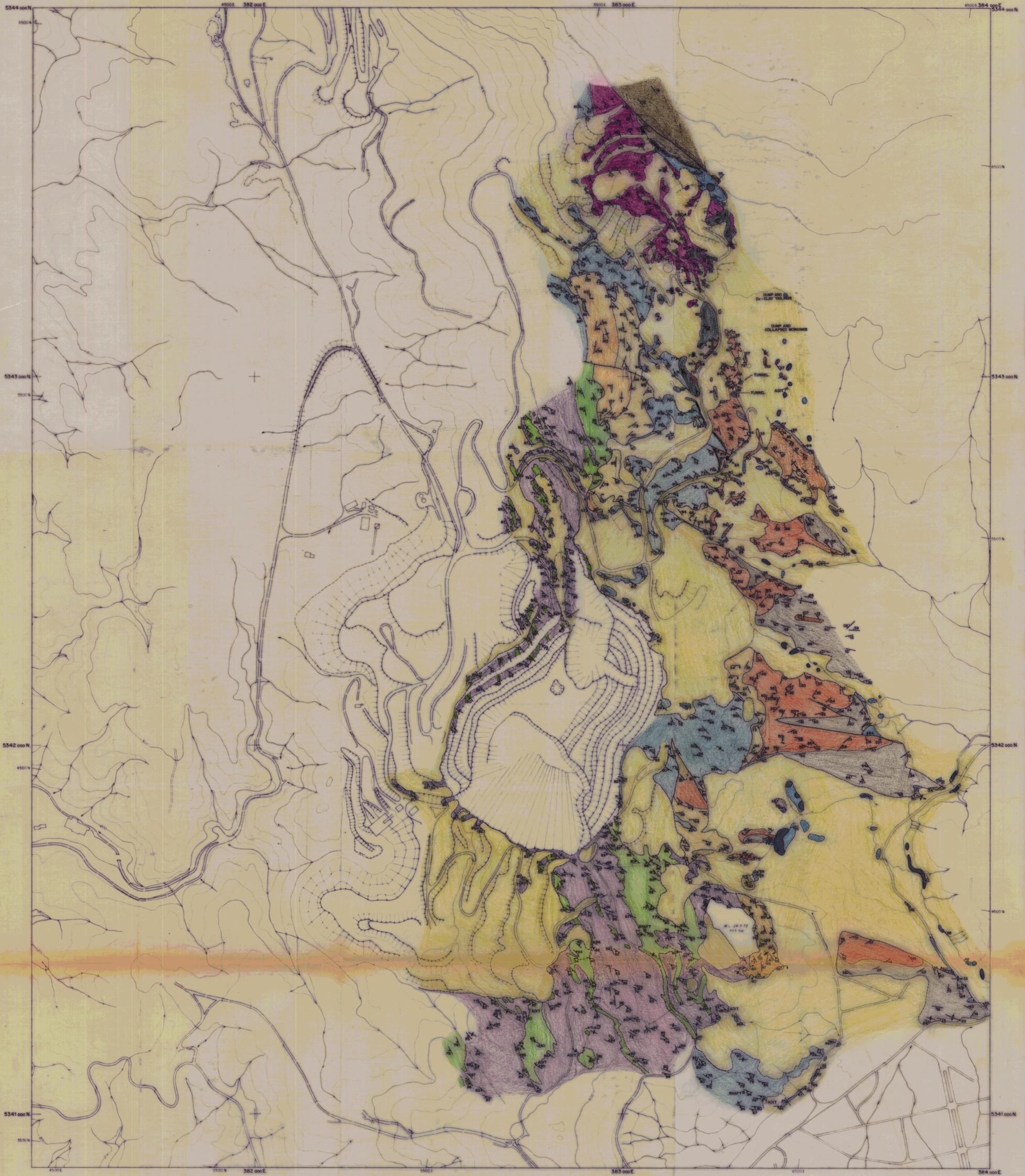
- ▬▬▬ PIONEER BEDS AND GORDON LIMESTONE
- ○ ○ OWEN CONGLOMERATE
- V V V MT READ VOLCANICS

86 108 5 cm 7277

REVISIONS	GOLD FIELDS EXPLORATION PTY. LIMITED	
GEOLOGIST	G. A.	<b>MT. LYELL - TASMANIA</b> <b>STRUCTURAL</b> <b>INTERPRETATION</b>
DRAWN	D.E.K.A.	
DATE	JULY, 1985	
CHECKED	G. A.	
SCALE 1:5000		PLATE 2

\* LIKELY TO BE PRESENT MORE EXTENSIVELY THAN IDENTIFIED AND SHOWN ON THIS MAP.

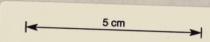
85-2474



- S1 CLEAVAGE
- S2 CLEAVAGE
- BEDDING
- BEDDING WITH FACING
- OVERTURNED BEDDING
- SYNCLINAL AXIS
- ANTICLINAL AXIS
- FAULT WITH DIP
- FAULTED CONTACT
- UNFAULTED CONTACT

- COVER OF MINE DUMPS AND ALLUVIUM AND COLLUVIUM ( SOME OF PLEISTOCENE GLACIAL ORIGIN ).
- LIMONITIC AND BLEACHED GORDON LIMESTONE. MASSIVE TRANSPORTED GOETHITE.
- GORDON LIMESTONE. BLACK CARBONACEOUS OR VARIABLY LIMONITIC PUGGY CLAY ASSUMED TO BE DERIVED FROM LIMESTONE.
- PIONEER BEDS. FINE CONGLOMERATE AND MEDIUM TO FINE SANDSTONE ( INCLUDING CHROMITE-BEARING QUARTZITE ).
- OWEN CONGLOMERATE
- MEDIUM TO FINE GRAINED SANDSTONE, SLATE; HEMATITIC.
- INTERBEDDED MEDIUM TO FINE CONGLOMERATE, COARSE TO FINE SANDSTONE, SLATE, HEMATITIC.
- COARSE CONGLOMERATE, ONLY MINOR SANDSTONE.
- UNDIVIDED; MAY INCLUDE ALL ROCK TYPES ABOVE. DARK AREAS INDICATE MASSIVE SILICA OR HEMATITE ALTERATION.
- MT. READ VOLCANICS
- MAFIC SCHIST, GENERALLY CHLORITIC, WITHOUT SILICEOUS PODS AND BANDS, VARIABLY SERICITIC AND SILICIFIED.
- SCHIST WITH SILICEOUS PODS AND BANDS OF FELSIC VOLCANIC DERIVATION, SERICITIC AND VARIABLY CHLORITIC.
- UNDIVIDED MIXTURE OF MAFIC SCHIST AND SCHIST WITH SILICEOUS PODS AND BANDS, AS ABOVE.
- UNDIVIDED MIXTURE OF MAFIC SCHIST AND SCHIST WITH SILICEOUS PODS AND BANDS ( AS ABOVE ) BUT ALSO INCLUDING LARGE AND SMALL BODIES ( HEADS ) OF SILICA-PYRITE.

86 109



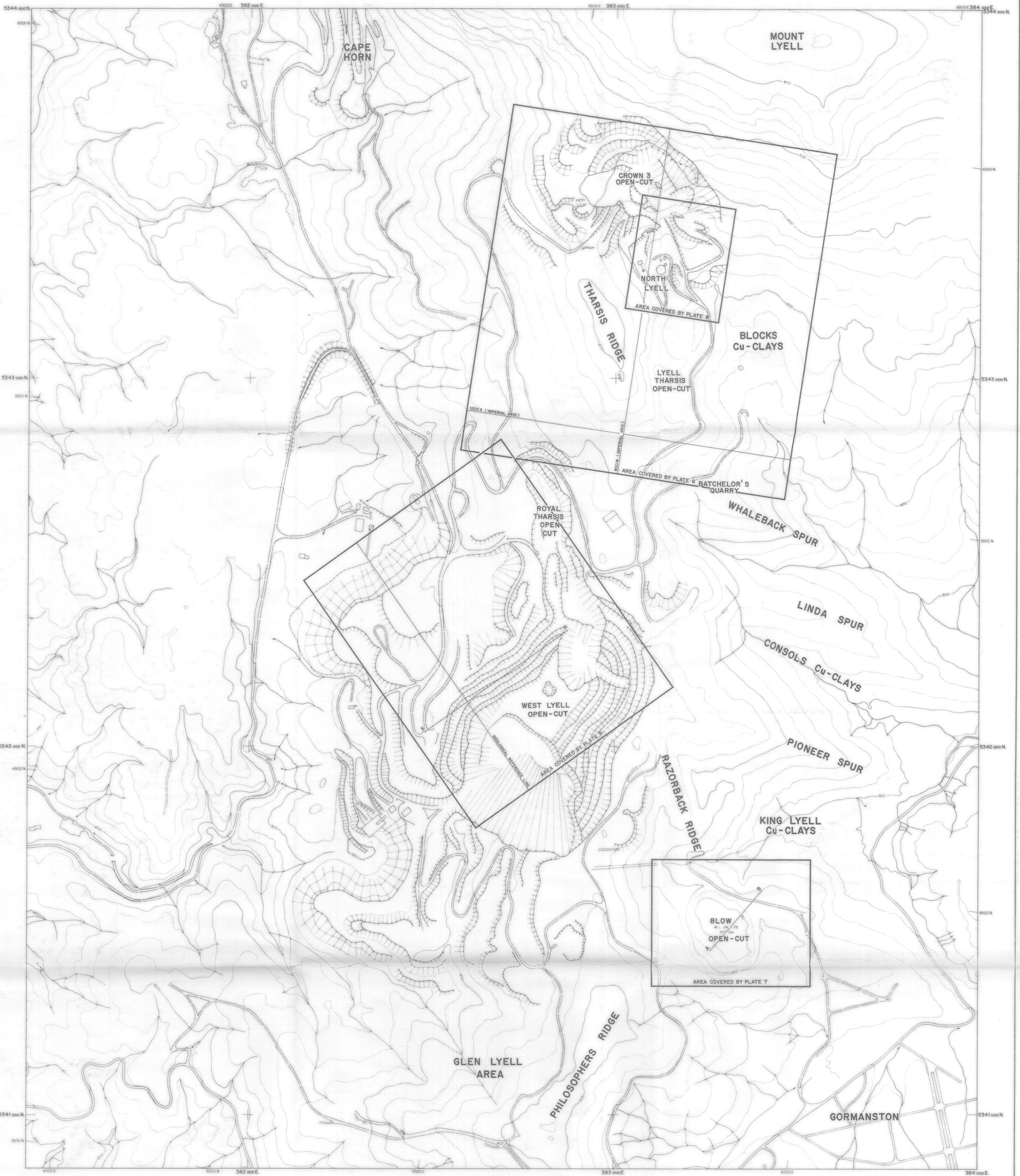
7278

REVISIONS		GOLD FIELDS EXPLORATION PTY. LIMITED	
BY	G.A.	<b>MT. LYELL - TASMANIA</b> <b>SURFACE GEOLOGY</b>	
DRAWN	D.E.K.A.		
DATE	JUNE, 1985		
CHECKED	G.A.		
SCALE 1:5000			

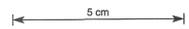
85-2474

PLATE 3





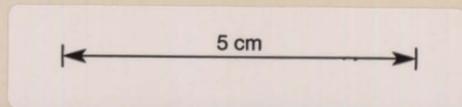
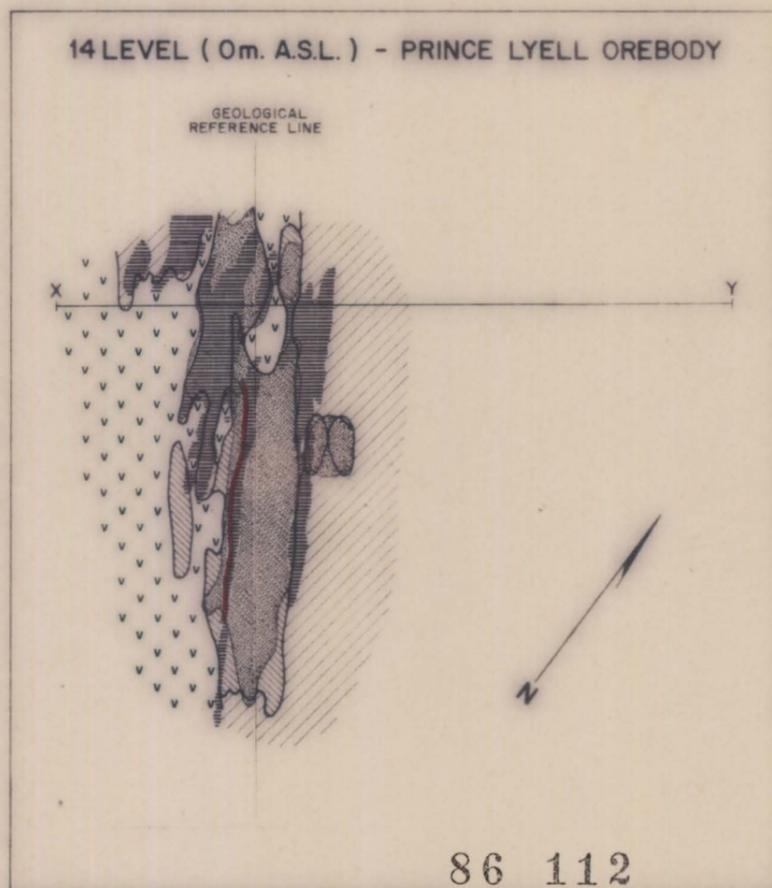
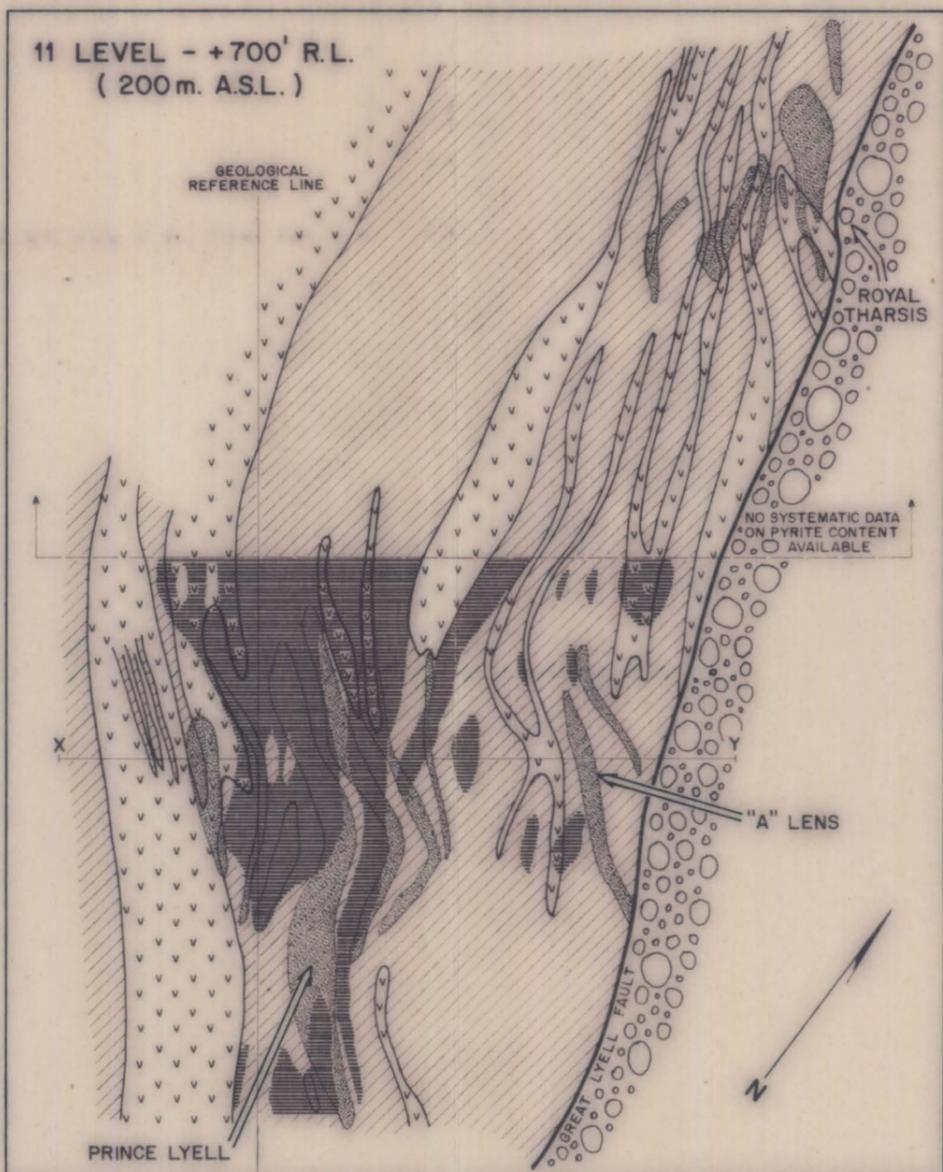
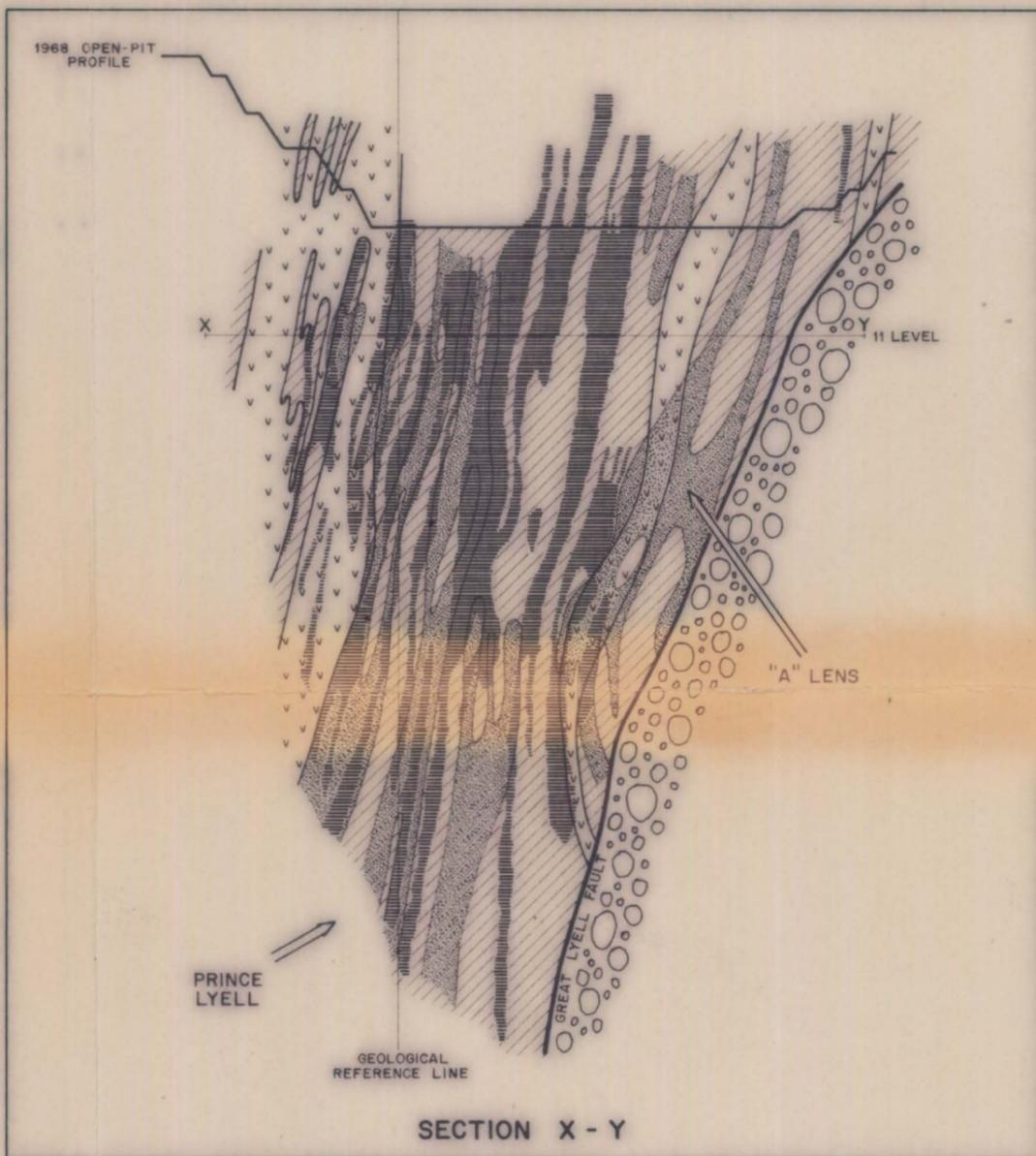
86 111



35-2474

7250

REVISIONS		GOLD FIELDS EXPLORATION PTY. LIMITED	
GEOLOGIST	G. A.	<b>MT. LYELL - TASMANIA</b> <b>LOCATION OF TOPOGRAPHIC</b> <b>FEATURES AND SUPPORTING</b> <b>PLANS, SECTIONS AND</b> <b>LEVEL PLANS</b>	
DRAWN	D.E.K.A.		
DATE	JULY '85		
CHECKED	G. A.		
1:250,000 Reference			
SCALE 1:5000			
		PLATE 5	



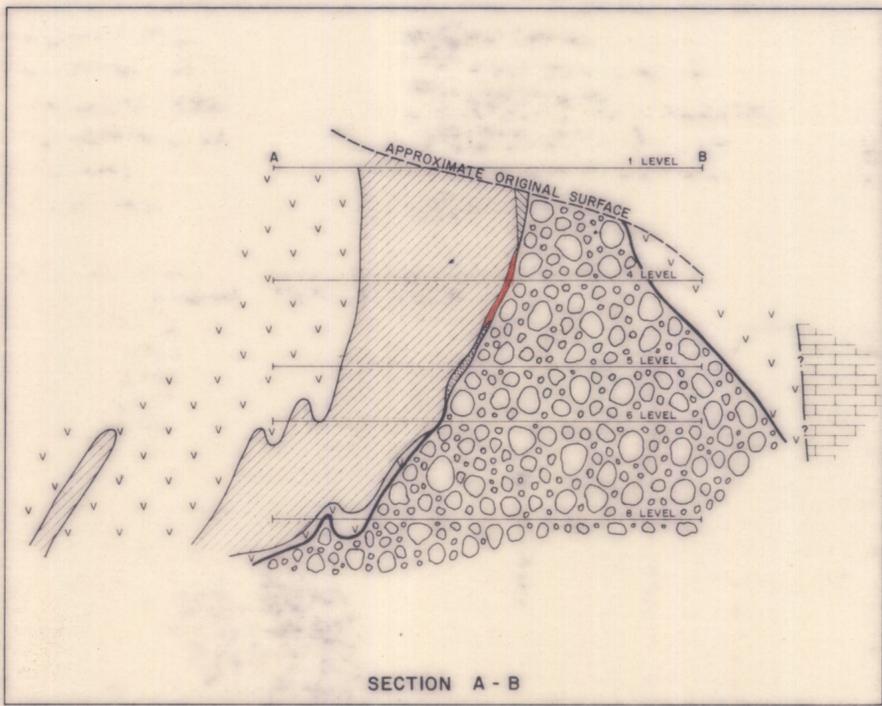
7281

- |  |  |  |  |
|--|--|--|--|
|  | CHLORITIC MAFIC SCHIST   |  | > 1.0% COPPER                                |
|  | BANDED AND FRAGMENTAL FELSIC SCHIST                            |  | > 10.0% PYRITE                               |
|  | SILICEOUS FRAGMENTAL WITH STRONGLY CHLORITIC MATRIX (14 LEVEL) |  | ZINC ANOMALOUS BAND (> 0.1% ZINC - 14 LEVEL) |
|  | OWEN CONGLOMERATE  |  |  |

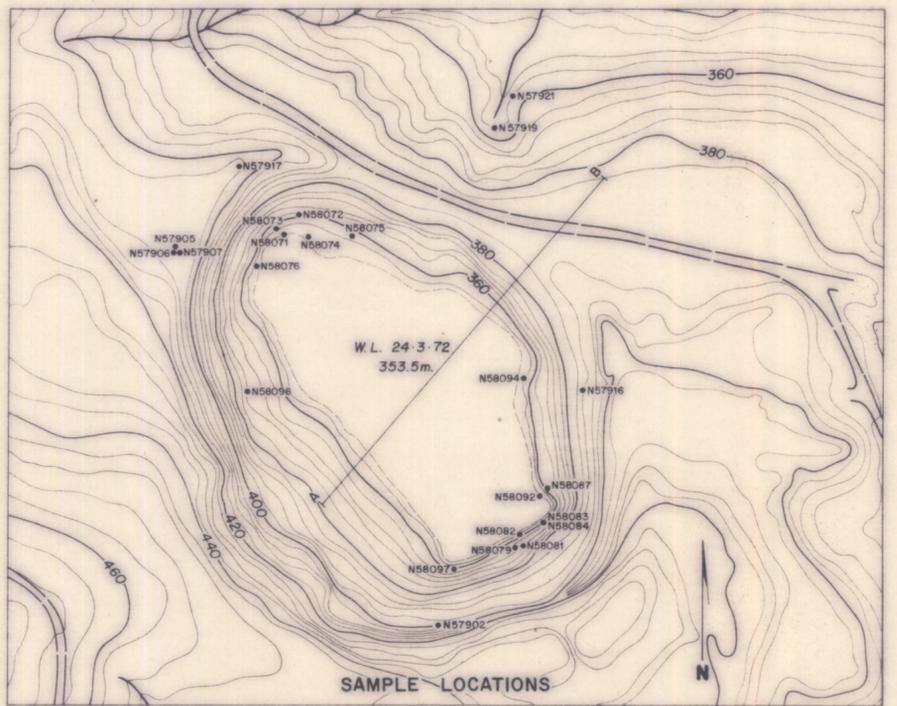
GOLD FIELDS EXPLORATION PTY. LIMITED	
Geologist:	G. A.
Drawn:	D. E. K. A.
Date:	JULY 85
Checked:	G. A.
1:250,000 Reference	
SCALE 1:5000	m. 50 25 0 50 100 150 m.
PLATE 6	

MT. LYELL - TASMANIA  
WEST LYELL OREBODIES  
SECTION AND LEVEL PLANS

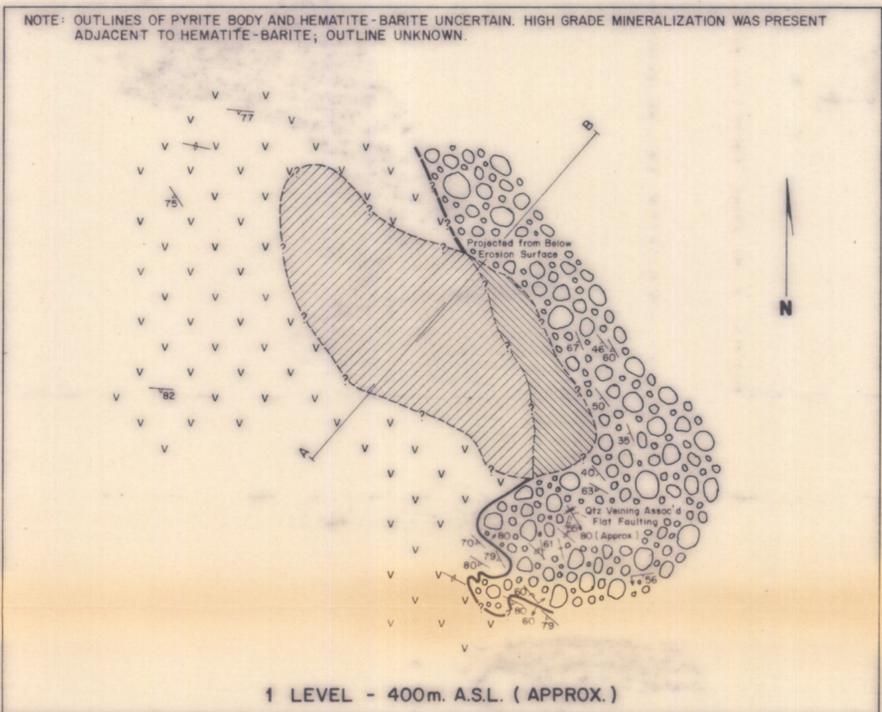
85-2474



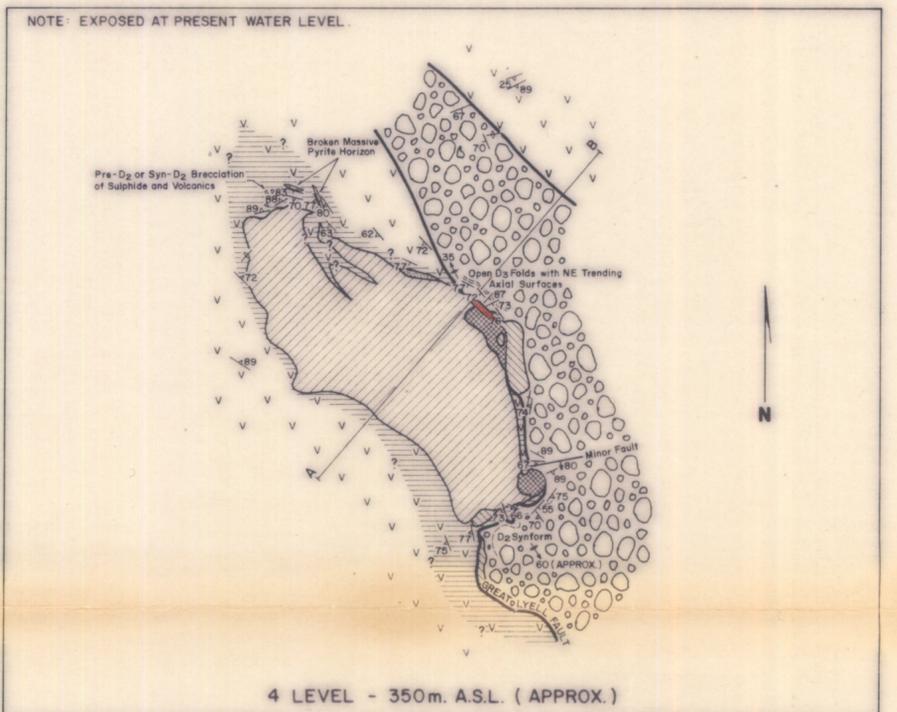
SECTION A - B



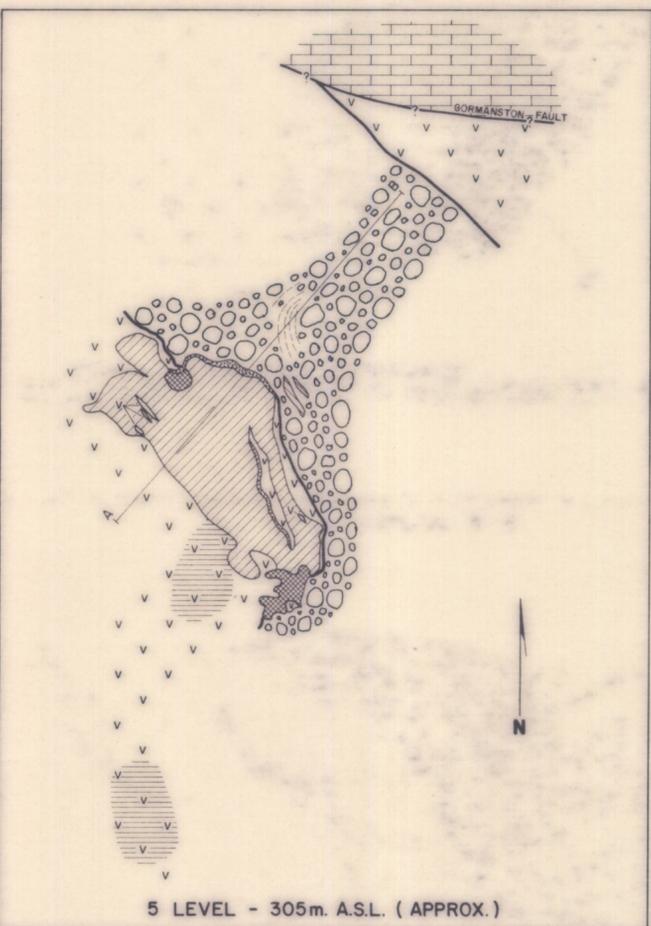
SAMPLE LOCATIONS



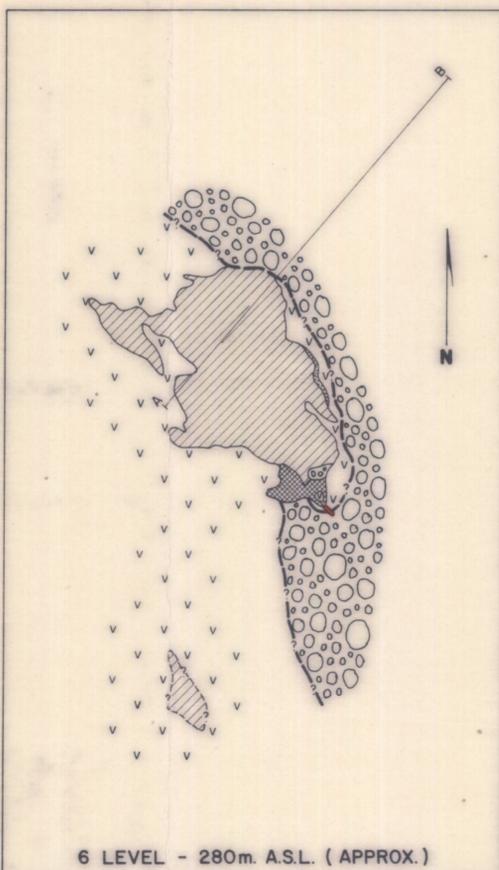
1 LEVEL - 400m. A.S.L. ( APPROX. )



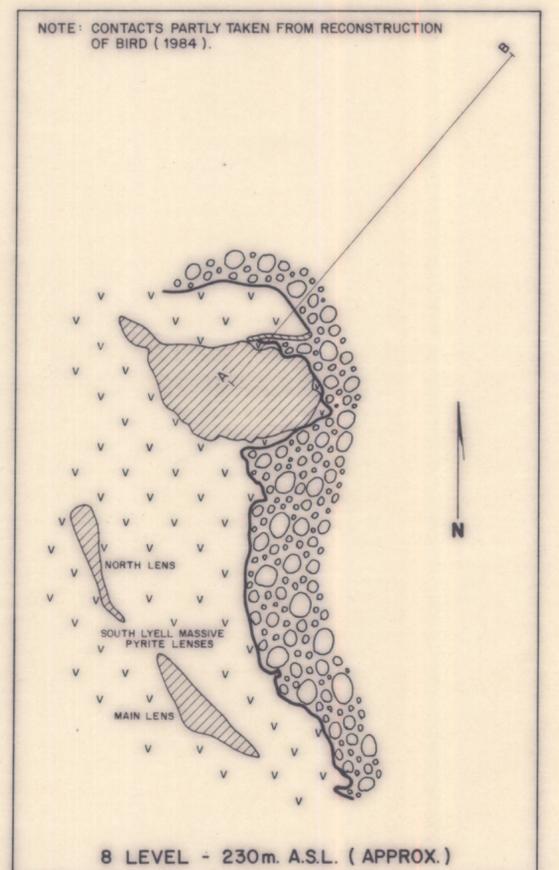
4 LEVEL - 350m. A.S.L. ( APPROX. )



5 LEVEL - 305m. A.S.L. ( APPROX. )



6 LEVEL - 280m. A.S.L. ( APPROX. )



8 LEVEL - 230m. A.S.L. ( APPROX. )

86 113

5 cm

7282

- S<sub>1</sub> CLEAVAGE
- BEDDING
- BEDDING WITH FACING
- OVERTURNED BEDDING
- SYNCLINAL AXIS
- FAULT / WITH DIP
- OWEN CONGLOMERATE
- FELSIC SCHIST - MT READ VOLCANICS
- FELSIC SCHIST WITH STRONG (>10%) DISSEMINATED PYRITE \*
- MASSIVE PYRITE WITH MINOR TETRAHEDRITE, CHALCOPYRITE, BARITE
- MASSIVE HEMATITE WITH BARITE
- HIGH GRADE ORE
- "BONANZA SILVER SHOOT"
- CHERT
- "GORDON LIMESTONE": GOSSAN AND BLACK PUG

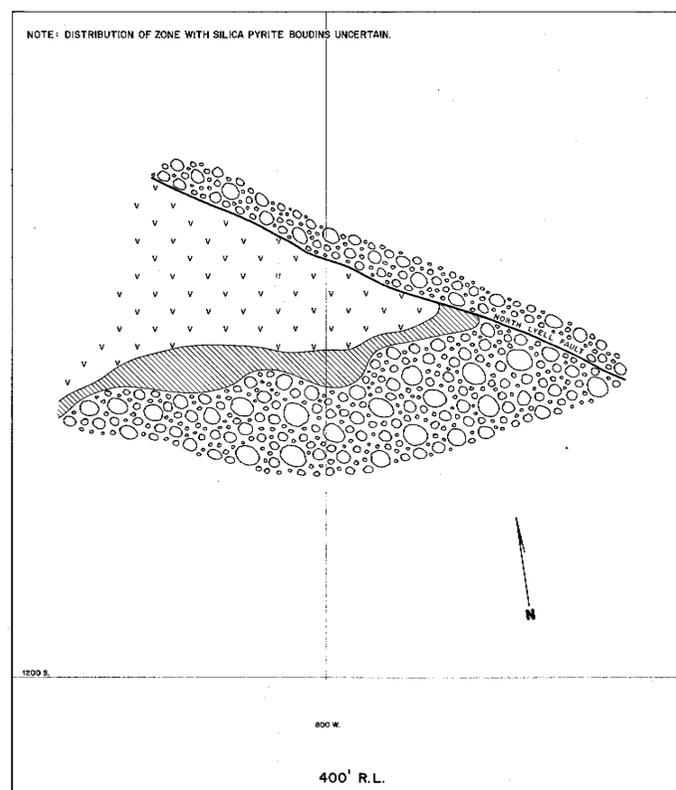
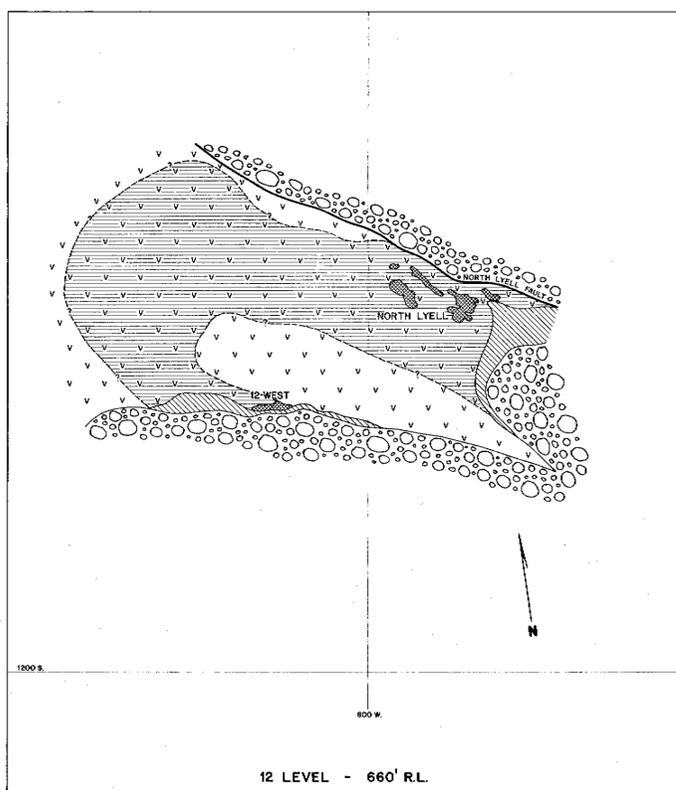
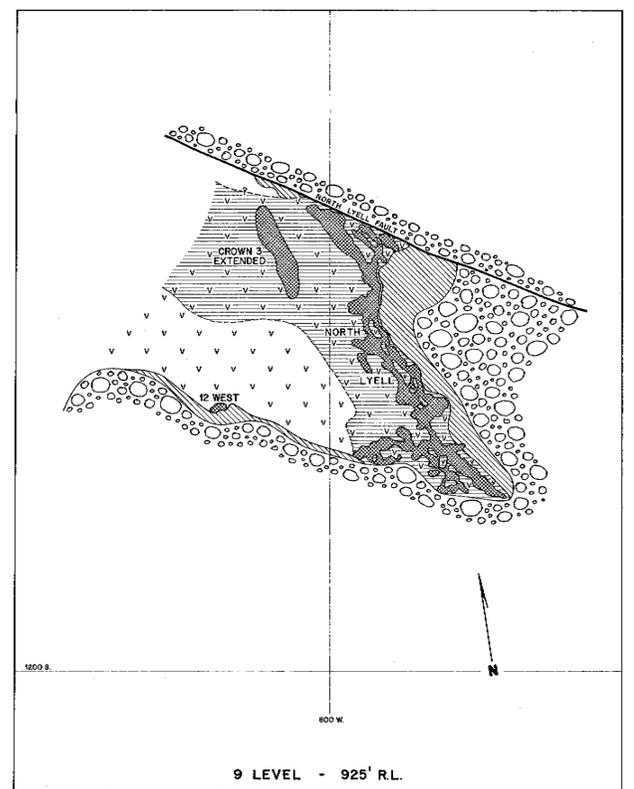
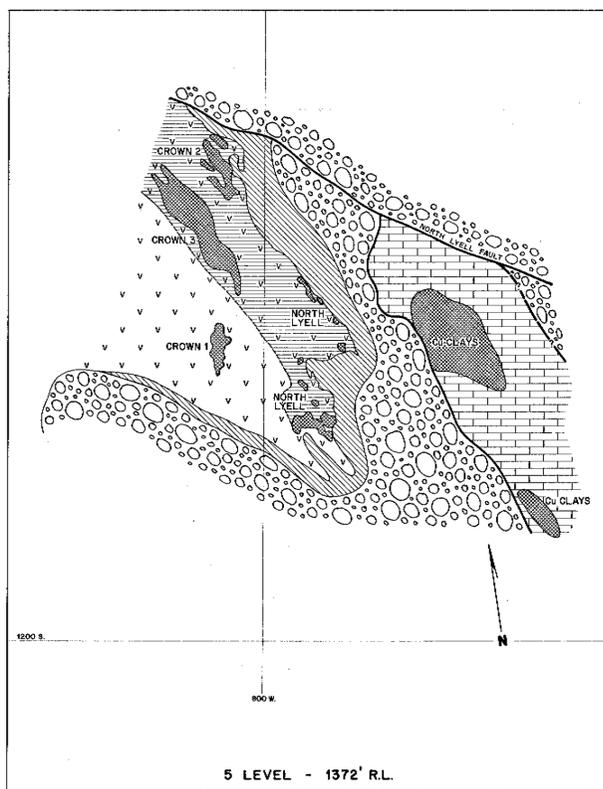
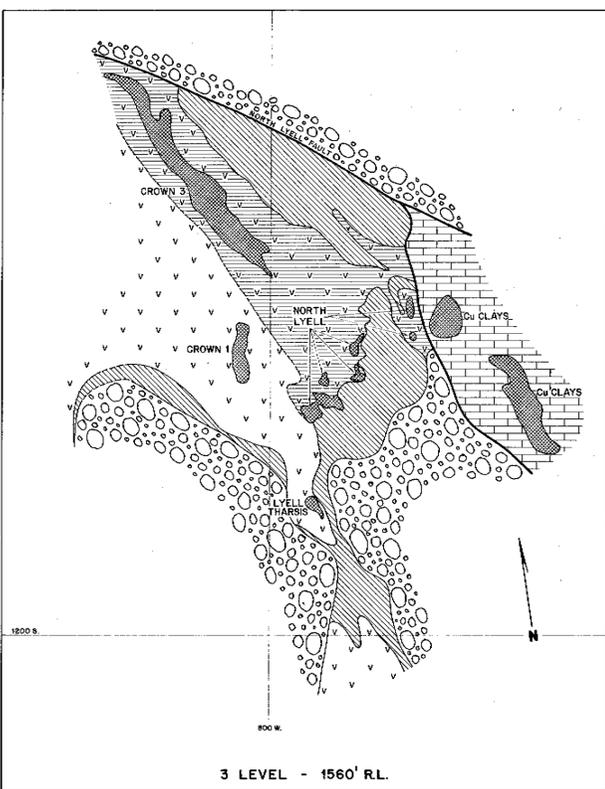
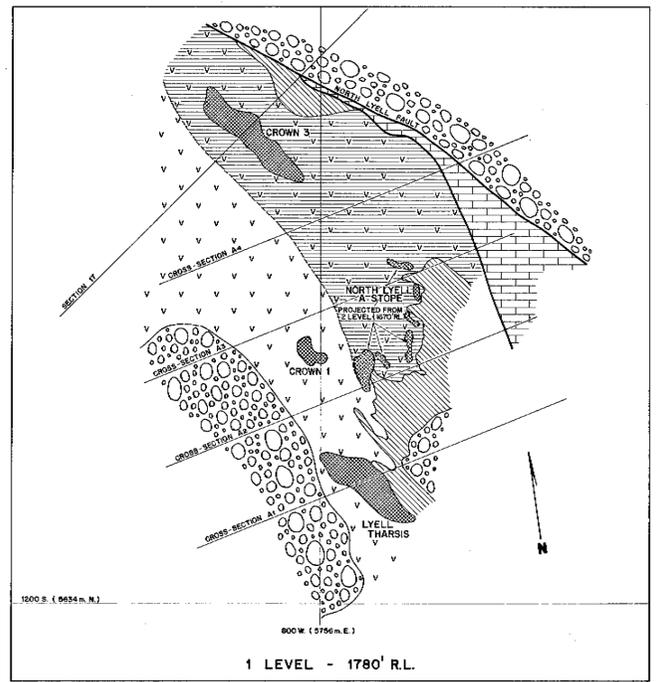
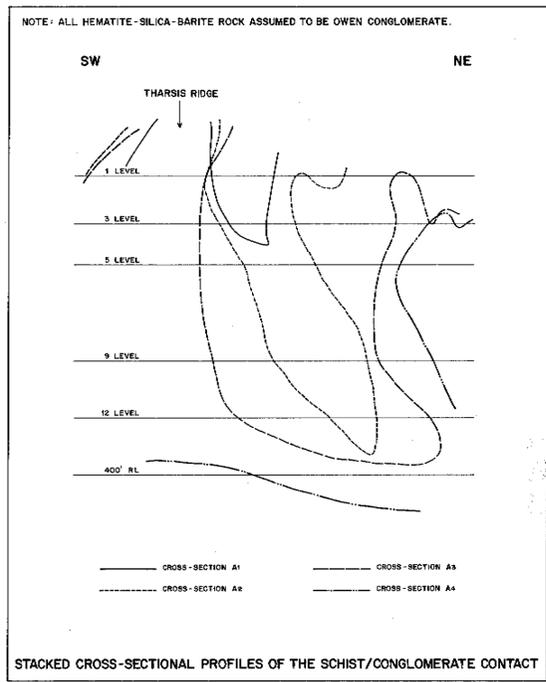
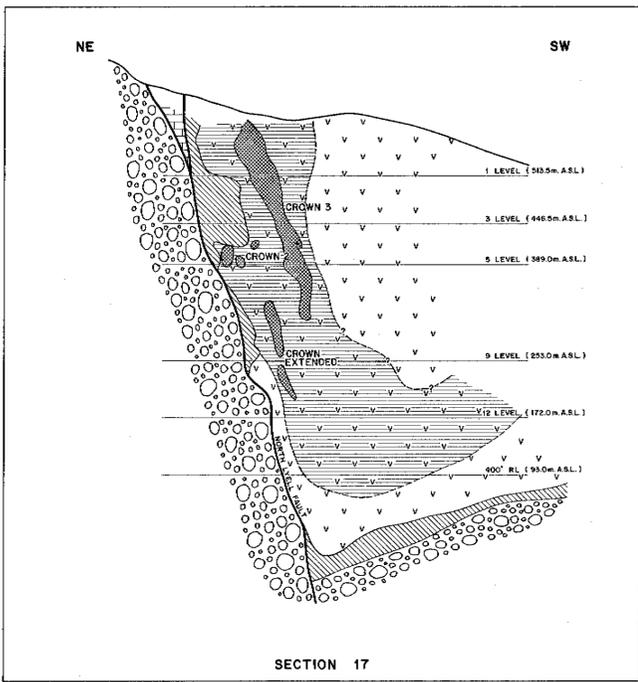
\*N58081 ROCK SAMPLE LOCATION / SAMPLE No.

\* — DISTRIBUTION LIKELY TO BE MORE WIDESPREAD THAN IDENTIFIED AND SHOWN ON THIS MAP.

GOLD FIELDS EXPLORATION PTY. LIMITED

GEOLOGIST:	G. A.	<b>MT. LYELL - TASMANIA</b> <b>THE BLOW OREBODY</b> <b>SECTION, SAMPLE LOCATION,</b> <b>LEVEL PLANS</b>
DRAWN:	D. E. K. A.	
DATE:	JULY, 1984	
CHECKED:	G. A.	
1:250,000 REFERENCE:		
SCALE 1:2500		PLATE 7

85-2474



- FAULT
- GORDON LIMESTONE
- OWEN CONGLOMERATE
- FELSIC SCHIST AND MAFIC SCHIST
- ZONE WITH LARGE AND SMALL BOUDINS OF SILICA AND SILICA-PYRITE SURROUNDED BY FELSIC AND MAFIC SCHIST
- HEMATITE-BARITE AND/OR SILICA-BARITE ALTERATION DERIVED MOSTLY FROM OWEN CONGLOMERATE
- OREBODY

\* PIONEER BEDS COULD NOT BE IDENTIFIED IN EXISTING LEVEL PLANS.

86 114

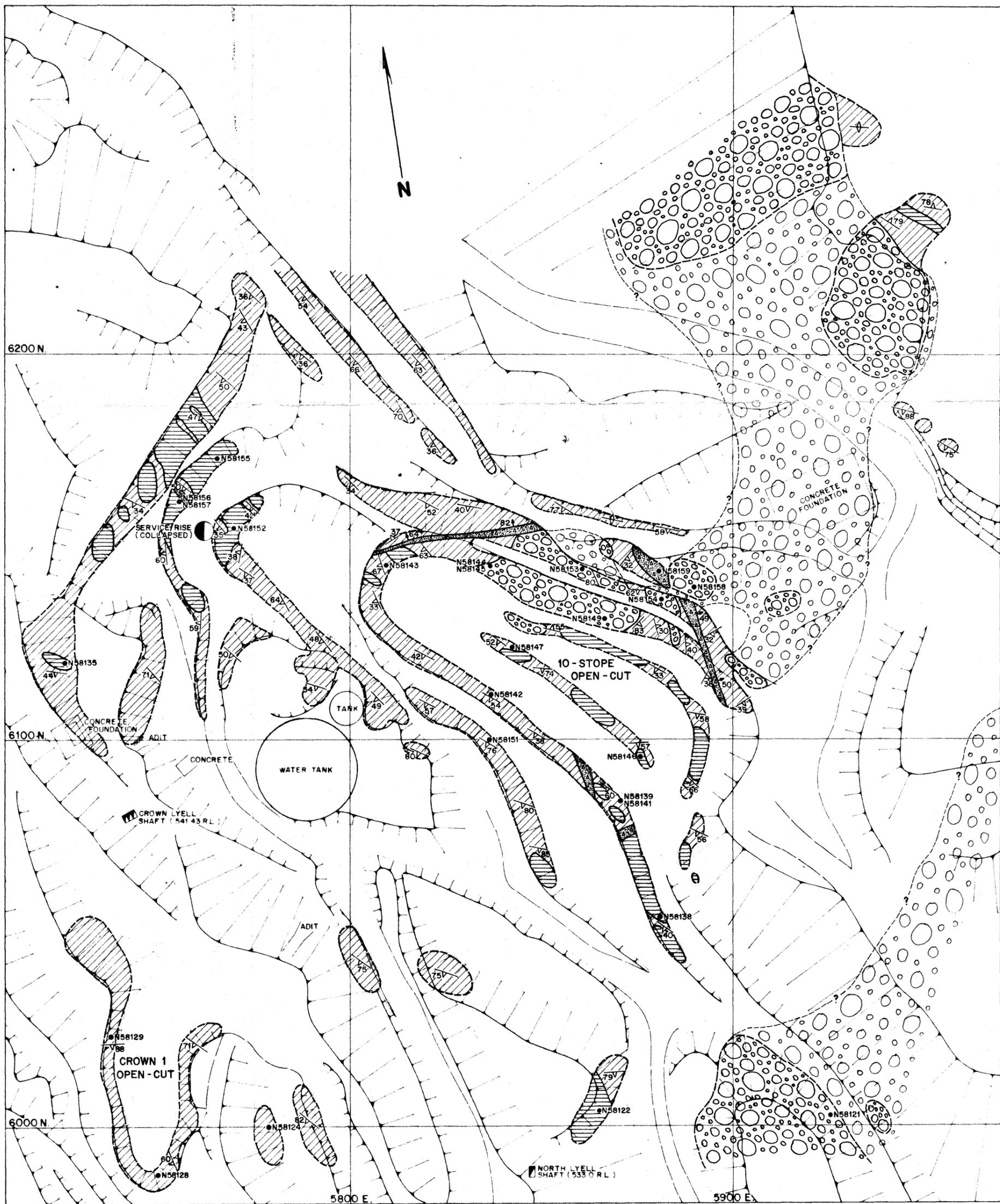
5 cm

7283

REVISIONS		GOLD FIELDS EXPLORATION PTY. LIMITED	
GEOLOGIST	G. A.	<b>MT. LYELL - TASMANIA</b> <b>NORTH LYELL OREBODIES</b> <b>SECTIONS AND LEVEL PLANS</b>	
DRAWN	D.E.K.A.		
DATE	JULY, 1985		
CHECKED	G. A.		
Reference:	1:250,000		
SCALE 1:50000			

PLATE 8

85-2474



- SILICEOUS BRECCIA/CONGLOMERATE, VARIABLY HEMATITIC, POSSIBLY MOSTLY OWEN CONGLOMERATE
- SILICEOUS "HEAD" WITHIN MT READ VOLCANICS; VARIABLY (OFTEN INTENSELY) PYRITIC
- QUARTZ-SERICITE (±PYROPHYLLITE) SCHIST DERIVED FROM MT READ VOLCANICS
- LATE ADJUSTMENT FAULT ZONE WITH BENDING AND BRECCIATION OF THE S<sub>2</sub> SCHISTOSITY. DIP INDICATED

- S<sub>2</sub> SCHISTOSITY
- BEDDING

● N58124 SAMPLE LOCATION/SAMPLE No.

5 cm

7284

85-2474

86 115

GOLD FIELDS EXPLORATION PTY. LIMITED	
Geologist	G. A.
Drawn	D.E.K.A.
Date	JULY '85
Checked	G. A.
Reference	1:250 000
SCALE 1:1000	m. 10 5 0 10 20 30 m.

**MT. LYELL - TASMANIA**  
**NORTH LYELL**  
**DETAILED GEOLOGY**  
**( 10-STOPE OPEN-CUT )**

PLATE 9