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EXCURSION GUIDE

MOUNT READ VOLCANICS AND ASSOCIATED ORE DEPOSITS, TASMANIA

Keith Corbett and Jocelyn McPhie

GENERAL ASSEMBLY
SEPTEMBER 1993 - CANBERRA AUSTRALIA

ANCIENT VOLCANISM & MODERN ANALOGUES

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Record 1993/63
Australian Geological Survey Organisation

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Hon. Michael Lee
Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Harvey Jacka

ISSN: 1039-0073

ISBN: 0 642 19664 8

IAVCEI 1993

Ancient Volcanism and Modern Analogues

EXCURSION GUIDE C3

MOUNT READ VOLCANICS AND ASSOCIATED ORE DEPOSITS, TASMANIA

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EXCURSION ITINERARY

DAY 1 — Monday 4 October — MT READ – HERCULES MINE AREA

Stop 1	Mt Read gate – Rosebery Fault
Stop 2	Rosebery lookout, Mt Read road
Stop 3	Summit of Mt Read
Stop 4	Mt Hamilton link track walk
Stop 5	Link track, hangingwall pumice breccia
Stop 6	G10 Glory Hole, hangingwall quartz-bearing mass-flow units
Stop 7	Hercules Mine 4 Level road
Stop 8	E Lode pit
Stop 9	4 Level road, footwall pumice breccia
Stop 10	Hercules access road, walk down to Williamsford

DAY 2 — Tuesday 5 October — HELLYER MINE AREA

Stop 1	Tailings dam canal, Animal Creek Greywacke, Hellyer basalt, Que River Shale
Stop 2	Haul road switchback, mixed sequence polymict breccia, dacite
Stop 3	Cradle Mountain Link Road, ignimbrite in Tyndall Group correlates
Stop 4	Hellyer Mine underground visit

DAY 3 — Wednesday 6 October — ANTHONY ROAD – HENTY AREA

Stop 1	Lookout above Anthony Dam
Stop 2	Newton Gap on Anthony Road, Owen Conglomerate sequence
Stop 3	Newton Dam spillway, volcaniclastics with sulphide clasts
Stop 4	Henty Canal, Tyndall Group breccia
Stop 5	Henty Gold Prospect, portal area
Stop 6	Hall Rivulet Canal, mass-flow breccia
Stop 7	Anthony Road, Tyndall Group banded crystal-rich sandstone
Stop 8	Anthony Road Andesite breccia

DAY 4 — Thursday 7 October — QUEENSTOWN – MT LYELL MINE AREA

Stop 1	West Lyell Open Cut
Stop 2	Tyndall Group near substation
Stop 3	Philosophers Ridge and Blow Open Cut

INTRODUCTION TO THE MT READ VOLCANICS

The Middle Cambrian Mt Read Volcanics form a belt 10–20 km wide extending for some 250 km through western and northern Tasmania (fig. 1). The sequence contains several world-class volcanic-hosted massive sulphide (VHMS) deposits and numerous prospects. The volcanics are calc-alkaline and predominantly rhyolitic, dacitic and andesitic, with relatively minor basalts. They interfinger to the west with Cambrian sedimentary sequences, but to the east are either faulted against, or unconformably overlie, a basement block of Precambrian quartzite and schist referred to as the Tyennan Region.

Recent publications dealing with the Mt Read Volcanics include those of Corbett and Solomon (1989), McPhie and Allen (1992), Crawford *et al.* (1992), and Corbett (1992).

Overlying and concealing the volcanics in many areas is a sequence of mainly shallow marine to terrestrial siliciclastic conglomerate and sandstone, of Late Cambrian–Early Ordovician age, referred to as the Owen Conglomerate. This hard, competent rock type forms most of the mountain peaks along the volcanic belt (West Coast Range), and is overlain in the synclinal valleys by a thick Ordovician limestone.

The volcanics have been through several periods of folding, cleavage development and faulting, and have undergone regional lower greenschist facies metamorphism in the Devonian and locally intense hydrothermal alteration in the Cambrian. All primary textures and compositions have been modified to some degree. Notable major faults which affect the sequence are the Henty Fault (and its associated splays including the Mt Charter Fault and the North and South Henty Faults), which cuts the belt obliquely from Henty to Hellyer (fig. 2), the Rosebery Fault, which dips east at 40° under the Rosebery mine, and the Great Lyell Fault, which extends N-S through the Queenstown area.

Detailed mapping at 1:25 000 scale of about 75% of the volcanic belt has recently been accomplished by the Mt Read Volcanics Project in the Division of Mineral Resources. This mapping, together with regional lithogeochemical studies involving major, trace and rare earth elements conducted jointly with Dr A. J. Crawford of the University of Tasmania (Crawford *et al.*, 1992), has established a regional lithostratigraphic framework based on five or six widespread units or associations. These are arranged more or less concentrically around the margin of the Tyennan Region, as follows:–

(1) A thin basal sequence of siliciclastic conglomerate, sandstone and shale resting unconformably (in places at least) on the Precambrian basement and referred to as the Sticht Range Beds.

(2) A sequence of quartz-feldspar-phyric lavas and volcaniclastic rocks, with intrusive porphyries and granitoids, referred to as the Eastern Quartz-Phyric Sequence. This sequence conformably overlies the Sticht Range Beds and interfingers westwards with:

(3) A central belt of mainly felsic (dominantly feldspar-phyric) lavas and interbedded pumice breccias, referred to as the Central Volcanic Complex (CVC). This lava-rich complex is well developed on the northwest side of the Henty Fault between Mt Read and Mt Block, and as a narrower zone southeast of the fault between Red Hills and Mt Darwin (fig. 2). The Complex interfingers westwards with:

(4) Extensive volcano-sedimentary apron-like sequences of sandstone, siltstone, shale and mass-flow breccia, with large tabular bodies of intrusive felsic porphyry in places. These sequences contain Middle Cambrian fossils in several areas, and include the Mt Charter Group, Dundas Group and Yolande River Sequence. Tectonic slivers of ultramafic-mafic rocks occur within these rocks west of the main volcanic belt, and separate the sequence from an older succession of basaltic greywacke and tholeiite referred to as the Crimson Creek Formation.

(5) Large lenses of andesitic and lesser basaltic rocks occur along the belt, within both the Central Volcanic Complex and Western Volcano-Sedimentary Sequence, and appear to be concentrated at a particular stratigraphic level in the late Middle Cambrian. The largest body is the Que–Hellyer Volcanics (fig. 2), from which a narrow extension leads through the Sock Creek area to a body at The Pinnacles. A second major zone occurs southeast of the Henty Fault from the Anthony Road to Mt Lyell.

(6) The youngest part of the volcanic pile is a post-andesite sequence of quartz-feldspar-phyric crystal-rich sandstones, mass-flow breccias and conglomerates with minor lavas and welded tuffs, referred to as the Tyndall Group. This sequence contains the only genuine ignimbrites in the Mount Read Volcanics (White *et al.*, 1993), and has late Middle Cambrian fossils in places. It is generally overlain by the Owen Conglomerate.

Detailed volcanological studies have been undertaken on the Mount Read Volcanics over the last few years using the recent maps as a base, and have greatly increased the understanding of these complex and difficult rocks. Work by Allen and Cas (1990) in the Rosebery–Hercules area has shown that the striking pumice-clast breccias in the host sequences, previously interpreted to be fiamme-bearing ignimbrites, are actually non-welded submarine mass-flow deposits. This interpretation removed the need to postulate large-scale rapid subsidence in the area to achieve the deep marine setting necessary for the VHMS deposits, but in a sense created another problem in accounting for the huge volumes of pumice in a submarine setting.

Detailed studies by McPhie of outcrops and drill core sections in the Hellyer–Pinnacles area has distinguished

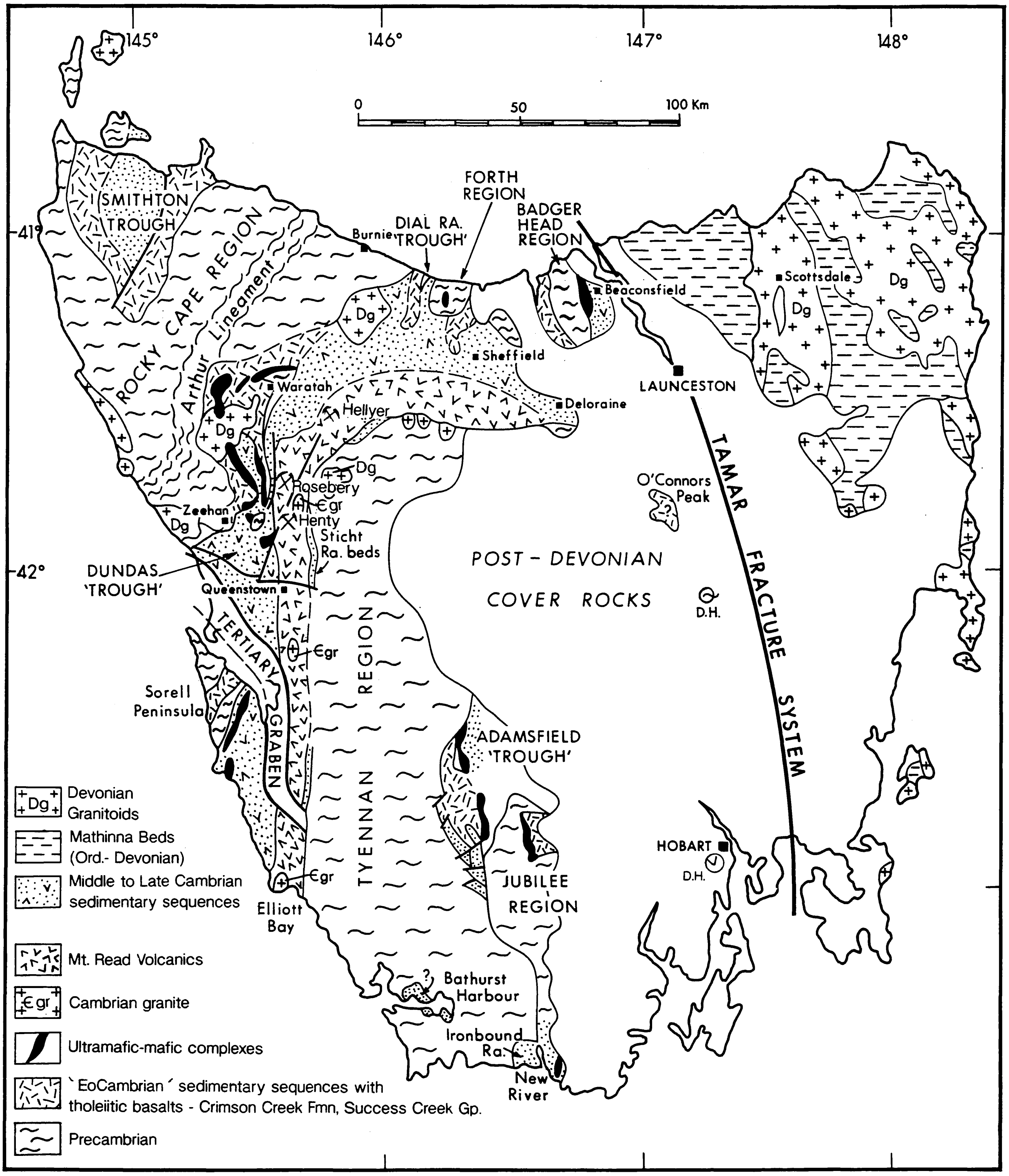

Figure 1.

Simplified geological map of Tasmania showing present distribution of major early Palaeozoic tectonic elements, including the Mt Read Volcanics belt. Ordovician-Silurian-Devonian sedimentary sequences have been omitted for clarity (after Corbett and Turner, 1989).

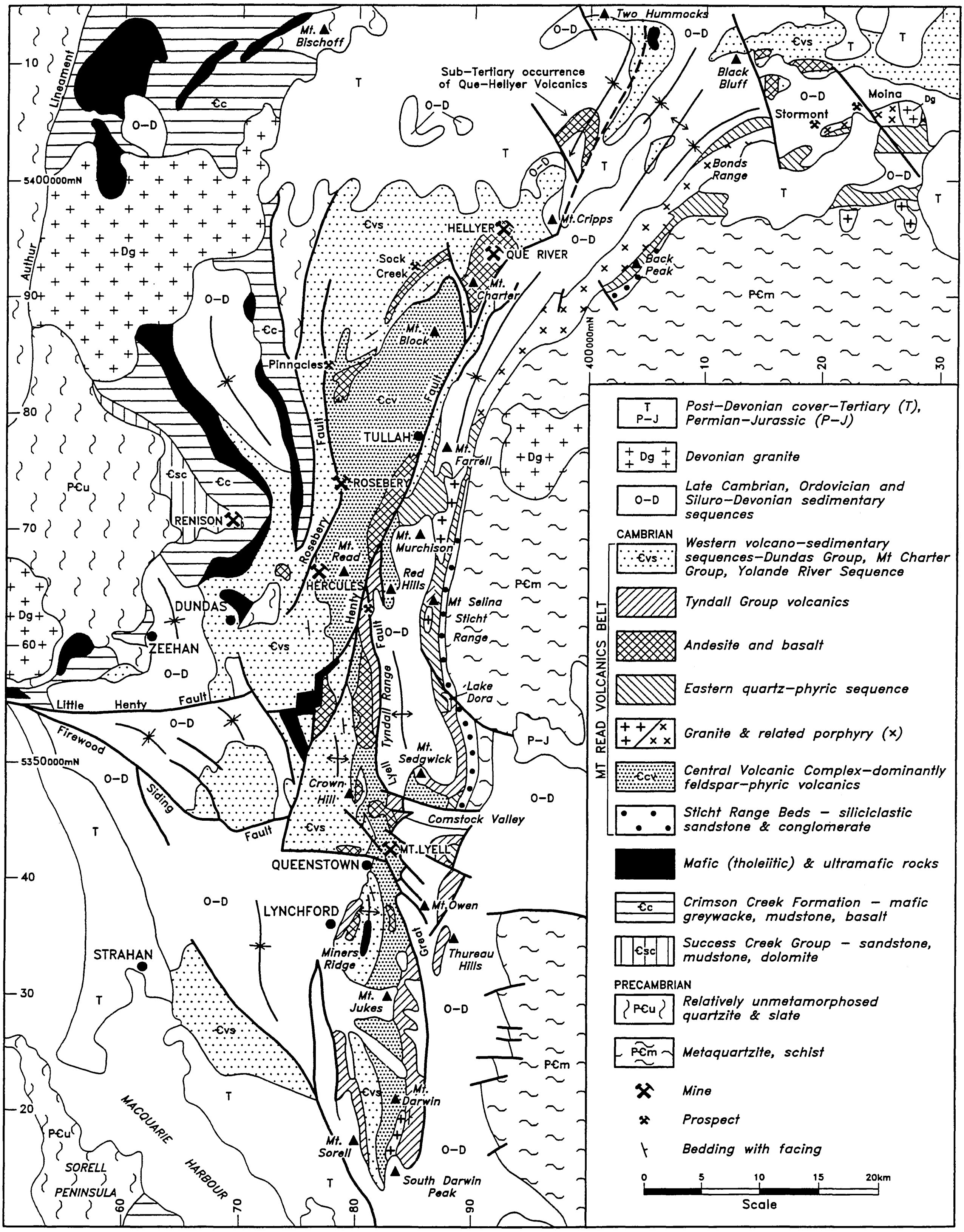

Figure 2.

Simplified bedrock map of central western Tasmania (Mt Darwin to Moina) showing major Cambrian sequences and lithostratigraphic subdivisions of the Mt Read Volcanics belt (from Corbett, 1992).

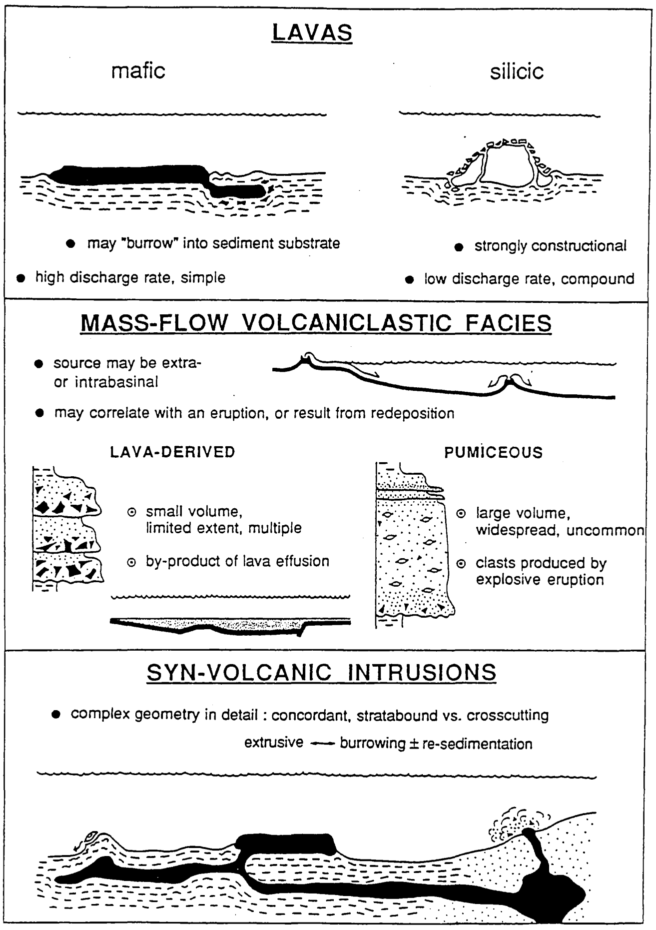

Figure 3.
Sketches showing the predicted original geometry for each of the principal facies in the northern Mt Read Volcanics. The contrasts in geometry strongly reflect differences in eruptive style and emplacement processes (from McPhie and Allen, 1992).

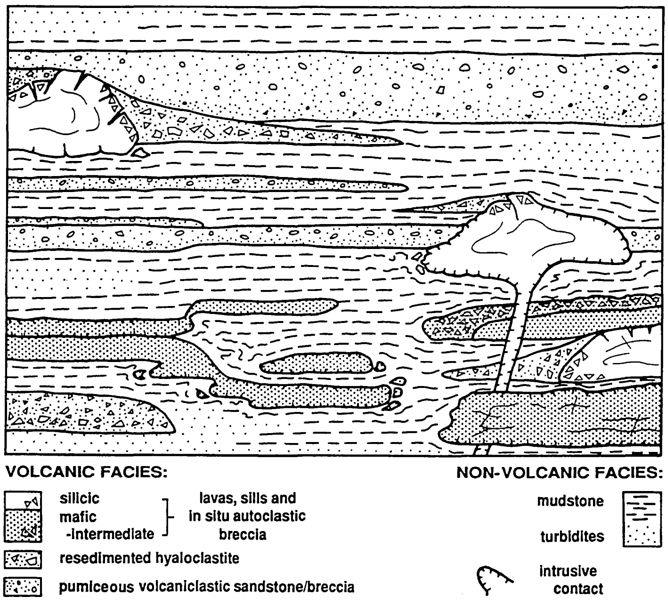

Figure 4.
Principal elements of the facies architecture of the northern Mt Read Volcanics. The sketch portrays the spectrum in facies geometry and facies relationships encountered in the Hellyer area (from McPhie and Allen, 1992).

and clarified the principal volcanic facies present (fig. 3, 4) and laid the foundation for piecing together the original facies architecture of the belt (McPhie and Allen, 1992; McPhie and Gemmell, 1992; McPhie *et al.*, 1992; McPhie *et al.*, 1993). These studies show the likely relationships between constructional submarine lavas (as in the Central Volcanic Complex) and associated clastic facies, intrusive to partly extrusive felsic and mafic igneous bodies, and the mass-flow deposits of various kinds and sources (ranging from locally-derived lava clast-rich types to extra-basinal far-travelled pumice-rich varieties).

The initial volcanological studies indicate the potential importance of the extensive mass-flow units in correlation between areas, particularly those units with distinctive compositional elements. Possible correlation of similar mass-flow units has already suggested a relationship between the Rosebery–Hercules host sequence and the sequence immediately above the Hellyer ore deposit (McPhie and Allen, 1992), a relationship not obvious from the more traditional stratigraphic mapping approach (e.g. Corbett, 1989).

INTRODUCTION TO ORE DEPOSITS IN THE MT READ VOLCANICS

The Mt Read Volcanics belt is the major volcanogenic base metal mining district in Australia, with the current major producers being Rosebery, Hellyer and Mt Lyell. Mines at Que River and Hercules have only recently closed. Prospectors in the latter part of last century discovered the deposits at Mt Lyell (1883), Hercules (1891) and Rosebery (1893), whereas Que River (1974), Hellyer (1983) and Henty (1984) are recent discoveries from modern exploration techniques. Recent descriptions of the ore deposits in the belt have been given by Solomon (1989), Large (1992) and Green (1990).

Several styles of mineralisation are represented within the belt, the most important being the polymetallic stratiform massive sulphide deposits. These deposits, represented by Rosebery, Hellyer, Que River and Hercules, are particularly rich in base and precious metals on a world scale, with average grades in the order of 15% Zn, 6% Pb, 0.5% Cu, 160 ppm Ag and 2.8 ppm Au. Rosebery, with an original reserve of 21 million tonnes of ore, and Hellyer, with 16 million tonnes, are world-class deposits of this type (Large, 1992).

A second major type is represented by the Mt Lyell group of generally low-grade disseminated and stockwork copper-gold-pyrite deposits, with grades averaging about 1.2% Cu and 0.4 ppm gold (Hills, 1990; Solomon and Carswell, 1989). This ore type is still being mined underground at Prince Lyell, the last of the Mt Lyell operations. The Mt Lyell field also includes massive to semi-massive pyrite-chalcopyrite deposits (Blow, South Lyell), chalcopyrite-bornite deposits (North Lyell, Crown Lyell II), banded galena-sphalerite-pyrite deposits which appear to be exhalative VHMS type (Tasman and Crown Lyell Extended, Lyell Comstock), and native copper-cuprite deposits in Ordovician limestone known as the 'copper clays'.

A recently recognised third mineralisation type is represented by the disseminated gold deposits with minor base metals seen at the Henty Prospect, South Hercules Prospect and the Que River footwall precious metal zone (PMZ). The Henty Prospect, located in lower Tyndall Group rocks on the footwall of the Henty Fault, is associated with a large hydrothermal alteration zone containing small pods of massive sulphide.

In addition to the volcanic-related deposits of Cambrian age, there are a number of small deposits related to the widespread intrusion of granitoid bodies in the Devonian. At least some of these involve the remobilisation of Cambrian mineralisation. Best known are the slate-hosted, vein-style silver-lead-zinc lodes of the Tullah–Sterling Valley area, where the last operating mine closed in 1973. Also in this area is the tin-gold-copper occurrence at Lakeside (Taheri and Green, 1990). Granite intrusion is considered responsible for the replacement of the deeper parts of the Rosebery massive sulphide body by pyrrhotite-magnetite-pyrite-tourmaline assemblages (Lees *et al.*, 1990).

DAY 1: MOUNT READ–HERCULES MINE AREA

Introduction

The day's traverse, weather permitting, takes us to the 'heart' of the Mt Read Volcanics on Mt Read itself, and then down through the spectacular workings of the now-defunct Hercules Mine on the western flank of the mountain. At 1124 metres altitude, the summit of Mt Read is an alpine area with a typical west Tasmanian alpine flora, and alpine weather to match. The mountain was glaciated during the Pleistocene, and also during the Late Carboniferous–Permian, as indicated by the presence of flat-lying remnants of pebbly glaciomarine sediments. The traverse provides an opportunity to examine the textural effects of hydrothermal alteration and deformation on partly devitrified lavas (including coherent and autoclastic facies) and on originally relatively porous pumice-rich volcaniclastic deposits.

General Geology

The bulk of the sequence on Mt Read has been included in the Central Volcanic Complex (Corbett and Lees, 1987), an extensive unit of dominantly feldspar-phyric felsic lavas and pumice breccias with some associated felsic intrusives (fig. 5, 6). At its western margin south of Williamsford, this sequence has an enigmatic contact relationship with a west-facing sequence of sandstone, siltstone and volcaniclastic breccia — the White Spur Formation. This contact was originally interpreted to be an unconformity (Corbett and Lees, 1987), but more recent work suggests it coincides with a significant original facies boundary in the volcanic sequence (R. L. Allen, pers. comm.; McPhie and Allen, 1992). North of Williamsford, the western margin is formed by the Rosebery Fault, a major reverse structure dipping 40°E and lying some 400 m beneath the Rosebery orebody.

A fairly consistent stratigraphy is evident between Rosebery and Hercules (fig. 7):–

(5) top: Felsic lava, pumice breccia, intrusives (Mt Black Volcanics, >1 km)

(4): Hangingwall quartz-bearing volcaniclastics (0–300 m)

(3): Black slate (0–50 m)

(2): 'Host rock' tuffaceous siltstone (0–35 m)

(1): Footwall feldspar-bearing pumice breccias (>500 m)

The sequence dips and youngs east in both areas, but is possibly affected by unmapped strike faults parallel to the Rosebery Fault. A complicated fold (-fault?) arrangement repeats the Hercules sequence to the east of Mt Hamilton (fig. 6), in a complex zone marked by numerous felsic intrusive bodies and a number of mafic dykes.

The Hercules Orebodies

Mining operations ceased at Hercules in 1986, having produced 3.12 million tonnes of ore (since 1900) at an average grade of 17.8% Zn, 5.7% Pb, 0.42% Cu, 180 g/t Ag and 294 g/t Au. The orebody consists of some twenty or so lenses, each being about 100 × 100 × 5–10 metres. Most lenses are joined to the neighbouring lenses at some point. The distribution of the lenses is controlled by a N-S oriented syncline-anticline fold pair (fig. 8, 9), the folds being open to tight with axial plane cleavage dipping 60–75°E. The ore lenses also have an overall dip of 70°E, and are oriented parallel to cleavage rather than to bedding. There are clear examples in the mine workings of ore lenses which have been transposed into the cleavage (which is probably Devonian), yet the lenses rarely penetrate either the overlying slates or the underlying siliceous footwall rocks (Lees *et al.*, 1990).

Most of the lodes are vertically and longitudinally zoned. Massive sphalerite-galena-pyrite ore forming the bulk of the lenses gives way to massive pyrite southwards and with depth, and thence to a siliceous pyrite–chalcopyrite-rich tail. The sphalerite–galena-rich ore lenses are commonly enveloped by a halo of carbonate-rich rocks.

A large alteration zone extends for at least 2 km along strike in the footwall pumice breccia sequence at Hercules, and is marked by sericitisation, chloritisation, silicification and pyritisation. 'Quartz-sericite schists' have been formed in the most intensely silicified areas.

MT READ–HERCULES EXCURSION STOPS

STOP 1 — Mt Read gate

The gate on the Telecom road is located about 30 m east of a cutting showing the Rosebery Fault near the old

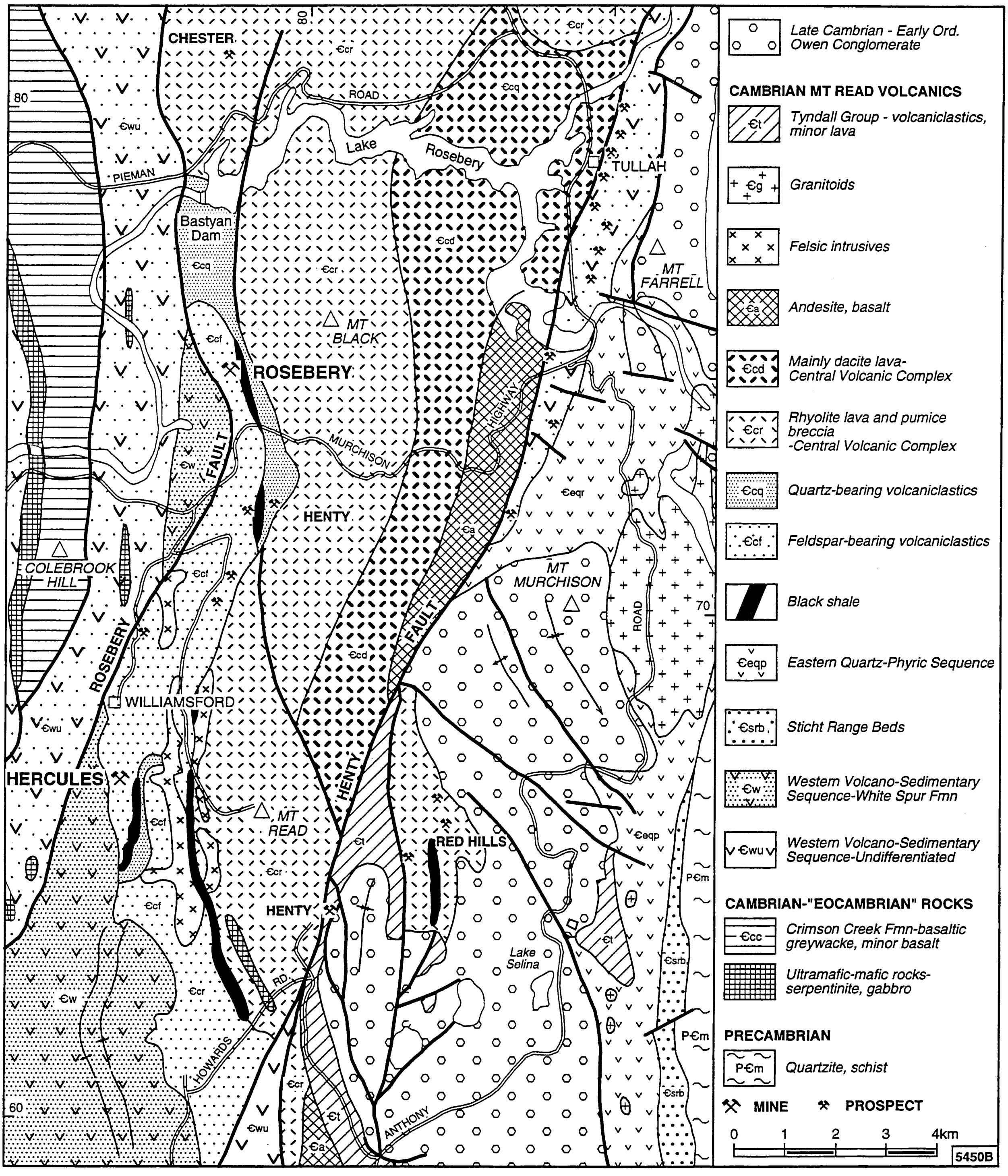

Figure 5.

Geology of the Rosebery–Mt Read area (after Corbett and McNeill, 1988).

copper-cuprite deposits in Ordovician limestone known as the 'copper clays'.

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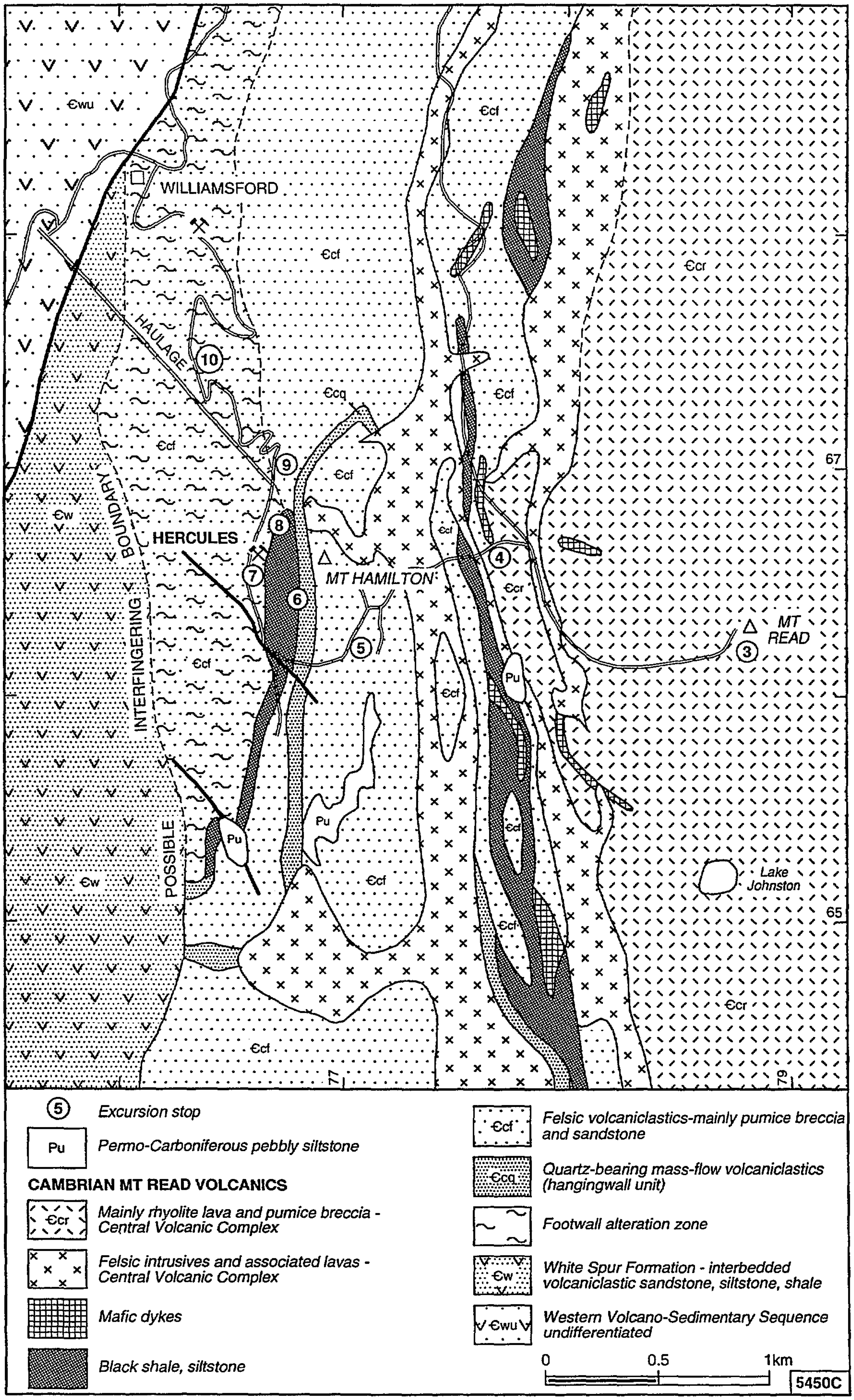
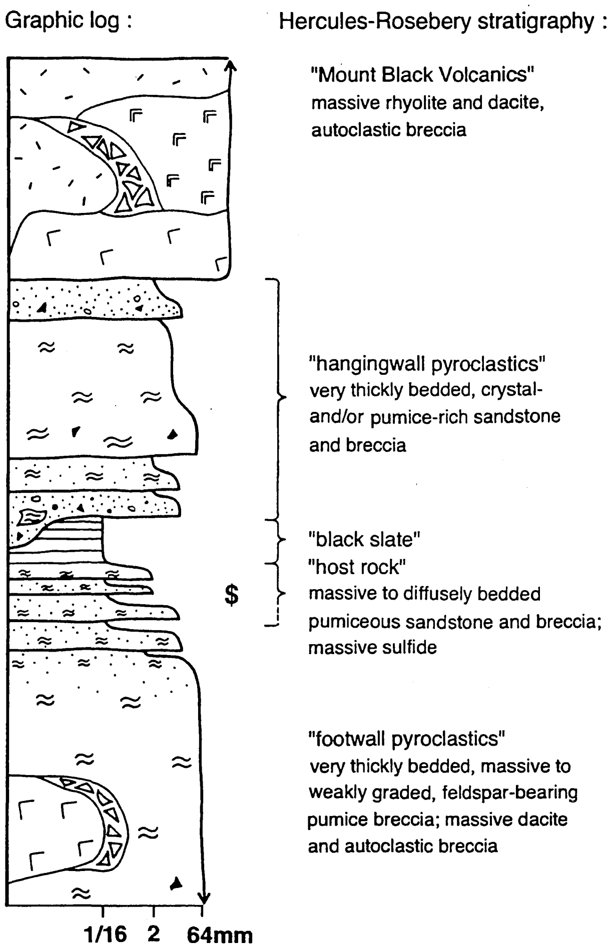


Figure 6.

Geological map of the Hercules–Mt Read area, showing excursion stops (after Corbett, 1986).



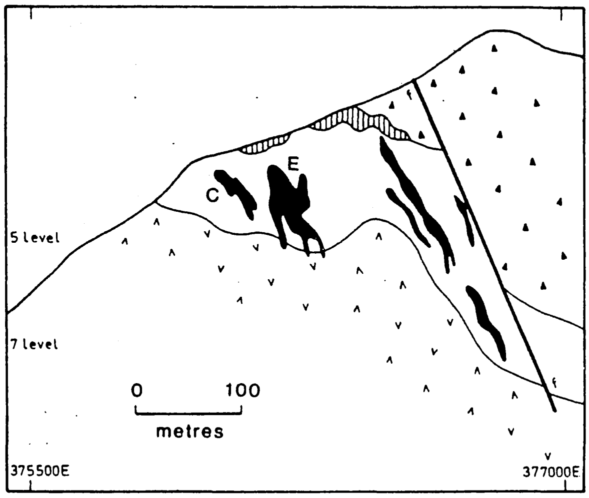


Figure 8 *(above).*

Cross-section of the Hercules mine at 5 366 750 mN, looking north, showing the relationship of the ore lenses to the footwall and hangingwall rocks (after Lees et al., 1990).

Figure 7 *(left).*

Simplified graphic log of the host volcanic sequence to the Hercules–Rosebery massive sulphide orebody (after Green et al., 1981; McPhie and Allen, 1992). The total thickness portrayed is about 2000 metres.

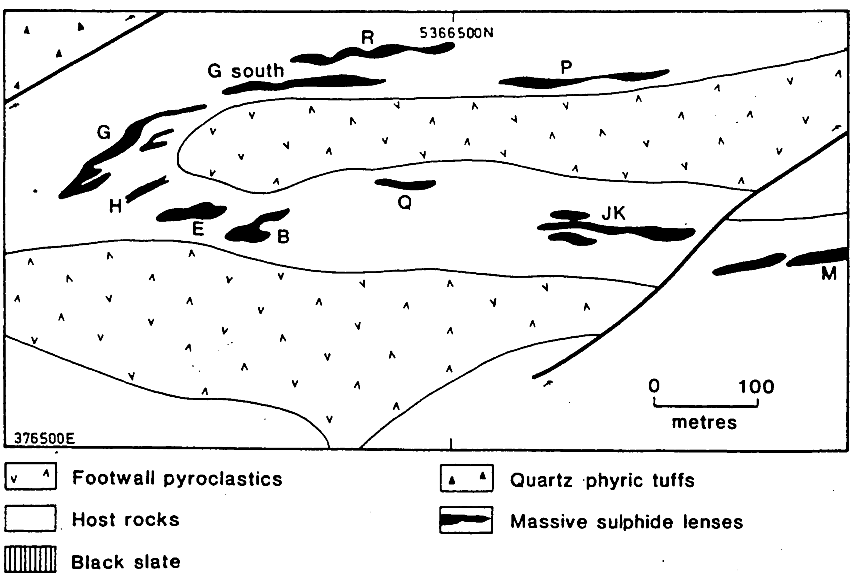


Figure 9.

Simplified geological plan of No. 5 level, Hercules mine, showing the distribution of ore lenses (after Lees et al., 1990).

STOP 3 — Summit of Mt Read (fig. 6)

Weather permitting, walk 150 m to the southeast for a view across to Mt Murchison, Red Hills, Tyndall Range, southern West Coast Range, Henty Fault Zone and Henty Gold Prospect. To the west are Mt Dundas, Moores Pimple, Mt Heemskirk, Mt Agnew and others. Otherwise, enjoy the alpine experience of a West Coast mountain top.

Walk around to north side of Telecom enclosure to see typical Central Volcanic Complex feldspar-phyric rhyolitic-dacitic lavas with well-developed flow banding and autobrecciation textures.

STOP 4 — Mt Hamilton link track walk (fig. 6)

The walk from the Mt Read road to Hercules takes us firstly through the flow-banded and brecciated CVC lavas, thence through the Jones Creek–Hercules shale horizon with associated volcaniclastic sandstone interbeds, thence through a quartz-phyric intrusive body, and finally into the feldspar-bearing pumice breccia of the Hercules hangingwall sequence. An excellent sample of Tasmania's alpine flora (including deciduous beech, several endemic conifers and waratah) is visible along the track.

STOP 5 — Hangingwall pumice breccias

The lower part of the link track passes through a thick sequence of pumice breccia, characterised by the presence of green phyllosilicate-rich lenses and wisps. Detailed study by R. L. Allen has shown that the lenses are relict fiamme and consist of phyllosilicate-altered, diagenetically compacted pumice clasts. The relict fiamme define a bedding-parallel foliation, and some have highly irregular, cuspate terminations where crenulated by or transposed into the regional cleavage. Within the intervening pale domains, the original tube pumice textures remain well preserved and can be seen to be uncompacted and non-welded (Allen and Cas, 1990). The relict fiamme are feldspar-phyric, and feldspar phenocrysts are equally abundant in the pale domains but much less obvious.

Careful observation with a hand lens reveals small fibrous tube pumice clasts in the pale zones between the chlorite wisps. Thin sections of these rocks commonly show 'froth' textures of well-preserved round bubble zones around feldspar phenocrysts, where the original bubbles were protected against flowage and stretching (which would have formed tubes) prior to eruption (McPhie et al., 1993).

The lower part of the link track crosses a silicified contact zone at the base of the pumice breccia, probably marking a fault, then crosses a zone of white, fine-grained siliceous rock that forms the upper part of a pumiceous mass-flow unit to be seen at the next stop.

STOP 6 — G10 'Glory Hole'

Several of the 'glory holes' have been formed where underground stoping has resulted in surface collapse. The contact between the black slate ('Hercules shale') and overlying quartz and feldspar-bearing mass-flow units is exposed here. The abundance of volcanic quartz crystals in these units is an unusual feature in an otherwise feldspar-dominated quartz-poor sequence, and allows correlation of the unit through to Rosebery and beyond. Whether the quartz is derived from local eruptions (possibly related to the intrusive quartz-phyric bodies) or from more distant sources is uncertain. It may or may not be a coincidence that a similar relationship between black shale and quartz-bearing mass-flow deposits occur above the Hellyer and Que River orebodies (McPhie and Allen, 1992).

The lower part of the two mass-flow units (fig. 10) is well exposed in the floor of the pit and is very coarse and lithic-rich, with rafts and blocks of shale up to five metres long. The shale fragments are probably intraclasts of local derivation. Oxidised massive sulphide clasts are also present. The matrix between the clasts is rich in quartz and feldspar crystals and small pumice clasts, and the finer-grained sandy upper parts consist mainly of relict glass shards, small pumice clasts and quartz and feldspar crystals.

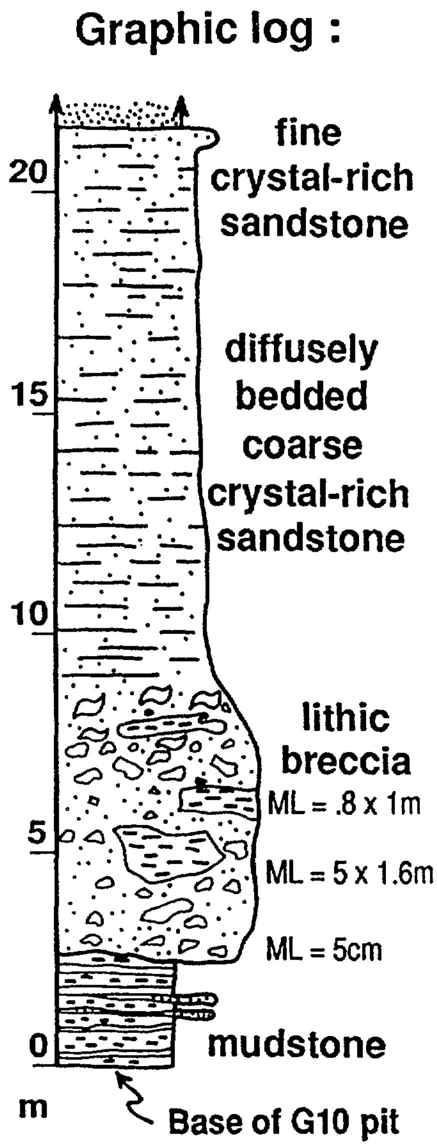


Figure 10.

Stratigraphic column for mudstone intraclast-rich, volcaniclastic mass-flow units at the G10 Glory Hole pit, Hercules mine (after Allen and Hunns, 1990).

STOP 7 — Walk along 4 Level Road, Hercules Mine

The old township of Mt Read, which included the Mt Read Hotel, was originally located at this level and was described as "the town with a view"! Ore from the mines was taken down on a self-acting haulageway, and initially railed out to the Zeehan Smelters via the North-East Dundas Railway. An aerial ropeway carried the ore to Rosebery from 1936.

Some of the features visible along the 4 Level road are:

(i) Highly altered and schistose host rock at the top of the footwall sequence, originally the fine-grained top of a graded, very thick feldspar-phyric pumice breccia unit.

(ii) Exposure of A lode mineralisation in an open cut.

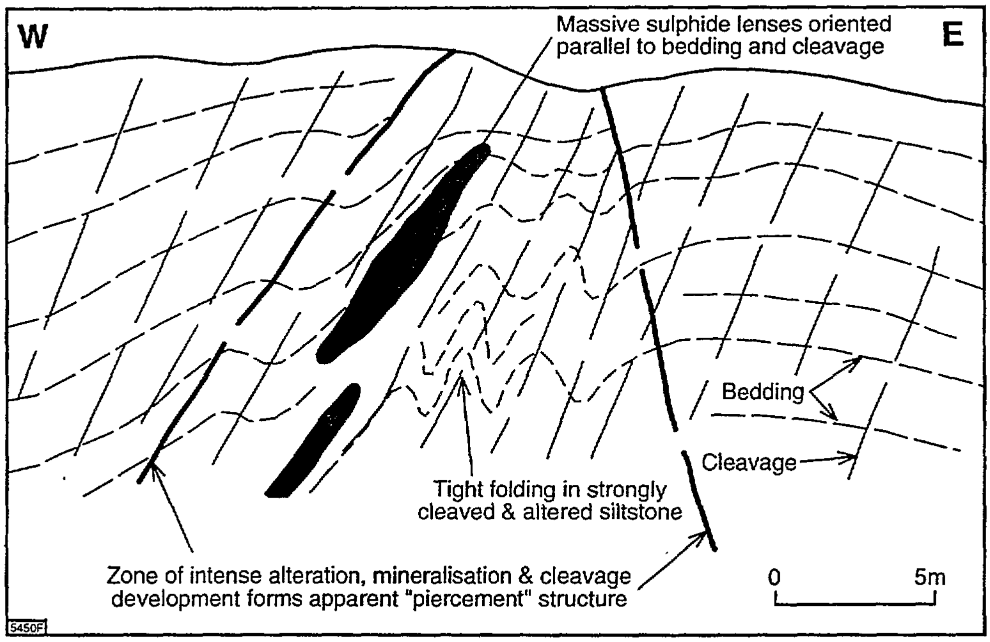


Figure 11.

Sketch of East lode, looking south, showing relationships between bedding, cleavage, massive sulphides and alteration.

(iii) Carbonate 'cannon balls' in diffusely bedded, carbonate-altered 'host rock', 50 m north of A lode.

(iv) Mineralisation (including massive and spotty ore) and various alteration effects, including carbonate 'oolites', on the margin of C lode at the contact between black slate and 'host rock'.

STOP 8 — Cross-cutting (?) mineralisation in E lode pit

The upper extremity of a steeply-dipping ore lode and associated alteration zone, apparently cross-cutting bedding in the black slate, is exposed here (fig. 11). The narrow lode consists of banded sulphide and dips steeply east, parallel to the strongly developed cleavage. A V-shaped halo of intense quartz-sericite alteration surrounds the sulphide lode, and gives the impression of piercing through the slate. However, careful observation indicates that the wavy, sub-horizontal bedding in the slate, developed over the crest of a gentle anticline, actually continues through the alteration zone.

There is continuing debate concerning the origin of this ore lode:

(i) Is it an original Cambrian exhalative body deformed into the Devonian cleavage?

(ii) Is it a structurally controlled Devonian replacement body?

(iii) Is it an original steeply-dipping syn-volcanic Cambrian replacement body?

STOP 9 — Footwall pumice breccias on 4 Level Road north of haulage shed

This cutting is just outside the main footwall alteration zone, and contains well-preserved tube pumice clasts and chloritic pseudo-fiamme. Note that some of the long, irregular chlorite wisps and stringers are clearly not pumice clasts or fiamme, but that others correspond more or less with original pumice clasts. The small, pale-coloured tube pumice clasts, which make up the bulk of the rock, are evident with a hand lens.

Although the chloritic structures do not represent original collapsed pumice clasts, and the rock is not a welded ignimbrite, there remains the problem of accounting for very large volumes of pumice in a deep submarine setting. The pumice is feldspar-phyric, and appears to be closely related to the feldspar-phyric lavas.

The footwall pumice breccia sequence is organised into a series of mass-flow units, some of which are up to 150 m thick. The units have a thick massive lower part and a thinner, diffusely stratified, normally graded top (Allen and Cas, 1990). Their components and lithofacies suggest they represent rapidly resedimented syn-eruptive deposits generated by large explosive eruptions.

STOP 10 — Walk down Hercules access road to Williamsford

The walk down the access road is mainly through the footwall alteration zone in strongly-deformed feldspar-phyric pumice breccia. Moderate to strong chlorite-sericite-quartz alteration is apparent, and most of the rocks are schistose. Chloritic 'pseudo-fiamme' are prominent in places.

The road intersects the upper part of a sulphide band originally mined at the Ring P.A. prospect. The main band is 10–15 cm wide and dips east at 50°. It consists of banded pyrite, sphalerite, galena and barite, with some intercalated grey shale. Two other smaller bands of pyrite and shale are present within a few metres of the main one. The bands are discordant to cleavage but appear to be parallel to faint bedding in the tuffaceous host rocks. Arguments continue as to whether the bands are primary

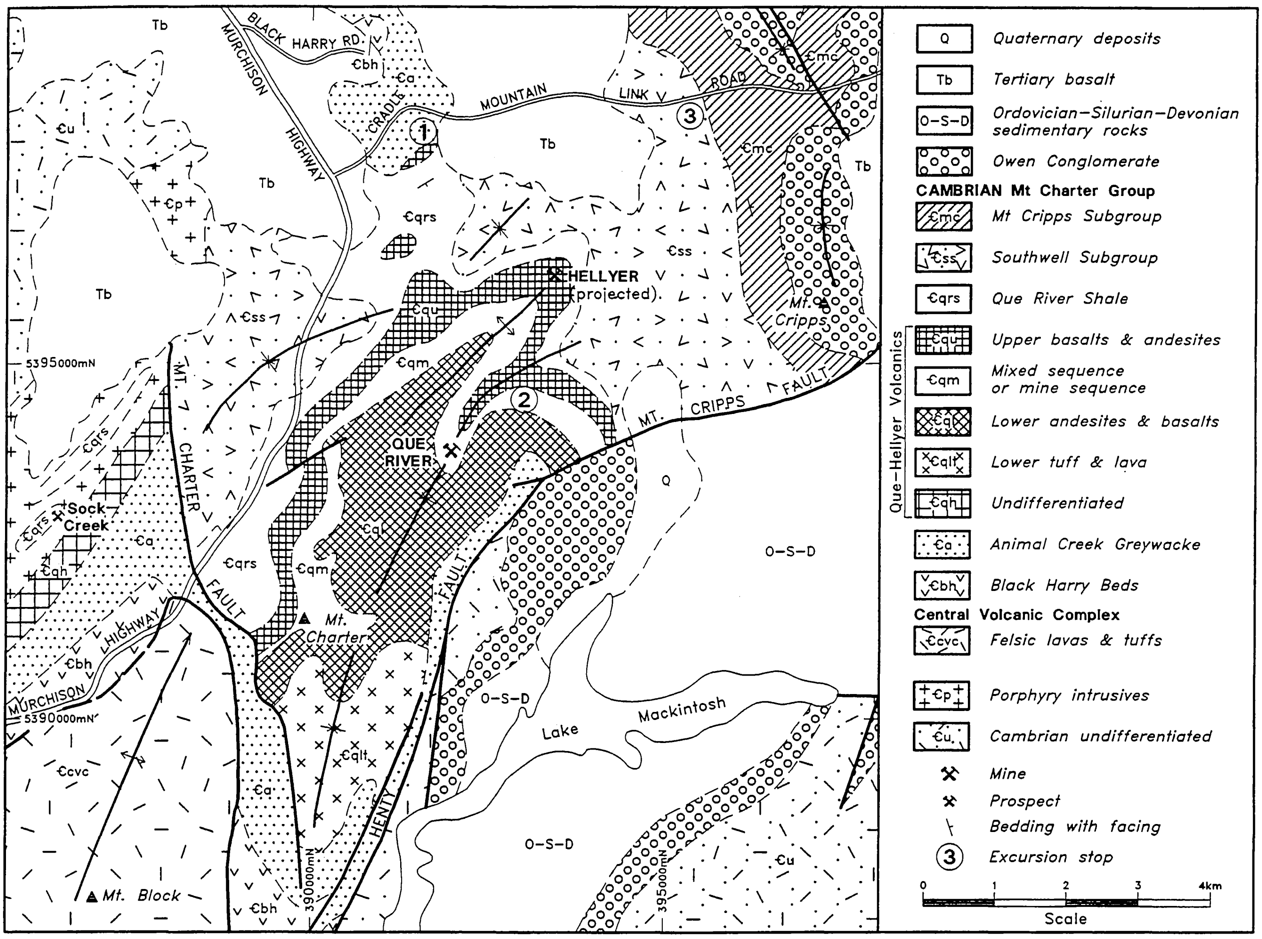


Figure 12.

Geological map of the Hellyer–Que River area (after Corbett, 1992).

exhalative features, remobilised structurally emplaced deposits, or late-stage (Devonian?) vein deposits.

DAY 2
HELLYER MINE AREA

Introduction

The Hellyer–Que River mining field lies within dense rainforest on a plateau-like area east of the Murchison Highway, falling away to the valley of the Southwell River and Lake Mackintosh to the east. The Mt Read Volcanics are buried beneath Tertiary basalt deposits just to the north of this area, although recent drilling indicates that the Hellyer host rocks continue beneath the 50–250 m thick basalt cover (Pemberton *et al.*, 1991).

Mining of the Que River deposit commenced in 1980 and ceased in 1991 (total production approximately 2.5 million tonnes). The Hellyer deposit, which lies 3 km north of Que River, was discovered in 1983 after drilling of a UTEM anomaly. The orebody was accessed by a 1.3 km long adit driven from the Southwell River valley in 1986, and ore production commenced in the same year. Total ore reserves are estimated at 16.9 million tonnes (McArthur and Dronseika, 1990).

General Geology

The Hellyer and Que River orebodies occur within a sequence dominated by andesitic and basaltic volcanic rocks, with minor felsic rocks, referred to as the Que–Hellyer Volcanics (QHV) (Komyshan, 1986*a, b*; McArthur, 1986; Corbett and Komyshan, 1989; Waters and Wallace, 1992). These rocks occupy a basin controlled by the Henty Fault Zone to the east and the Mt Charter Fault to the south (fig. 12). The volcanics are up to about one kilometre thick, but thin rapidly to the northeast. A thin continuation of the sequence is present to the southwest of the Mt Charter Fault between Sock Creek and the Pinnacles. The original relationship of the Que–Hellyer Volcanics to the Central Volcanic Complex felsic rocks is difficult to determine because contacts are faulted in the Mt Charter area. Consideration of relationships in the Pinnacles area suggests that the bulk of the CVC might be older than the QHV, but that there is time-equivalence and interfingering between QHV and upper levels of the CVC (McPhie and Allen 1992; Corbett, 1992).

The stratigraphy and terminology of the sequence in the Hellyer–Mt Charter area is shown in Figure 13. At the base, in faulted contact with the CVC rocks, is a sequence of tuffaceous sandstone, shard-rich mudstone, shale and

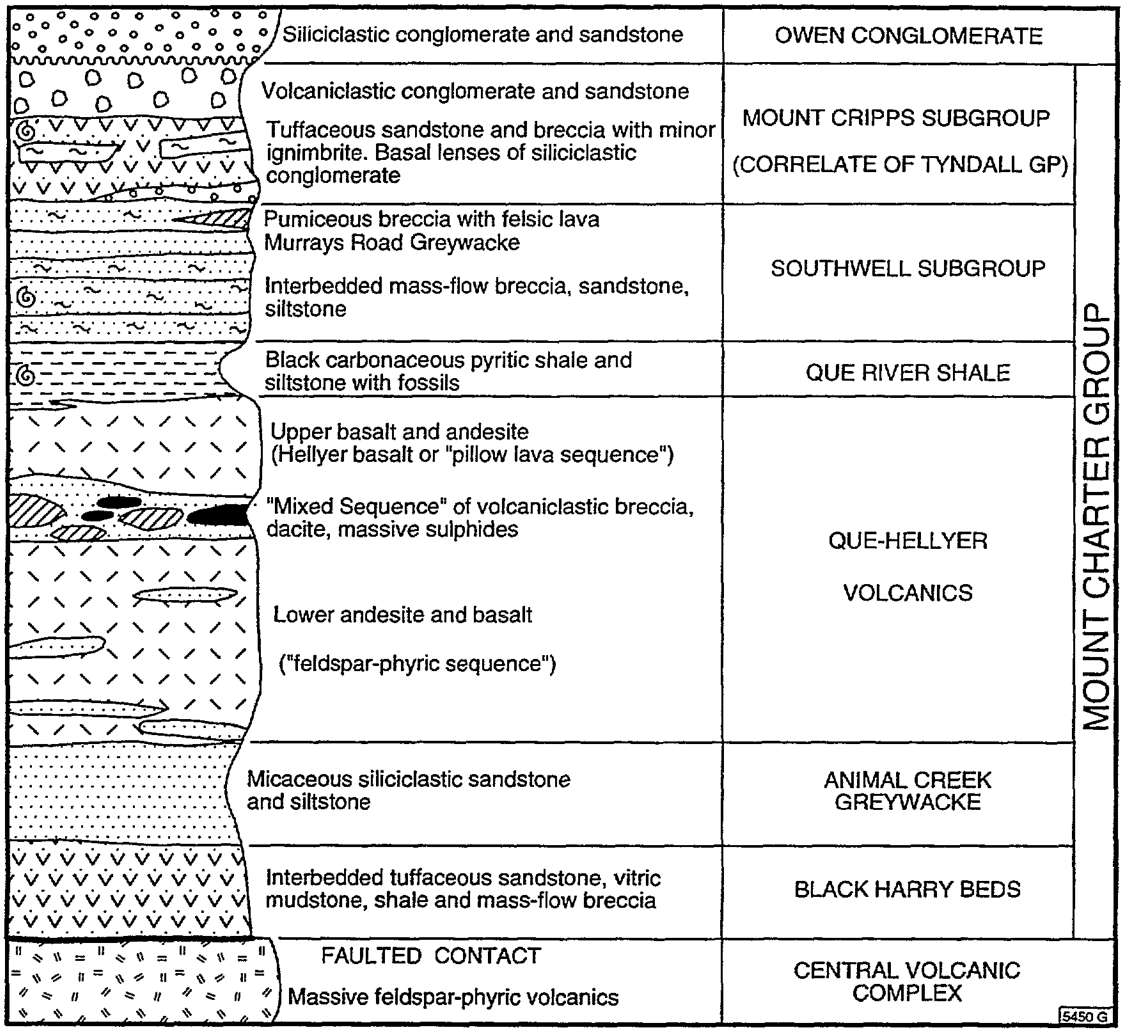


Figure 13.

Stratigraphic column for the Que–Hellyer area (after Corbett, 1992).

minor volcaniclastic breccia referred to as the Black Harry Beds (Corbett, 1992; "Lower vitric tuff sequence" of Pemberton *et al.*, 1991). Gradationally overlying this is a sequence of some 300 m of well-bedded micaceous siliciclastic greywacke interbedded with siltstone and shale, referred to as the Animal Creek Greywacke. Sandstone detritus in this sequence is predominantly derived from Precambrian metasedimentary rocks, but also includes chromite grains derived from ultramafic rocks. Graded bedding and other turbidite features are common.

The Que–Hellyer Volcanics consist of three main units: lower andesites and basalts; 'mixed sequence' or host sequence (containing the massive sulphide ore bodies); and upper basalts and andesites (fig. 13, 14).

The ***lower andesites and basalts*** ("feldspar-phyric sequence" of mine terminology) are 400–500 m thick near the Que River mine. They consist of coherent and brecciated andesitic and basaltic lavas with minor lenses of sandstone. The andesites are typically vesicular, porphyritic in plagioclase and clinopyroxene, and commonly show perlitic groundmass textures. Pumpellyite is a common alteration mineral. Chemically, the andesites are transitional medium to high-K calc-alkaline orogenic volcanic rocks with moderate to strong enrichment in LREE (Crawford *et al.*, 1992).

The '***mixed sequence***' is highly variable in thickness (5–150 m) and lithology, but is characterised by the presence of dacitic lava and polymict volcaniclastic breccia. The dacites are typically plagioclase-phyric and spherulitic, and occur as lava flows and partly extrusive cryptodomes that comprise coherent and autoclastic facies. The units of polymict volcaniclastic breccia are typically thick-bedded to massive, with clasts up to 30 cm of dacite, basalt, andesite, cherty sedimentary rock and minor sulphide and barite. Waters and Wallace (1992) have distinguished five lithofacies within the polymict breccia units, and suggest that most are by debris flow deposits of local derivation. Many of the units thicken in the vicinity of the orebodies, suggesting deposition in topographic depressions. Hydrothermal alteration is common in the breccia units, with sericite, pyrite, fuchsite, carbonate and quartz being typical alteration minerals.

The ***upper basalts and andesites*** ("Hellyer basalt" or "pillow lava sequence") generally range from 100–200 m

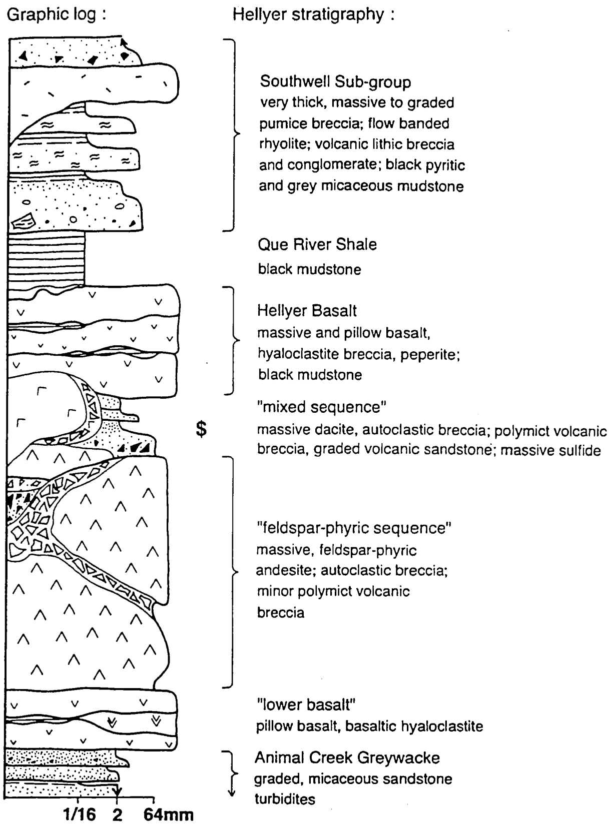


Figure 14.

Simplified graphic log of the host volcanic sequence to the Hellyer massive sulphide orebody (after Waters and Wallace, 1992; McPhie et al., 1993). The total thickness portrayed is about 2400 metres.

in thickness. The sequence includes pillowed lava, massive lava, basaltic hyaloclastite breccia, and mudstone-basalt peperite (intrusive hyaloclastite). The pillowed basalt above the Hellyer orebody shows distinctive enrichment in P_2O_5 (up to 0.6%) and LREE (La/Yb = 10–20), and is considered to have shoshonitic affinities (Crawford *et al.*, 1992).

Above the Hellyer basalt is a unit of black pyritic carbonaceous shale, with minor sandstone, referred to as the ***Que River Shale*** (Corbett and Komyshan, 1989). The shale is of the order of 150 m thick, and contains agnostid trilobites and other fossils, indicating a late Middle Cambrian age. A deep marine anoxic environment prevailed during accumulation of the shale.

Conformably overlying the shale is a sequence of interbedded volcaniclastic mass-flow breccia, tuffaceous sandstone and siltstone, with minor felsic lava, referred to as the ***Southwell Subgroup*** ("upper rhyolitic sequence" of mine terminology). The breccia units are typically quartz and feldspar-bearing, with clasts of sericitic relict pumice and quartz-feldspar-phyric lava (Corbett and Komyshan, 1989; McPhie and Allen, 1992). Rare fragments of trilobite-bearing limestone, presumably derived from a shallow marine environment, occur in some of the mass-flow units.

The Southwell Subgroup is overlain by a sequence of crystal-rich sandstone and volcaniclastic conglomerate with minor fossiliferous shale, welded ignimbrite and andesitic lava, referred to as the Mt Cripps Subgroup. This sequence is a lithostratigraphic correlate of the Tyndall Group of the Queenstown area. It is overlain at Mt Cripps by siliciclastic conglomerate and sandstone of the Owen Conglomerate.

GEOLOGY OF THE HELLYER MINE

Introduction

The following summary is taken from Drown (1990). The Hellyer orebody lies 90 m below the surface at its nearest point. It was discovered in 1983 after a UTEM survey detected a moderate conductor northwest of Que River. The first drill hole intersected 24 m of massive sulphide and was followed by an intensive diamond drilling programme on a 50 m grid. Ore production commenced at 250,000 tonnes per annum in December 1986, and increased to 1,000,000 tonnes per annum in mid-1989. Average grade of the 17 million tonne orebody is 14% Zn, 7.6% Pb, 0.4% Cu, 168 g/t Ag and 2.5 g/t Au.

Que–Hellyer Volcanics in the Hellyer mine area

Andesitic rocks, which are footwall to mineralisation, are mainly massive to in situ brecciated lavas, with minor polymict volcaniclastic lithologies (Drown, 1990). The upper part of the sequence at Hellyer consists of volcaniclastic breccias, with the thickest accumulation immediately beneath the orebody, suggesting the existence of a pre-ore topographic depression. The footwall rocks immediately below the orebody are pervasively altered to form a well-defined footwall stringer zone (fig. 15).

The Hangingwall Volcaniclastic Sequence (HVS) overlaps the orebody and ranges from 0–40 m in thickness. Two main lithologies are present: poorly sorted, open framework, polymict (andesite dominated) volcaniclastic breccia; and massive to well-laminated, fine and coarse volcaniclastic sandstone turbidites composed largely of basaltic grains.

Above the HVS and massive sulphides is a thick unit of vesicular basalt referred to as the Pillow Lava Sequence (PLS). Thickness varies from 80–250 m, with the thickest section being directly above the orebody. Pillows are well developed, with chilled margins and inter-pillow pyritic to cherty mudstone. Several basaltic dykes which intrude the footwall sequence are thought to be feeders for the PLS (fig. 15). A hydrothermal alteration plume affects the basalts directly above the orebody.

Structural geology

Folding evident in the mine area is considered to be due to a widespread event in the Middle Devonian, but Cambrian tectonism — particularly syn-depositional fault movements — was probably also important in the history

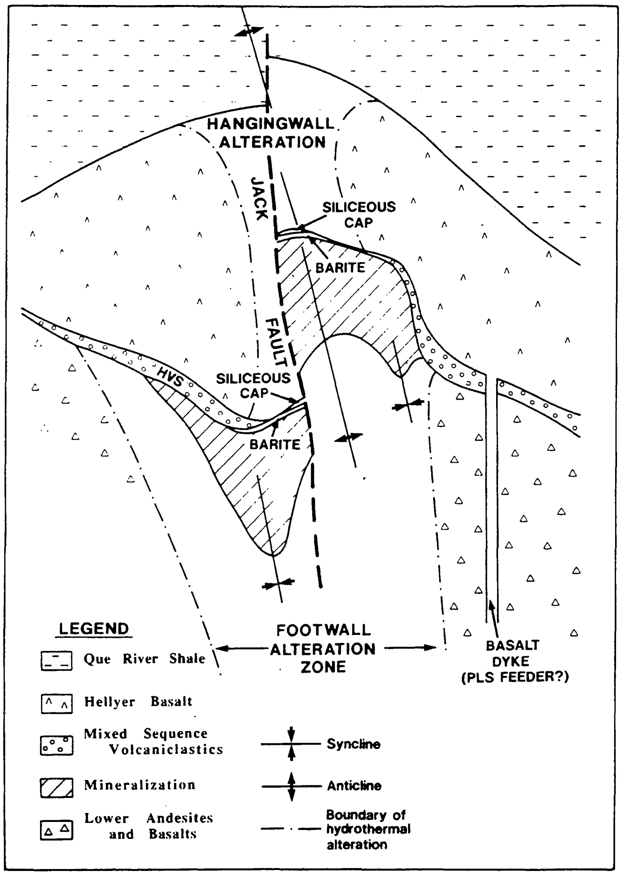


Figure 15.

Schematic cross-section through the Hellyer deposit showing the distribution of stratigraphic units relative to the ore body. After Waters and Wallace (1992) and Drown (1990).

of the area. Folds at Hellyer plunge 20–25° to the NNE, and have an associated axial planar cleavage dipping steeply to the ESE. The orebody lies on the hinge of a broad anticline. Strain has been strongly partitioned into the phyllosilicate-rich rocks in both the footwall and hangingwall alteration zones, and into the galena–sphalerite-rich outer zones of the orebody. Cleavage and small-scale folding are predominant in these areas, whereas brittle-style faulting and vein arrays tend to dominate in the unaltered footwall and hangingwall lithologies, in the highly siliceous core of the footwall alteration zone, and in the pyritic zones of the orebody.

A later wrench-faulting event is also evident in the mine area. The main Jack Fault (fig. 15) trends NNE and cuts acutely across the centre of the orebody, which it displaces 30 m vertically and 130 m horizontally (east-side north). Smaller dextral faults are common.

Mineralisation and alteration

Although faulted, the Hellyer orebody is a single deposit with virtually no internal waste. It extends over 800 m in strike length and is 200 m wide, and averages 43 m in thickness. Its southern extremity is 90 m below surface, while its northern end is known to a depth of 500 m.

The stringer zone (STZ) of subeconomic vein mineralisation beneath the orebody is 50 to 100 m wider than the orebody itself in an east-west direction, and continues uninterrupted to the north and south of the orebody extremities. The STZ extends to at least 550 m below the orebody, although drilling indicates that it narrows with depth. Strong zoning is evident within the STZ, with a strongly siliceous core (quartz + chlorite + sericite) surrounded by concentric shells of chlorite-carbonate, sericite-chlorite, and sericite-quartz. Eight stages of veining have been distinguished in the STZ (Gemmell and Large, 1992), three of which were syn-mineralisation and carried the sulphides to the orebody.

The sulphide deposit is unusually sulphide-rich, averaging 54% pyrite, 20% sphalerite, 8% galena, 2% arsenopyrite and 1% chalcopyrite with minor tetrahedrite (i.e. more than 85% sulphides). The remaining 15% gangue is quartz, barite, calcite, chlorite, sericite and siderite. Crystalline barite up to 15 m thick forms a hangingwall cap to much of the orebody.

A zone of hydrothermal alteration is also present in the hangingwall basalts, and is characterised by the presence of green fuchsite and a broad zone of pervasive calcite alteration and veining. This alteration is localised along the plane of the Jack Fault, suggesting that this structure was active in the Cambrian.

HELLYER MINE AREA EXCURSION STOPS

STOP 1 — Tailings Dam Diversion Canal

Three units can be seen in the walls of the canal: Animal Creek Greywacke, Que–Hellyer Volcanics, and Que River Shale. At the northeast end, the south-dipping south-facing Animal Creek Greywacke comprises interbedded micaceous quartzwacke sandstone and grey siltstone, largely of Precambrian derivation. Well preserved sedimentary structures include graded bedding, ripple cross-stratification, convolute lamination, and flame structures. Minor units of mass-flow breccia containing shale clasts in a tuffaceous matrix are also present.

A 1–2 m wide sub-horizontal dyke of weathered medium-grained basaltic rock intrudes the Animal Creek Greywacke sequence in the canal. The dyke has a thin chilled margin, and contains carbonate-filled vesicles, large biotite crystals, and xenoliths up to 60 mm across of granite, quartzite and schist. Thin section examination shows the rock to be an altered biotite-olivine-pyroxene-quartz-phyric lamprophyre, probably of Devonian age, and geochemically distinct from either the adjacent Tertiary basalts or Que–Hellyer basalt (Pemberton *et al.*, 1991).

Further southwest in the canal, a thin unit (5–10 m) of vesicular basalt is exposed in contact with the overlying Que River Shale. This basalt has the same geochemical signature as the upper basalts ("Hellyer basalt") of the

Que–Hellyer Volcanics (McNeill, *in* Pemberton *et al.*, 1991), and apparently represents the 'feather edge' of the large lens of basalts and andesites that thickens to the south. The contact between the basalt and overlying shale is sharp and irregular, and there are abundant pyrite nodules and framboids in the adjacent shale. Large irregular masses of pyrite are present at the basalt-shale contact further west.

The Que River Shale is a distinctive black carbonaceous shale-siltstone sequence, with only minor tuffaceous greywacke beds. It comprises suspension-settled mud and mud turbidites,and may mark a significant hiatus in volcanism. The shale is fossiliferous in places, containing agnostid trilobites, hydroids, dendroids, inarticulate brachiopods and sponge spicules, indicating a late Middle Cambrian age (Gee *et al.*, 1970; Corbett and Komyshan, 1989).

STOP 2 — Switchback area on haul road — Mixed sequence dacitic breccia

A series of excellent exposures of the Que–Hellyer Volcanics and overlying units was previously available along the access road to the Hellyer Portal, but the ore-trucking activities have now largely covered these with mud. We will examine an exposure of the 'Mixed Sequence' or Mine Sequence on the Que River mine road close to the 'Switchback' corner on the haul road. At this locality, a dome-like body of dacite lava is flanked by monomict to polymict breccia composed mainly of pink dacite clasts, with other clasts of andesite, basalt and massive sulphide.

STOP 3 (optional) — Welded ignimbrite in the Tyndall Group, Cradle Mountain Link Road.

The cutting at AMG reference CQ954987 shows the basal part of the Tyndall Group correlates (Mt Cripps Subgroup) overlying the Southwell Subgroup. The lower part of the sequence consists of interbedded black siltstone and sandstone turbidites and mass-flow emplaced siliciclastic conglomerate (fig. 16). This is followed to the east by weathered pink quartz-feldspar crystal-rich sandstone in abrupt irregular contact with purplish-pink, welded, quartz-feldspar-phyric ignimbrite. Well preserved flattened shard textures can be seen in thin section. The sequence above the ignimbrite includes trilobite-bearing mudstone, turbidites and volcaniclastic mass-flow deposits. The section is disrupted by faults, and the top of the ignimbrite is not exposed. The presence of welded ignimbrite within a sequence deposited below wave base, and the relationship of the ignimbrite to the partly enclosing sandstone, are points of considerable interest (White *et al.*, 1993).

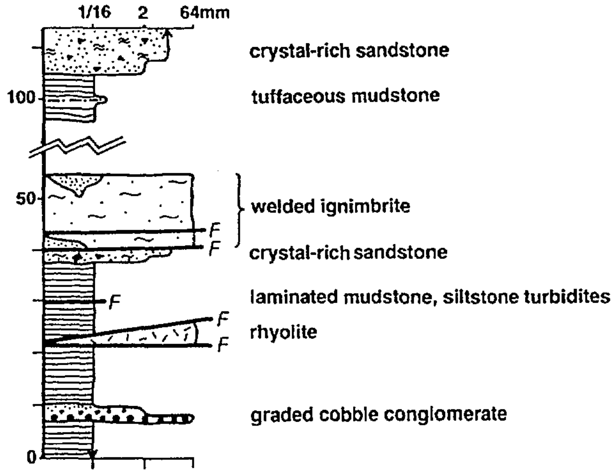


Figure 16.

Graphic log showing the context of welded ignimbrite in the Tyndall Group correlates (Mt Cripps Subgroup) on the Cradle Mountain Link Road. The section is disrupted by faults and neither the base nor the top of the ignimbrite are clearly exposed.

DAY 3
ANTHONY ROAD – HENTY AREA

Introduction

The Anthony Road (fig. 17) was constructed by the Hydro-Electric Commission in the mid-1980s to provide access from Tullah and Queenstown to the Henty–Anthony Power Scheme. The road provides a scenic alternative to the old Murchison and Zeehan Highways through Rosebery and Renison Bell to Queenstown. The road traverses massive volcanic rocks of the Eastern Quartz-Phyric Sequence, the sub-volcanic Murchison Granite, and a broad cross-section of the siliciclastic Owen Conglomerate, before emerging on the western side of the West Coast Range near Newton Dam. Pleistocene glacial features, including cirque lakes, moraines and till plains, are well preserved within the range, and large erratic boulders of conglomerate are a prominent feature of the area.

The western margin of the Owen Conglomerate is marked by the Great Lyell Fault (fig. 17), a syn-depositional structure against which nearly 2 km of conglomerate and sandstone was deposited in the Late Cambrian–Early Ordovician. The partly-exhumed fault scarp forms the spectacular western flank of the Tyndall Range, visible from the Anthony Road. Further west, the road traverses the precipitous forested slopes of the Langdon River gorge, across which can be seen the large terminal moraine near Basin Lake.

Three major lithostratigraphic units are present within the volcanic sequence west of the range. The units strike N-S and generally young to the east, and comprise, in stratigraphic order, the Yolande River Sequence, Anthony Road Andesites, and Tyndall Group. The Yolande River Sequence consists of interbedded volcaniclastic sandstone (turbidites), siltstone, tuffaceous siliceous mudstone and mass-flow volcaniclastic breccia, intruded by tabular bodies of felsic quartz-feldspar (± pyroxene ± muscovite) porphyry.

The Anthony Road Andesite consists of massive and brecciated feldspar-hornblende-phyric andesites, and

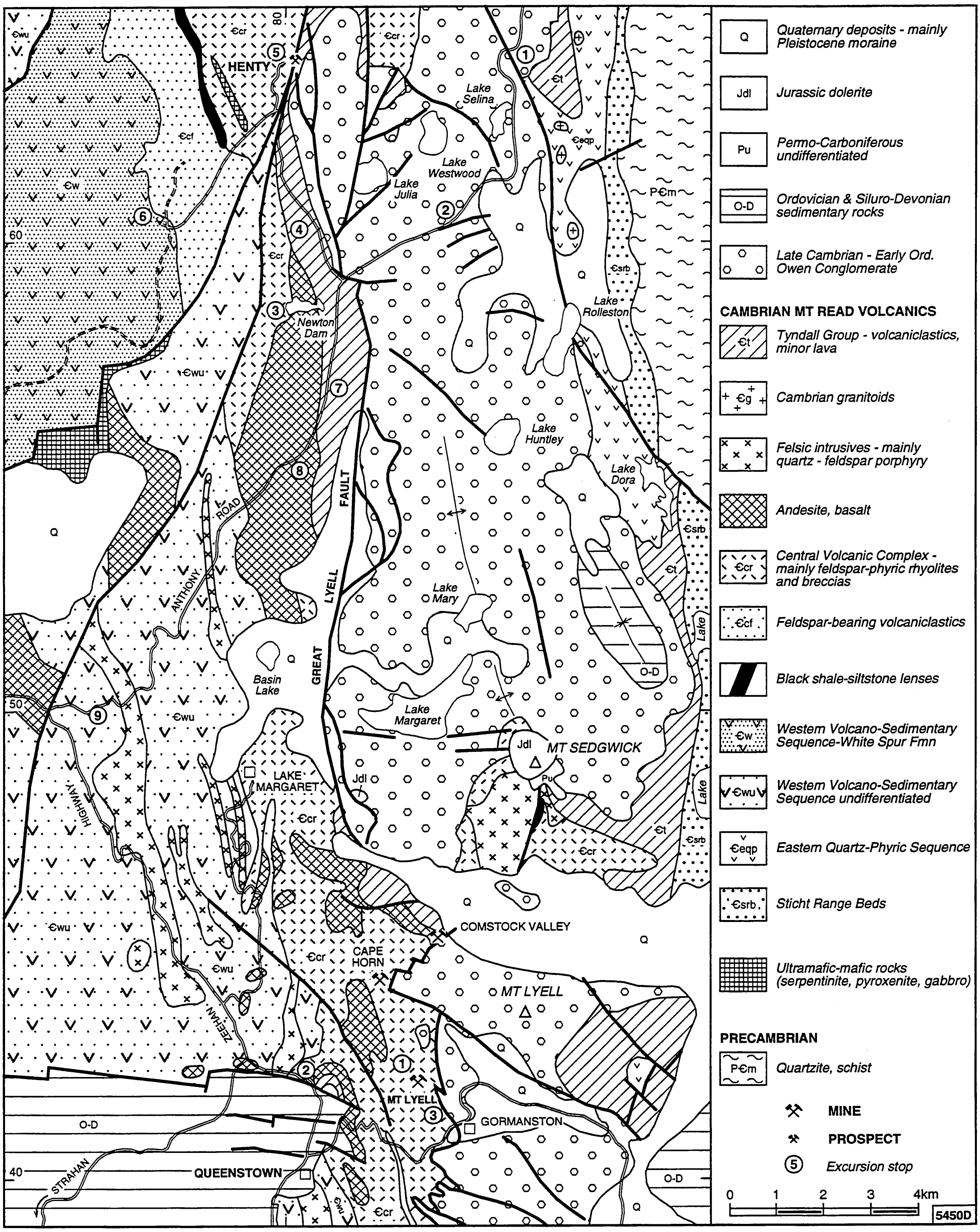


Figure 17.

Geological map of the Henty-Queenstown area, showing major stratigraphic subdivisions of the Mt Read Volcanics, and excursion stops.

includes both intrusive and extrusive rocks. Hornblende phenocrysts are generally prominent, and partly resorbed quartz phenocrysts occur in some units. Hydrothermal alteration and minor exhalative mineralisation occur in the upper part of the andesite sequence adjacent to the Tyndall Group contact.

The Tyndall Group sequence comprises banded pink and green crystal-rich sandstone, graded polymict volcaniclastic conglomerate and breccia, and quartz-feldspar-phyric lava and lava breccia. The sequence hosts the gold and sulphide mineralisation at Henty Prospect, and is locally overlain by the Newton Creek Sandstone member of the Owen Conglomerate, containing middle Late Cambrian fossils.

ANTHONY ROAD EXCURSION STOPS

STOP 1 — Lookout above Anthony Dam

This lookout point provides an excellent view southwards across the Anthony Valley to the Tyndall Range, with its broad anticlinal structure developed in the Owen Conglomerate. Glacial outflow features are evident at the head of the Anthony Valley towards Lake Rolleston. To the east, the heavily wooded Mt Selina is underlain by volcaniclastic rocks, and further east are the barren ridges of Precambrian quartzite.

STOP 2 — Owen Conglomerate at Newton Gap

The road cutting here gives an excellent cross-section through part of the Owen Conglomerate, the siliciclastic sequence which overlies the Mt Read Volcanics along the West Coast Range. The sequence has been poorly studied, despite the wealth of exposure, but appears to have been deposited in a variety of shallow marine, fluvial-deltaic and delta-front to submarine-fan environments. Much of the sequence is oxidised to a pink-red colour. Quartzite and quartz schist of Precambrian derivation are the predominant clast types, but fine-grained pink to green chert of possibly Cambrian age is common in some units. The cutting shows the contact from the sandy, chert-rich, well-bedded 'Upper Owen' to the massive cobble conglomerate of the 'Middle Owen'.

STOP 3 — Newton Dam Spillway

This spectacular exposure was created by the HEC in 1990 and was the source of considerable excitement in the geological-exploration world when clasts of massive sulphide were found in the sequence by an Honours student in 1991. Great interest has been shown in the clasts (which have the geochemical-isotopic characteristics of typical Cambrian VHMS) by the exploration companies in the area, although there is some irony to the fact that the Exploration Licence boundary between two rival companies crosses the spillway halfway down (see fig. 18).

It is not entirely clear where the spillway sequence belongs in terms of the major lithostratigraphic units in the area — it is possibly an in-faulted block of Tyndall Group within the Anthony Road Andesite (Gibson, 1991). A wide diversity of volcaniclastic facies is exposed, but the structural complexity is rather unnerving. There are at least 22 faults in the outcrop (fig. 18), all but one of which are steeply dipping. A low-angle thrust fault at the foot of the south wall at the top of the spillway separates massive feldspar-phyric dacite and a thin unit of siltstone above from the volcaniclastic sandstone sequence below. Massive feldspar-hornblende-phyric andesite, typical of the Anthony Road Andesite, is in fault contact with the sequence at the bottom of the spillway.

The main spillway sequence may be considered in terms of two lithofacies associations separated by fault F10 (fig. 18). Association A consists of three thick sedimentation units, each comprising polymict volcanic breccia at the base grading upward to diffusely bedded coarse crystal-rich sandstone. Bedding dips and youngs to the southeast, and the upper unit, which is at least 13 m thick, is truncated by the thrust fault. Clasts in the basal breccias are composed of dacite, rhyolite and andesite lava, together with minor clasts of chert, mudstone and massive sulphide. Most of the massive sulphide clasts occur in the upper part of the upper sedimentation unit. They consist mainly of sphalerite and galena, with only minor chalcopyrite and pyrite. The basal breccia in each case grades abruptly to quartz-feldspar crystal-rich, diffusely banded coarse sandstone similar to the breccia matrix.

Lithofacies association B is more texturally and compositionally varied, but again is dominated by volcaniclastic mass-flow breccia and sandstone, with some laminated mudstone and minor cherty pyritic mudstone. Some bedding is disrupted due to syn-depositional slumping. Clasts in the breccias are predominantly of rhyolite and dacite.

In both lithofacies, the bedforms and their internal organisation are consistent with deposition from a variety of subaqueous volcanic mass flows, notably high density turbidity currents and density-modified grain flows. The abundant angular lava clasts in association A breccia may have been generated by autoclastic processes associated with submarine lava eruption, and subsequently re-sedimented, or fragmentation may have accompanied wholesale gravitational collapse of an unstable lava pile. The massive sulphide clasts could have been derived from a source associated with the source of the lava clasts that dominate the breccia, or else were eroded by the mass flow from a separate source en route (fig. 19).

STOP 4 — Tyndall Group breccia, Henty Canal

The Henty Canal (which diverts water from the headwaters of the Henty River into the Anthony and ultimately the Murchison system) has provided an excellent section through the Tyndall Group sequence from its base to the top. The locality to be visited shows an unusual mass-flow breccia containing disturbed bedding structures, scattered lithic clasts, and a large irregular block of andesitic rock showing pyrite-silica alteration.

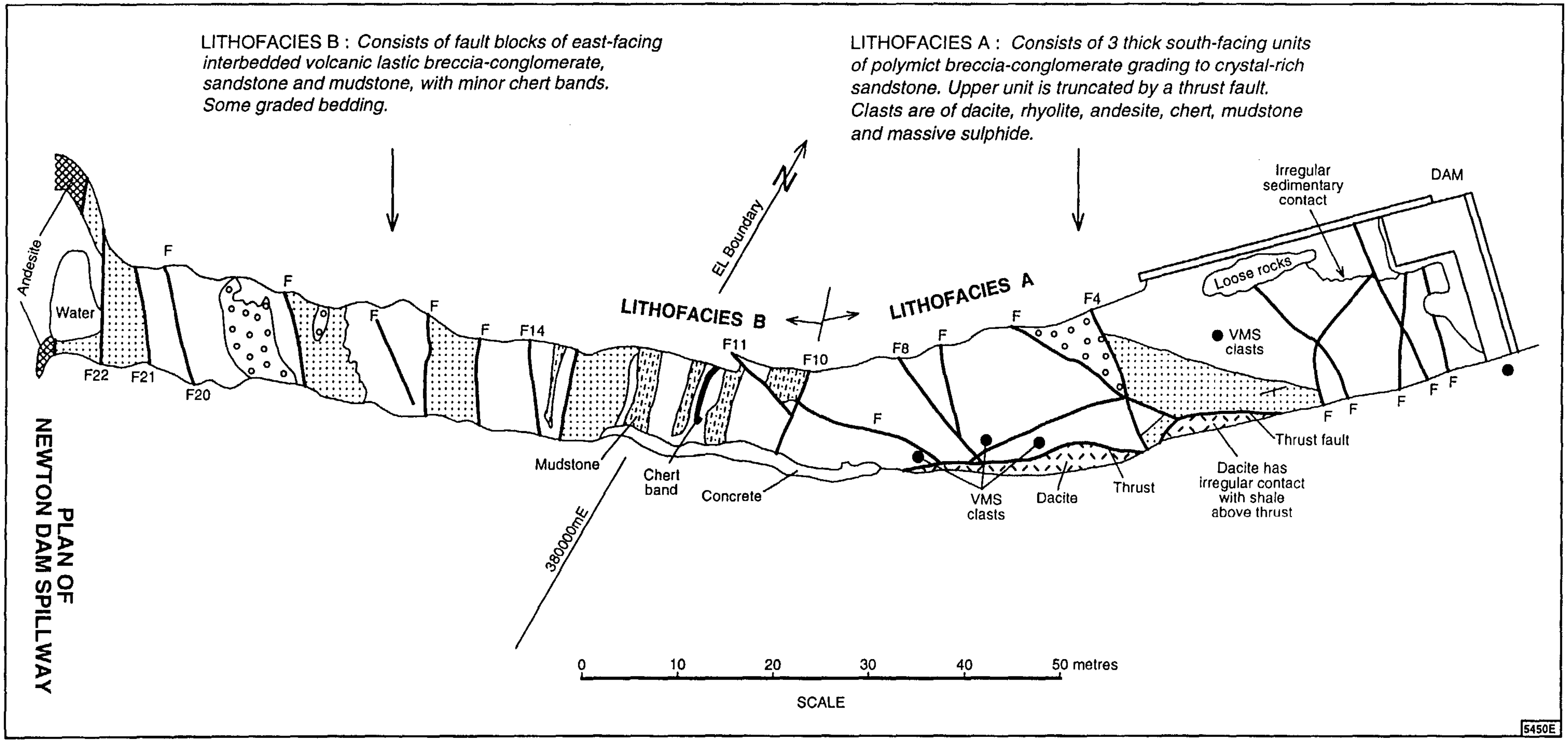


Figure 18.

Simplified map of Newton Dam Spillway (after Aberfoyle geologists and Gibson, 1991).

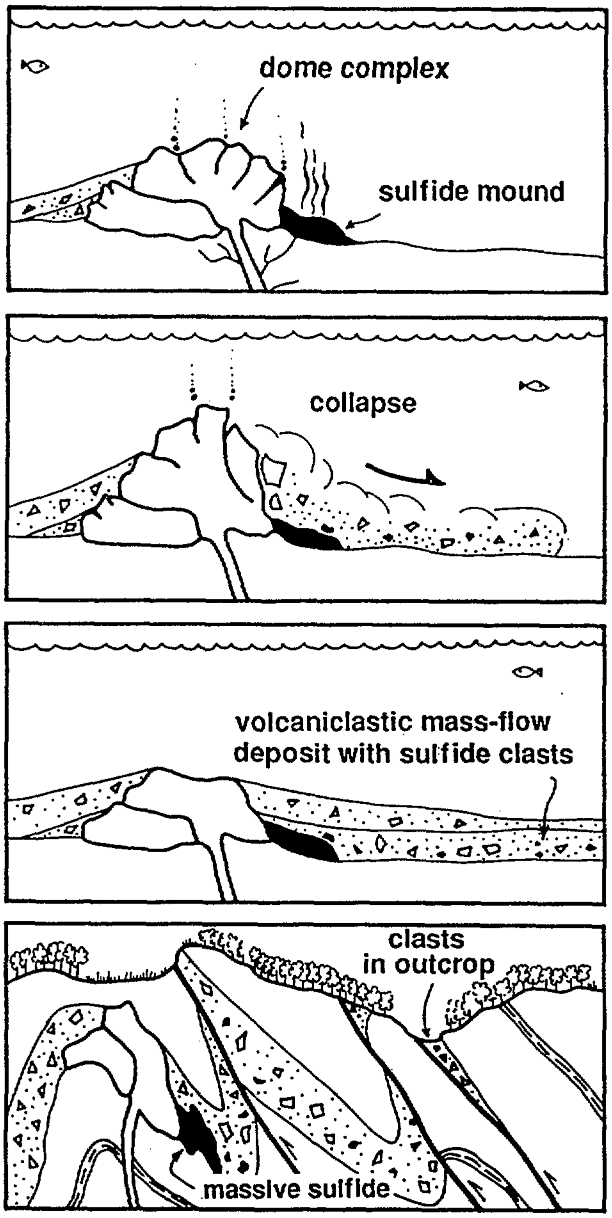


Figure 19.

One interpretation of the stages involved in the formation of the massive sulphide clast-bearing breccia in the Newton Dam Spillway (after McPhie et al., 1993)

Outcrops just to the west show another mass-flow breccia unit with large rafts of sedimentary rock, and one with abundant clasts of pink lava apparently derived from the underlying lava unit.

STOP 5 — Henty Gold Prospect

The existence of a significant gold prospect at Henty was realised in 1984, when drill core from base metal drilling in the area was re-assayed for gold. Subsequent drilling (over 100 holes) has indicated a broad zone of mineralisation extending to 400+ metres below the surface (fig. 20), with erratic gold grades to over 100 g/t. A decline was driven into the best zone of shallow mineralisation ('sill area') in 1989, but deeper drilling revealed a much bigger resource of higher grade mineralisation about 400 m below surface. This latter zone ('Zone HP96') gave an intersection of 7.5 m at 107 g/t gold, and has since been shown to include an inferred resource of 160 000 t at 91 g/t gold. Present development at the site is aimed at sinking a 440 m shaft to provide access for drilling and bulk sampling of Zone HP96. Descriptions of the Henty Prospect have been given by Roberts (1990), Roberts and Fleming (1990), the Development Proposal and Environmental Management Plan prepared by Environmental NSR Consultants in 1990, and McNeill and Corbett (1992).

The Henty gold mineralisation is contained mostly within pods and shoots of massive quartz (MQ) occurring within a 20-metre wide silica-sericite-pyrite alteration zone bounded to the west by the footwall of the 65° west-dipping Henty Fault. Rhyolitic to dacitic lavas and minor volcaniclastics of the Central Volcanic Complex occur on the western side of the fault and are intruded by abundant altered mafic dykes of tholeiitic basalt and dolerite. The alteration zone lies within the lower part of the east-younging but overturned Tyndall Group sequence, and grades east into strongly sheared but relatively unaltered sedimentary rocks. Lenses and pods of massive sulphide also occur within the alteration zone, and one of these pods was initially costeaned in 1973. The alteration zone extends along strike for about one kilometre, and contains two main zones (A and B) of siliceous mineralisation in which shoots of massive quartz contain the bulk of the gold (fig. 20). The massive quartz shoots in the sill area are up to 50 m in strike length and 1.5 m in width, but appear to be much wider than this in the Zone HP96 area. The A Zone appears to be partly truncated by the Henty Fault, with its hangingwall intersection in the fault plunging southwards at about 40°. The two zones appear to amalgamate at depth below the HP96 area.

The Henty gold-sulphide mineralisation is unlike the other known deposits in the Mount Read Volcanics belt. There has been considerable speculation as to whether the mineralisation represents a structurally-controlled, Devonian granite-related deposit, such as Lakeside and the Farrell lodes further north on the Henty Fault (Taheri and Green, 1990), or an unusual Cambrian VHMS-type deposit, or some combination of both. Its position on the footwall of the Henty Fault suggests some degree of structural control, but this orientation is also parallel to strike in the overturned stratigraphy, and does not preclude a largely syngenetic origin. The presence of pods of massive sulphide (up to 1.5 m thick) associated with a large sericitic-pyritic alteration zone is suggestive of a volcanic-exhalative origin.

STOP 6 — Hall Rivulet Canal Mass-Flow Breccia

The recently constructed Hall Rivulet Canal and associated access road form a westerly continuation of Howards Road from the White Spur Dam, and provide an excellent series of exposures through the White Spur Formation and part of the Central Volcanic Complex. The contact between these two units was initially interpreted to be an unconformity at the base of the west-younging

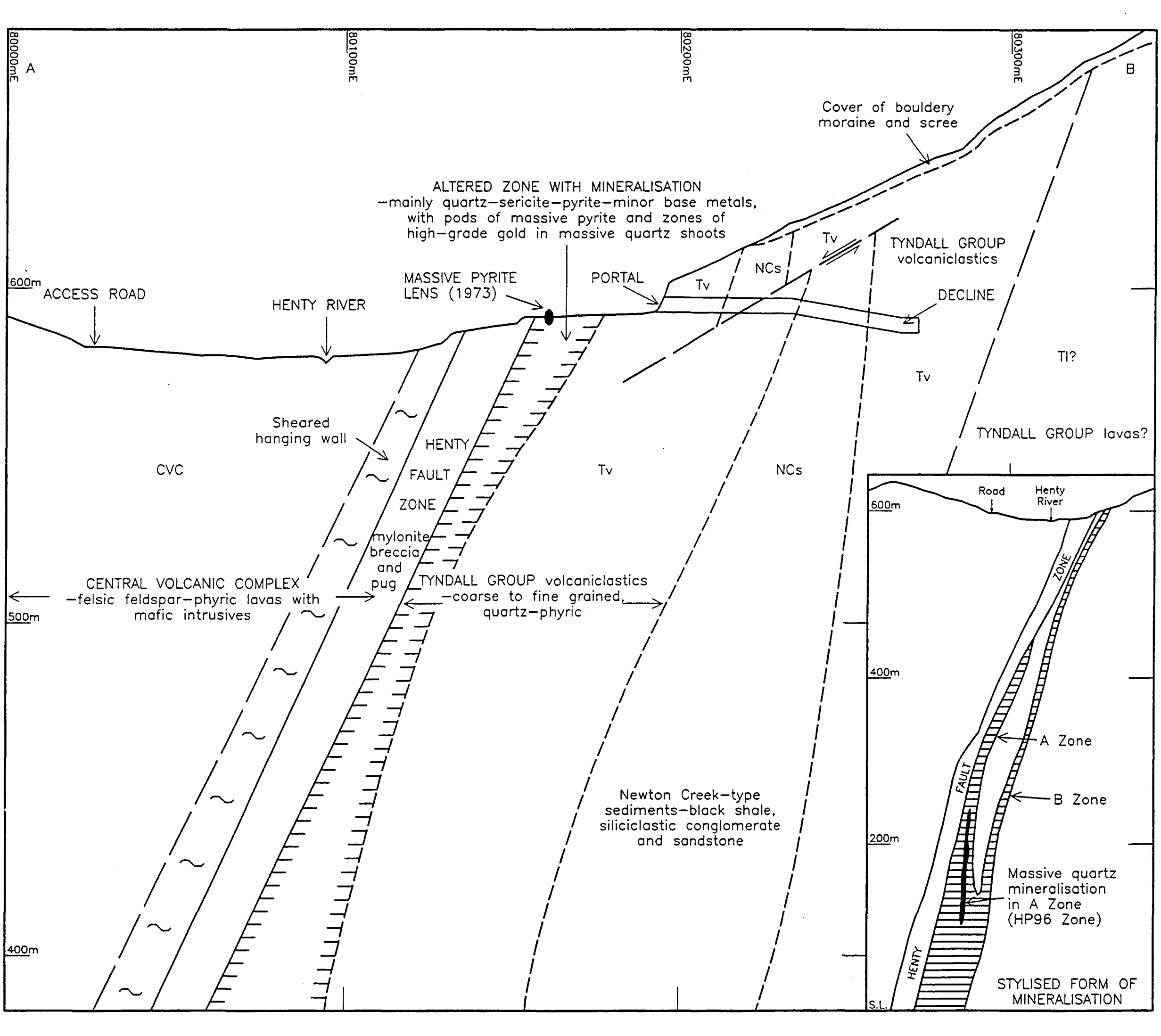


Figure 20.

Cross-section of the Henty Gold Prospect, with inset showing deeper cross-section with stylised form of mineralisation in Zone 96 area. After McNeill and Corbett (1992) and Roberts (1990).

White Spur Formation (Corbett and Lees, 1987), but further work suggests it may be an interfingering or gradational contact between two partially equivalent units (McPhie and Allen, 1992; McPhie *et al.*, 1992).

The volcano-sedimentary sequence of the White Spur Formation is particularly well displayed, and consists of interbedded volcaniclastic sandstone, breccia, siltstone and mudstone. Some of the volcaniclastic units are very thick and massive, and form topographic ridges. They are typically crystal-rich (feldspar, quartz), with a significant component of small pumice clasts and shards, and a variable proportion of volcanic lithic clasts and sedimentary intraclasts. Many units are graded from lithic-rich breccia at the base, though coarse crystal-rich sandstone, and finally shard-rich siltstone-mudstone at the top. Erosional bases to such units indicate an origin as high concentration mass-flow deposits.

The exposure to be visited is of a coarse lithic breccia with abundant dark grey mudstone clasts and 'rafts', forming the base of a thick mass-flow unit (fig. 21). The erosional contact on the underlying fine sandstone is well exposed, and some of the large irregular blocks in the breccia appear to be intraclasts of this material.

STOP 7 — Tyndall Group Banded Sandstone, Anthony Road

The Tyndall Group was first recognised as a mappable unit in the upper part of the Mt Read Volcanics sequence in 1974, based on the distinctive pink and green banding (Corbett *et al.*, 1974). The banding is due to alternation of albite-rich (pink) and chlorite-rich (green) zones more or less parallel to bedding in the crystal-rich sandstones, and appears to be an early alteration feature (diagenetic?) related to widespread deposition of secondary fine albite in pore spaces. Lithic clasts in the sandstones commonly have a halo of secondary pink albite, and these halos may coalesce to form an irregular banding. Although the banding is roughly parallel to bedding in most outcrops (presumably reflecting porosity variations related to deposition), there are also examples of pink albite bands following joints perpendicular to bedding.

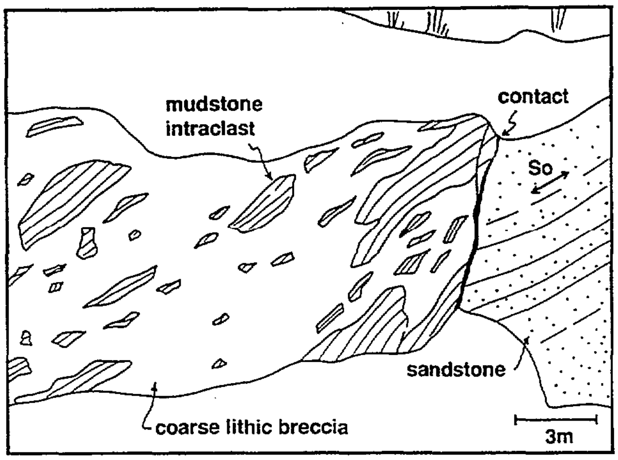


Figure 21.

Sketch of outcrop at Stop 6, Hall Rivulet Canal, where the base of a very thick, mudstone interclast-rich, graded polymict volcanic breccia–crystal-rich sandstone unit in the White Spur Formation is exposed (after McPhie et al., 1992).

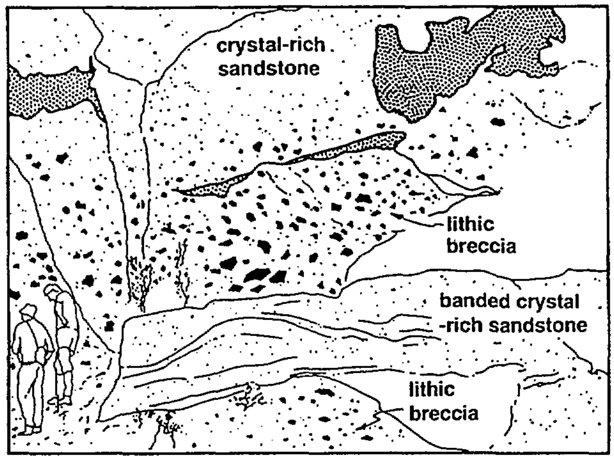


Figure 22.

Sketch of interbedded graded volcanic lithic breccia and banded crystal-rich sandstone of the Tyndall Group at Stop 7 on the Anthony Road (after McPhie et al., 1992).

The exposure to be visited consists of two interbedded lithofacies (fig. 22):–

(a) Very thickly-bedded volcaniclastic breccia, consisting of angular volcanic lithic fragments (mostly quartz-feldspar-phyric lava) up to 10 cm across in a crystal-rich (quartz and feldspar) matrix. Some beds contain lenticular or irregular clasts of feldspar-phyric chloritic material which may be altered pumice.

(b) Thinly-bedded to laminated, pink and green banded, coarse to fine-grained crystal-rich sandstone.

Several sedimentation units in the section show grading from breccia in the basal part to laminated fine sandstone in the upper part, and small-scale erosional features may be seen at the base of one unit. An origin as deposits from high concentration mass flows (megaturbidites) seems likely for most units.

The abundance of angular volcanic quartz and feldspar crystals in the sandstone suggests a syn-eruptive origin and that some crystal concentrating mechanism has been active, perhaps related to transformation of subaerial pyroclastic flows into water-supported subaqueous mass flows (White *et al.*, 1993). A large block of welded ignimbrite occurs within this sequence in a cutting further south, and several other examples of welded ignimbrite within Tyndall Group rocks have recently been described by White *et al.* (1993).

STOP 8 — Andesite Breccias, Anthony Road

This locality shows one of several breccia types within the Anthony Road Andesite. Although time has dulled the original colour contrasts, the monomict, locally jigsaw-fit breccia texture is still evident. The clasts are hornblende-feldspar-phyric andesite, and have been pervasively weakly chlorite-epidote altered. The matrix consists mainly of fine hornblende-bearing volcaniclastic siltstone derived from the andesite. Subsequent silicification preferentially replaced the more porous matrix and encroached on the margins of the clasts, leaving unaffected cores.

The andesite clasts range up to 30 cm across and are mostly angular to sub-angular with curviplanar surfaces. The pale siliceous alteration rims to the clasts could be accentuating original quenched margins. The matrix is faintly bedded to laminated in places. An origin from quench fragmentation of lava in a submarine environment seems likely.

DAY 4
QUEENSTOWN – MT LYELL AREA

Introduction

Mining in the Mt Lyell field has been going on continuously for 110 years, since gold was first discovered in Linda Creek (on the eastern side of the mine) in 1883. Prospectors traced the gold to its source in a large gossanous iron 'blow' on the side of Philosophers Ridge, and blasting away of the ironstone revealed the rich copper deposit below. The colourful history of mining at Mt Lyell, with its two rival companies, two railways to the coast, its larger-than-life characters, and the development of the revolutionary pyritic smelting process which enabled the mine to run profitably but had a devastating effect on the forests, is recounted in Geoffrey Blainey's *Peaks of Lyell*. The Lyell area has fascinated and frustrated geologists for over a century, because of the variety and complexity of its outcrops, structures and orebodies, and continues to do so today.

The present underground mining operation, owned by Renison Goldfields Consolidated, is due for closure in

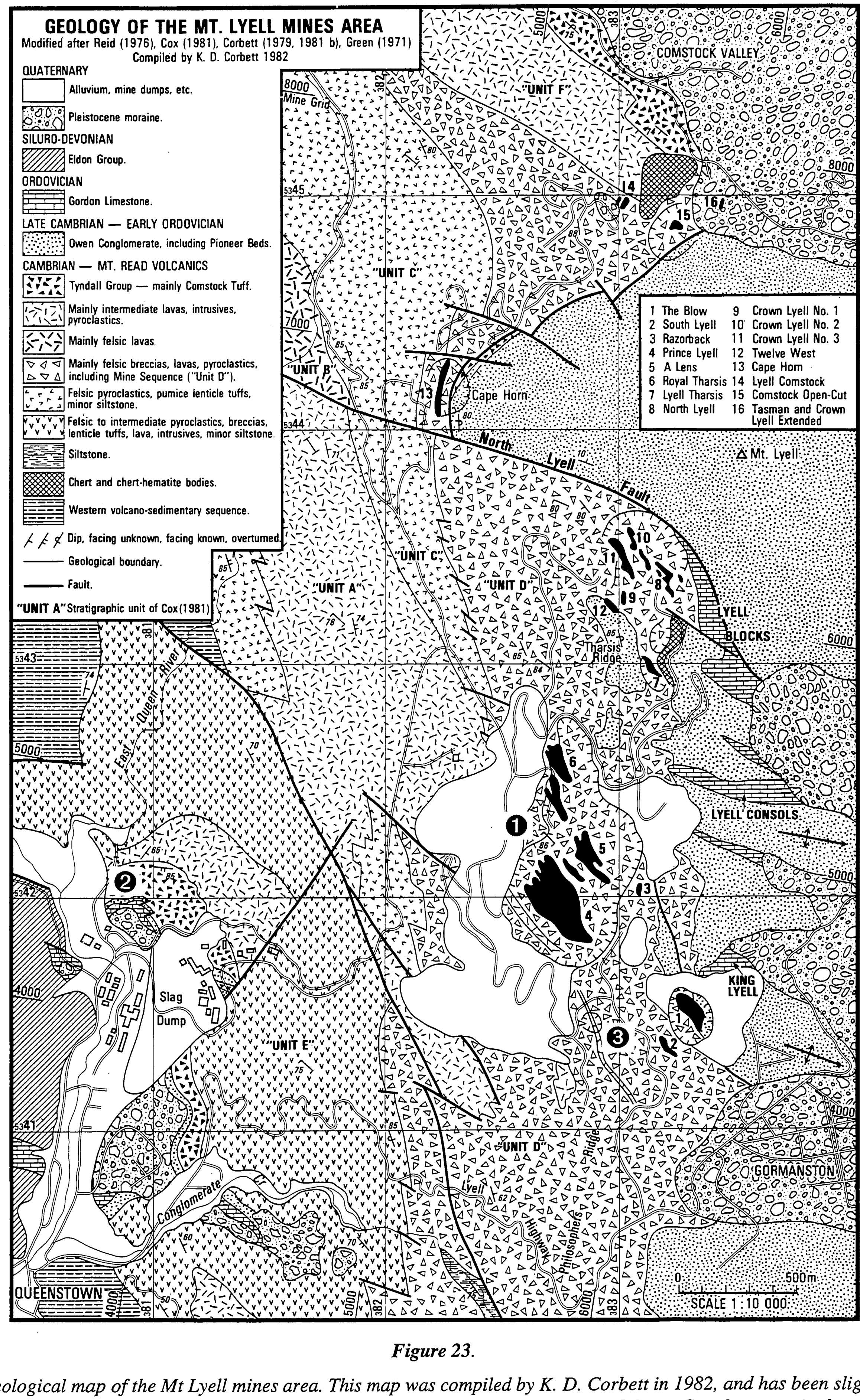


Figure 23.

Geological map of the Mt Lyell mines area. This map was compiled by K. D. Corbett in 1982, and has been slightly modified by later mapping in a few areas. The contact between the volcanics and Owen Conglomerate in the area between the Blow and North Lyell represents the North Lyell Fault.

1995. Over its lifetime the mine has produced over 105 million tonnes of ore, containing 1.3 million tonnes of copper and over 42 tonnes of gold (Hills, 1990). Attempts are being made to find an alternative operator-buyer for the mine, to carry on a smaller operation which could involve alternative extraction techniques such as leaching.

Geology of the Mt Lyell Area

The ten or so separate orebodies of the Mt Lyell field (fig. 23) are associated with a very large (8 × 1.5 km) pyrite-sericite-chlorite alteration zone developed within a complex sequence of rhyolitic, dacitic and minor andesitic lavas and breccias of the Central Volcanic Complex (Cox, 1981; Hills, 1990; Solomon and Carswell, 1989). Primary textures, which can still be distinguished through the overprint of alteration and strong cleavage development, suggest that at least part of the sequence consists of submarine flow-banded felsic lavas complexly intermixed with hyaloclastite breccias, as seen on Philosophers Ridge.

The felsic lava-rich sequence interfingers westward with a volcano-sedimentary succession (Yolande River Sequence) of volcaniclastic sandstone turbidites, mass-flow breccia, siltstone, black mudstone and tuffaceous mudstone. The sequence faces east in the mine area, but is truncated by the Great Lyell Fault, which throws siliceous Owen Conglomerate against the volcanics on a complex contact. In the Comstock Valley area, at the northern edge of the mining field, the altered and mineralised rocks are predominantly andesitic, and are overlain by Tyndall Group sandstone and volcaniclastic conglomerate.

Several small exhalative-type massive sulphide bodies (Zn-Pb-Cu) occur at Comstock, but the majority of the Mt Lyell deposits are either disseminated or semi-massive chalcopyrite-pyrite 'footwall' type or bornite-chalcopyrite-chert replacement type. An unusual occurrence is of native copper and cuprite in goethite of the 'copper clay' deposits, hosted in Ordovician limestone on the eastern side of the Great Lyell Fault.

The Great Lyell Fault appears to have been active during the Cambrian volcanism, and may have been the major plumbing structure for the extensive hydrothermal alteration system and associated mineralisation. Active subsidence on the fault in the late Cambrian resulted in accumulation of over 1000 metres of siliceous Owen Conglomerate against the scarp, following which a phase of reverse movement in the early Ordovician caused local folding of the early Owen beds and resulted in the spectacular intra-Owen Haulage Unconformity (Corbett *et al.*, 1974).

The strong schistosity which is evident throughout the volcanics of the mine area (the 'Lyell schists') appears to be largely a result of a major period of folding, faulting and cleavage development in the mid-Devonian. This resulted in some spectacular fold and fault structures in the highly competent Owen Conglomerate, with deformation in the volcanics being expressed mainly as cleavage development. Sulphide orebodies were deformed in the cleavage direction, with elongations up to 150% (Cox, 1981).

MT LYELL AREA EXCURSION STOPS

STOP 1 — West Lyell Open Cut

A viewing point on the northwest wall of the West Lyell pit gives a good impression of the scale of the original open-cut operation and the present underground block-caving operation. The original open pit provided access to three orebodies (Prince Lyell, 'A' Lens, Royal Tharsis, fig. 23), but only the Prince Lyell deposit is now being worked. This steeply-dipping, low-grade (about 1% Cu, 0.25 g/t Au) disseminated orebody has yielded some 60 million tonnes of ore, and persists undiminished at depth. The majority of the ore consists of about 20% total sulphide (pyrite, chalcopyrite) in a schistose quartz-sericite or quartz-chlorite groundmass. Bands of massive sulphide, 15–20 cm thick and up to 150 m long, are associated with the ore zone and have been interpreted as small exhalative bodies.

STOP 2 — Tyndall Group near substation

The youngest part of the Mt Read Volcanics in the Queenstown area is the Tyndall Group, and the characteristic banded crystal-rich sandstones are well developed in a small area near the HEC substation. The sequence overlies andesitic rocks here, and is itself overlain, with a sharply angular unconformity, by the siliciclastic Pioneer Beds, representing the upper part of the Owen Conglomerate.

A traverse through part of the sequence shows the following:–

(a) A spectacular mass-flow breccia in the lower part, containing intraclasts of sandstone eroded from the immediately underlying unit, abundant rounded pebbles (resedimented from a shoreline or subaerial source?), large irregular blocks of lava, and lenticular chloritic clasts (relict pumice?).

(b) The right-angle unconformity between Tyndall Group volcaniclastic breccia-sandstone and overlying siliciclastic conglomerate and sandstone of the Pioneer Beds. The unconformity demonstrates folding of the volcanic sequence prior to or during the early Ordovician, possibly associated with the Haulage Movement. Note the presence of heavy mineral bands of chromite in the Pioneer sandstones. Weathered Gordon Group limestone overlies the Pioneer Beds about 10 m to the south, so that this 10 m of siliciclastic sediment is the equivalent of the one kilometre or more of Owen Conglomerate deposited on the eastern side of the Great Lyell Fault.

(c) Typical banded crystal-rich sandstones and breccias of the Tyndall Group at the ridge crest overlooking the Mt Lyell mine works. The Pioneer Beds unconformity and Pleistocene glacial gravels are also exposed here.

STOP 3 — Philosophers Ridge and Blow Open Cut

Primary textures and structures in the Mt Lyell host volcanic sequence are probably best seen on Philosophers Ridge, where prolonged natural weathering has etched out subtle differences in composition. However, the intense cleavage development still presents problems. A short traverse from the gate at the end of the Blow access road to the nearest high point of the ridge shows the major features.

Two main facies can be seen — these are alternating and intermixed in irregular fashion. A *breccia facies* ranges from sand texture through granule and pebble-cobble grade to the coarsest type, which has isolated boulder-size clasts. Faint bedding due to grainsize variations is apparent in places. The larger clasts commonly show flow banding, and all clasts appear to be of the same lava type as the second facies.

A *flow-banded lava facies* occurs as irregular zones, lobes and patches, mixed with and commonly more or less surrounded by the breccia facies. The flow banding is mostly on a very fine scale and is commonly folded and contorted. Disruption and modification of the flow banding by the strong anastomising cleavage is typical, leading to secondary brecciation and boudinaging effects and a less coherent appearance.

Truncated edges of flow-banded sections against breccia can be seen in places, as can examples of apparent gradation from flow-banded lava to massive or bedded breccia. Thin layers of breccia separate adjacent lobes of flow-banded lava in places.

These two facies resemble the submarine rhyolite lobes and associated hyaloclastite described by De Rosen-Spence *et al.* (1980) from the Rouyn-Noranda Archaean sequence of Canada (Corbett, 1989). According to this interpretation, the breccia facies comprises quench fragments spalled off from lava lobes that came in contact with seawater on the ocean floor, in much the same way as basaltic pillow breccias are formed. Large piles of in situ and resedimented hyaloclastic breccia may accumulate, interlaced with connected and isolated lobes of lava.

The lookout above the Blow Open Cut provides an excellent view of this large hole in the ground — all that remains of the original Iron Blow orebody. The deposit was mainly massive pyrite and chalcopyrite, originally rich in copper (2.85%), gold (2.8 g/t) and silver (80 g/t), with a bonanza shoot which had grades of 21% Cu and 31,310 g/t Ag. However, after the initial high grade ore was extracted, the average grades fell to about 0.4% Cu and 0.4 g/t Au, and the body was mined primarily as smelter flux to treat the richer North Lyell ore. The orebody lies against the Great Lyell Fault, such that the eastern wall of the open cut is formed by the Owen Conglomerate.

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