Mt Read Volcanics

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Mount Read Volcanics, Tasmania  
Global comparison of massive sulfides  
GEODE

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4.1 Age and tectonic/structural setting

4.1.1 What is the age of your VMS district?  
• Extent, type and precision of geochronolgy? (belt scale and deposit scale)  
• Palaeontological control

Zircon dating of syn-mineralisation volcanics was reported by Perkins and Walshe (1993) and Black et al (1997). The Perkins and Walshe data are based on standard SL13 and should be adjusted up by 1.3% to match the later data, which was relative to the QGNG standard. Stratigraphically, footwall rocks have an average age of 503 Ma and hanging wall rocks have an average age of 506 Ma. Measurement error for most samples is ~ 7 Ma, so the fact that the footwall rocks appear younger than hanging wall rocks is not significant. At the precision of SHRIMP dating these ages are identical.

Palaeontological control on ages is summarised by Laurie et al. (1995). In all cases the VHMS deposits (excluding Henty) are overlain by Middle Cambrian rocks. Que and Hellyer are overlain by the Que River Shale, with an Floran (504-505 Ma on the AGSO time scale) to Undillan fauna. Mt Lyell is overlain by Tyndall Group with a Undillan fauna. Rosebery and Hercules are more difficult, but stratigraphic correlations place them substantially lower than Idamean (Late Cambrian) strata and probably below Boomerangian (late Middle Cambrian). There is no fossil evidence for the maximum age of these deposits but in most cases the fossils are from just above the deposits and should be close to the actual age. The Henty Deposit is in the Tyndall Group, which is late Middle Cambrian in age (Undillan and Boomerangian).

The time scale developed by AGSO as reported in Laurie et al 1995, suggests Floran is 504-505 Ma and thus the zircon SHRIMP dates are consistent with mineralisation occurring in a short period in the Middle Cambrian.

Fig 1.1: Location of major deposits in the Mt Read Volcanics, Tasmania.

4.1.2 What is the current interpretation of the tectonic setting of your VMS district? (include

Table 1.1: Dates for MRV Volcanics.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Volcanics</th>
<th>Original</th>
<th>Adjusted</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PandW 1993</td>
<td>Mount Black Dacite</td>
<td>495</td>
<td>9</td>
<td>501 ?footwall Rosebery</td>
</tr>
<tr>
<td>Black et al 1997</td>
<td>Bond Range Porphry</td>
<td>505</td>
<td>7</td>
<td>?Footwall Hellyer</td>
</tr>
<tr>
<td>Black et al 1997</td>
<td>Mt Jukes Lava</td>
<td>503</td>
<td>7</td>
<td>Footwall Mt Lyell</td>
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<td>495</td>
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<td>501 Hanging wall Mt Lyell</td>
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<td>7</td>
<td>509 Hanging wall Mt Lyell</td>
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<td>Anthony Road Andesite</td>
<td>502</td>
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<td>509 Hanging wall Mt Lyell</td>
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<td>Mt Charter Group</td>
<td>503</td>
<td>8</td>
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<td>4</td>
<td>Hanging wall Hellyer/Que River</td>
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<td>Average</td>
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</table>
A tectonic model for the setting of Mt Read Volcanics (MRV) magmatism was presented by Crawford and Berry (1992). A 2-stage cartoon showing the stages of development of western Tasmania from 600Ma to 500Ma (Fig. 1) is based on the Crawford and Berry model, and shows the MRV as a post-collisional suite, being erupted in half-graben developed in recently assembled crustal collage of an arc-continent collision zone. A 600Ma-old east-facing volcanic passive margin, represented by the Rocky Cape block of NW Tasmania, collided with the forearc section of a west-facing intra-oceanic arc probably about 510Ma. This resulted in west-directed emplacement of large, forearc-derived allochthonous sheets of boninite-dominated ophiolitic rocks and some parautochthonous basement slices, onto the passive margin. The latter must have been very attenuated crust, like the leading edge of many modern passive margins, as post-collisional magmatism was largely submarine, implying that large collision-related mountain ranges were not produced in this rather ‘passive’ collision.

In the latter stages of collision exhumation of some of the underthrust (sub-ophiolite) passive margin crystalline crust imposed a structural control on the appearance of post-collisional magmatism, restricting MRV largely to half graben west of the actively exhuming crystalline crust that eventually formed the Tyennan nucleus of Tasmania. There is no compelling evidence that the MRV are associated contemporaneous subduction. However, major crustal extension is recorded in the progression of magma types throughout the life of the MRV, with a late change from primitive shoshonitic basalts to tholeiites (most as dykes). Cessation of extension is recorded by the sudden demise of mafic magmatism, and the felsic ‘flare-up’ at the end of MRV magmatism, coupled with the sudden appearance of extensive black shales above the mafic volcanics.
4.1.3 What is the tectonic interpretation based upon:
- structural mapping and interpretation? (quality of mapping?)
The Crawford and Berry (1992) model and interpretation of the MRV as a post-collisional suite was deduced in large part from lithostratigraphic information provided by regional mapping and structural studies, and petrological-geochemical evidence.

The whole of the Mt Read Volcanics has been mapped at 1:25,000. Near mineralisation, 1:5000 maps are available. The level of vegetation cover and paucity of outcrop means that these maps are not as good as might otherwise be expected, but they represent a major resource and more lithological mapping can only be attempted where drillcore support is available.

Structural data is available on these maps. More structural data has been obtained and a structural interpretation produced along a number of sections (Berry 1999 and unpublished). The structure is dominated by Devonian folding and thrusting so that the Cambrian structure is very poorly known except in a few local areas. Gravity is dominated by Devonian granites and has not been useful in determining the structural controls on mineralisation. Magnetics has been affected by a number of processes but has been used to recognised some Cambrian intrusives.

A high resolution seismic section was attempted across parts of the region but the lack straight roads, complex geology (with steep dips and complex variations in layering has hampered interpretation of this data. At present the only public interpretations are to simple to be any help in structural interpretation. The deep seismic sections have no resolution in the top few km and have not been integrated with the surface geology.

A very large database of high quality analyses of MRV (see below) has enabled thorough studies of the geochemical affinities of the lava suites constituting the MRV (Crawford et al., 1992). Medium- and high-K calc-alkaline and shoshonitic lavas are best represented, based on detailed trace element data including REE patterns and comparisons with modern suites.

4.1.4 Is there a comprehensive and high quality database of volcanic geochemistry to assist with tectonic interpretation?

- How many whole-rock/trace analyses on least-altered rocks?
- Type and quality of trace element data?
- What isotope data are available?

More than 500 wholerock major and trace element analyses are available, including data for all recognised magmatic suites within the MRV. Data available before 1992 are summarised by Crawford et al., (1992), and considerably more data has derived from several AMIRA projects, for which confidentiality restrictions have expired. Approximately half of these analyses are of rocks in which alteration is either insignificant, or unlikely to have affected useful geochemical discriminators. All analyses are by XRF for major elements and about 13 trace elements (Rb, Ba, Sr, Ni, Cr, V, Sc, Zr, Nb, Y, Cu, Pb, Zn). About one quarter of these analyses are complemented by more detailed trace element data, including for most of these REE, Th, U, Hf, (and more precise Nb data) by ICP-MS. Presently, about 15 Nd-Sr isotope analyses are available across the range of lithostratigraphic units represented in the MRV. Work in progress (P.Hollings, T. Crawford) is focussing on the felsic rocks within the MRV, to determine approximately what proportion of these are crustal melts, and how much are the products of extensive AFC from more mafic parental magmas. Other studies in progress (G.Davidson, W Herrmann) are assembling further Sr-Nd isotopic data to elucidate alteration pathways and budgets. A small unpublished database of Pb isotopic data for the Hellyer basalts and associated rocks also exists.


4.1.5 Have the district-scale and deposit-scale ore-fluid plumbing structures been identified? Size of structures? How were they defined (mapping?, alteration?,...
4.1.6 Have detailed structural studies of the deposits been undertaken? Which deposits?

Hellyer
The Devonian and Cambrian structural environment well defined.
Downs, R.C., 1993, Syn-depositional fault controls on the Hellyer volcanic-hosted massive sulphide deposit. (M Econ Geol Thesis, University of Tasmania, Unpubl.)

Que River
The Devonian structure relatively well known. No serious attempt to understand the Cambrian structural controls on mineralisation

Rosebery
A very extensive literature. The Devonian structure is well described. The intense Devonian faulting makes resolving Cambrian structure difficult but some attempts have been made (Berry and Keele 1997 and R Allen unpublished reports.)

Hercules
A few general papers showing the late structural history of the deposit. Lots of unpublished data on the geometry and genesis. The interpretation of this relatively inaccessible data remains to be done.

Mt Lyell
Very extensive literature. The late structure and mapping is well constrained. The Cambrian geometry and controls on mineralisation have been investigated but remain highly contentious.
Cox, S.F., 1981, The stratigraphic and structural setting of the Mt Lyell volcanic-hosted sulfide deposit. Econ. Geol. 76, 231-245.

Henty
Devonian structure well constrained. Evidence for structural control on mineralisation limited.

4.1.7 What further research is needed to improve the tectonic interpretation?

One major consideration that would improve our understanding of many aspects of the Mt Read Volcanics would be the availability of a geochronological technique that could date rocks with a relative error of ±
1m.y., rather than the 5 m.y. error currently given on SHRIMP zircon dates. No suitable technique is currently available to match this precision.

We do not know what underlies the main section (Central Volcanic Complex) of the Mt Read Volcanics along the length of the belt. To test this, one or more drill holes in excess of 3km depth would be required. Deep seismic reflection presently available does not provide adequate resolution at shallow crustal levels (<5km) to answer questions relating to the basement of the Mt Read Volcanics.

Finally, whereas detailed structural and volcanological data are available for near-mine sequences, a more belt-wide synthesis of the structural and volcanological data, together with ‘filling-in’ of obvious gaps along the belt, would certainly contribute to an enhanced understanding of the tectonic setting of this important belt.

4.1.8 List key references

See above.

4.2. Volcanic architecture

4.2.1 What are the scales of geological maps available for the district and the deposits? Has a comprehensive systematic stratigraphy been established for the district?

High quality 1:25,000 regional geological maps were produced by Mineral Resources Tasmania during the 1980s, taking advantage of new HEC roads and excavations. These maps cover the central portion of the MRV and surrounding formations, giving information on lithology, stratigraphy, structure, and alteration. These maps also introduced systematic lithostratigraphic terminology for the region. Some of the maps have accompanying reports in which the geology is described in detail. Unpublished maps of geology and alteration at widely varying but generally larger scales have been produced for the major massive sulfide deposits and prospects by mining and exploration companies previously and currently active in the area. An additional unpublished geological map resource exists in research theses at the University of Tasmania.

The Mount Read Volcanics have been divided into four regionally mappable lithostratigraphic units that comprise a range of volcanic and sedimentary facies (Corbett and Lees, 1987; Corbett, 1992). The principal lithostratigraphic units are: the Eastern quartz-phyric sequence, the Central Volcanic Complex, the Western volcano-sedimentary sequence (comprising the Dundas Group, Mount Charter Group and Yolande River Sequence) and the Tyndall Group (Corbett, 1992). There are in addition locally important, separately named volcanic successions that can be distinguished on the basis of lithology and/or composition (e.g. Que-Hellyer Volcanics, Anthony Road Andesite). North-south elongate Cambrian granites (Darwin Granite, Murchison Granite) intrude the succession, mainly along the eastern side. Some ambiguity remains as to the relative timing of these lithostratigraphic units. Also, although some lithostratigraphic units (e.g. Tyndall Group) or parts of units (e.g. Dundas Group, Mount Charter Group) have been formally defined, most have not.

4.2.2 How do the VMS deposits relate to volcanic facies? Provide some sketch diagrams if available. Do the VMS deposits occur at a single stratigraphic position? Do the VMS deposits occur in proximal or distal volcanic facies? Percentage of volcaniclastic rocks versus coherent flows or intrusions?

The main massive sulfide ore deposits in the Mount Read Volcanics occur in successions composed of diverse volcanic and non-volcanic sedimentary rocks (Corbett and Lees, 1987; Corbett, 1992). They are not restricted to a single stratigraphic unit although the largest (Rosebery and Mount Lyell) occur in the Central Volcanic Complex (Corbett and Solomon, 1989). Footwall and hangingwall volcanic facies include lavas, syn-volcanic sills, volcaniclastic and sedimentary facies (McPhie and Allen, 1992; Waters and Wallace, 1992; Allen and Cas, 1990; Large et al., 2001). The lavas and sills comprise both coherent and autoclastic (autobreccia, hyaloclastite, resedimented hyaloclastite and peperite) facies (McPhie and Allen, 1992). The volcaniclastic facies include massive to graded beds of rhyolitic pumice breccia, massive to diffusely stratified
crystal-rich sandstone, massive to graded beds of polymictic volcanic conglomerate or breccia, and massive or laminated shard-rich siltstone (Allen and Cas, 1990; McPhie and Allen, 1992; White and McPhie, 1997; Corbett, 1992; Corbett and Lees, 1987). Sedimentary facies include black pyritic mudstone, and Precambrian basement-derived micaceous mudstone and lithic sandstone (McPhie and Allen, 1992).

The Hellyer and Que River massive sulfide ore deposits are hosted in the Que-Hellyer Volcanics, an important interval of mainly andesitic volcanic facies apparently near the base of the Mount Charter Group in the northern Mount Read Volcanics (Corbett and Komyshan, 1989). The massive sulfides occur above a footwall comprising feldspar-phyric andesitic and basaltic lava and sills, together with associated autoclastic breccia (mainly hyaloclastite) and peperite (Waters and Wallace 1992). The hangingwall is dominated by basalt (Hellyer Basalt). The abundance of basalt-mudstone peperite indicates that most of the basalt units are sills that intruded black mudstone (Que River Shale). Very thick, graded units of rhyolitic pumiceous and volcanic lithic breccia interbedded with turbidites and mudstone occur in the upper parts of the hangingwall (Southwell Subgroup). The two ore bodies are quite separate but apparently occur at the same stratigraphic position. At Hellyer, the ore position is marked by coarse polymictic volcanic breccia, sandstone and mudstone. At Que River, dacitic lavas and domes and dacite-derived volcanic breccia are the dominant facies at the ore position.

Trilobites in the Que River Shale, very thick sections of black mudstone and the abundance of graded mass-flow units collectively indicate that the Hellyer massive sulfide formed in a deep (>1000 m?) submarine setting. The volcanic facies association indicates proximity to intrabasinal vents for effusive, basaltic and andesitic eruptions and syn-volcanic intrusions.

The Rosebery and Hercules massive sulfide lenses occur in part of the Central Volcanic Complex dominated by very thick, weakly graded units of feldspar-phyric rhyolitic pumice breccia. The ore lenses are located in the stratified pumiceous sandstone and mudstone top ("host rock") of very thick pumice breccia that forms most of the footwall (Allen and Cas, 1990). The hangingwall comprises thick graded beds of variably crystal-rich and pumiceous sandstone ("hangingwall pyroclastics") interbedded with black mudstone.

A below-wave-base submarine setting for the Rosebery-Hercules succession is clear from the presence of very thick graded beds and black mudstone but there are no features that provide more precise constraints. The volcanic facies association is dominated by syn-eruptive pumiceous mass-flow deposits generated by a voluminous rhyolitic explosive eruption. This area was a major depocentre in proximity to active vents although no vent positions have been identified within the area encompassed by existing exposures.

The Mount Lyell massive sulfide ore bodies also occur in the Central Volcanic Complex (Corbett, 1992; Cox, 1981). However, understanding of the stratigraphic context of these deposits has been inhibited by the difficulty of facies identification and interpretation in the large areas of intense hydrothermal alteration. The host succession is dominated by massive or locally flow-banded, feldspar-phyric, rhyolitic lavas, domes and intrusions intercalated with thick intervals of feldspar-phyric pumice breccia. The volcanic facies provide few clear constraints on the depositional setting. Very thin intervals of laminated shard-rich mudstone and mixed-provenance mudstone are consistent with a below-wave-base setting. The thick felsic lavas and domes are probably products of intrabasinal vents and essentially occupying source positions. Thick beds of pumice breccia could be derived from the similar intrabasinal vents or else, from more remote vents outside the existing exposures.

The Henty gold deposit is the Tyndall Group which is the youngest lithostratigraphic unit in the MRV (Corbett, 1992). At Henty, the lower part of the Tyndall Group comprises crystal-rich volcanic sandstone, volcanic breccia, quartz-phyric rhyolitic lava and autoseismic breccia, welded ignimbrite, mudstone and hematitic fossiliferous limestone (White and McPhie, 1996, 1997; Halley and Roberts, 1997). The upper part is dominated by very thickly bedded, polymictic volcanic and mixed-provenance conglomerate and sandstone. The mineralised zone is stratabound and occurs at the base of the Tyndall Group. The immediate host facies is an intensely altered assemblage of carbonate, silica, albite and phyllosilicates.

The Tyndall Group differs from other lithostratigraphic units in the MRV in containing evidence for deposition in relatively shallow water (shelf, up to few hundred metres). In particular, it includes limestone with a shallow marine fossil assemblage (Jago et al., 1972) and in situ welded ignimbrite (White and McPhie, 1997), and overlies an unconformity surface involving substantial erosion of older MRV lithostratigraphic units. The Tyndall Group may also be significantly younger (up to 5 Ma) than the rest of the MRV (Perkins and Walshe, 1993). At Henty, the volcanic succession includes the proximal products of intrabasinal vents.
(rhyolite lava and breccia) and also a more distal association of reworked and resedimented volcaniclastic facies generated by felsic, mainly explosive volcanic centres ignimbrite (White and McPhie, 1996).

In summary, VHMS mineralisation in the Mount Read Volcanics occurs in diverse volcanic facies and both at seafloor positions (Hellyer and Que River, Gemmell and Large, 1992) and as shallow sub-seafloor replacement (Rosebery and Hercules, Allen and Hunns, 1990; Khin Zaw and Large, 1992). Rosebery and Hercules both occur in a distinctive pumice breccia-dominated facies association at more or less the same stratigraphic position, probably near the top of the Central Volcanic Complex. The hangingwall successions at Rosebery-Hercules and Hellyer-Que River are very similar, comprising black shale interbedded with quartz-bearing volcaniclastic mass-flow units. Correlation of these two successions would imply that the massive sulfide ore bodies formed approximately contemporaneously, or at least during a fairly narrow time interval coinciding with a hiatus in the accumulation of volcanic facies (McPhie and Allen, 1992). This speculation cannot presently be extended to include the Mount Lyell ore bodies as existing stratigraphic constraints are inadequate. The Henty ore deposit is clearly younger, occurring in the Tyndall Group which unconformably overlies the Central Volcanic Complex.

4.2.3 What is the composition (rhyolite?, basalt?) of the VMS host package? Is there a change in volcanic composition at, or close to, the ore position?

Geochemical research in the MRV has been biased toward lavas and intrusions, with little attempt to sample and analyse the diverse and voluminous volcaniclastic facies present. Nevertheless, the data clearly show that medium to high K calc-alkaline rhyolite and dacite are predominant, with locally abundant andesite and basalt (Crawford et al., 1992).

At Hellyer and Que River, the footwall volcanic succession is dominated by andesite and basaltic andesite, with only very minor dacite. Dacitic lavas and lava-derived breccia are important at the level of the ore bodies, especially at Que River. The hangingwall comprises black pyritic mudstone intruded by basaltic and basaltic andesite sills termed the Hellyer Basalt (Corbett and Komysshan, 1989; Whitford et al., 1989; Waters and Wallace, 1992). The Hellyer Basalt has a distinctive geochemical signature, ranging from high K calc-alkaline to shoshonitic in character (Crawford et al., 1992). Higher parts of the hangingwall succession are rhyolitic, including quartz-phyric pumice breccia and minor lavas.

The Rosebery and Hercules ore bodies are hosted by a rhyolitic and dacitic volcanic succession (Corbett, 1992). The ore lenses occur in the fine-grained stratified top of a very thick interval of feldspar-phyric pumice breccia (Allen and Cas, 1990). Most of the footwall pumice breccias are rhyolitic (Ti/Zr ~ 6), however pumice breccia at the ore position is dacitic (Ti/Zr ~ 11) (Large et al., 2001). Volcaniclastic units in the hangingwall are also rhyolitic but distinctive in being quartz(+feldspar)-phyric (Lees, 1987; Lees et al., 1990).

Most of the Mt Lyell ore bodies occur in strongly altered, rhyolitic to dacitic volcanic rocks of the Central Volcanic Complex. However the Comstock ore body is hosted in an interval of andesitic lavas and breccias stratigraphically between the Central Volcanic Complex and the Tyndall Group (Corbett, 1992).

The Henty Gold deposit occurs in part of the Tyndall Group dominated by calc-alkaline rhyolite (Corbett, 1992; Crawford et al., 1992). In some places, crystal-rich volcaniclastic sandstone at the base of the Tyndall Group (Lynchford Member; White and McPhie, 1996) reflects an andesitic to dacitic provenance.

In summary, in most cases, there is no clear pattern involving a distinct change in geochemistry coincident with the massive sulfide ore bodies in the Mount Read Volcanics. A possible exception occurs at Hellyer where footwall and hangingwall compositions show the most marked differences.

4.2.4 What is the interpreted range of water depth during deposition of the volcanic succession, and immediate host rocks? What criteria were used to estimate water depth (e.g. volcanic facies, sedimentary structures, fossils, fluid inclusions)?

A below-wave base, submarine environment of deposition is interpreted for most of the lithostratigraphic units in the Mount Read Volcanics, based on the presence of trilobites and other marine fossils, thick successions of turbidites and black pyritic mudstone in the sedimentary facies association. This interpretation is consistent with the presence of very thick (tens of metres) volcaniclastic mass-flow units, hyaloclastite,
peperite and pillow lava in the volcanic facies association. Although neither the sedimentary nor the volcanic facies associations give precise depth limits, the Central Volcanic Complex, Western Volcano-sedimentary sequence and Eastern quartz-phyric sequence were probably deposited in a relatively deep-water environment (>1000 m?). The occurrence of limestone, shallow marine fossils and welded ignimbrite in the Tyndall Group suggests that it was deposited in a shallower water, shelf setting, at or just below storm wave base (Jago et al., 1972; White and McPhie, 1997). Thus, the Rosebery, Hercules, Hellyer, Que River and Mount Lyell ore bodies probably all formed in a deep submarine environment, whereas the Henty gold deposit formed in a shallower submarine environment.

4.2.5 What further research is needed to define the relationship between ore formation and volcanic architecture?

Additional geochronology, preferably U/Pb in zircon dates. The current data are high quality but too few. This is especially critical for the Tyndall Group, recently recognised as prospective for gold-rich mineralisation.

A combination of geochemistry and volcanic facies analysis could clarify and refine correlations among the principal lithostratigraphic units. The best facies to target would be large-volume, thick pumiceous mass-flow units that present mapping suggests were originally widespread. Similar units have already been identified in parts of the Western Volcano-sedimentary sequences (Southwell Sub-group, Yolande River Sequence and White Spur Formation) and the Rosebery-Hercules hangingwall. Correlation of these units would greatly advance understanding of the timing of massive sulfide formation.

The massive sulfide deposits of the Mount Lyell field are the least well understood in terms of volcanic facies context. Strong alteration has discouraged any serious attempt at volcanic facies analysis. However, facies research on surrounding, less strongly altered areas could significantly improve knowledge of the host succession and enable an extension of facies analysis into the more altered areas.

Stratigraphic relationships among the main lithostratigraphic units are in most cases poorly constrained. Poor exposure, rugged terrain and alteration. Investment in carefully positioned, deep, diamond drill holes would provide stratigraphic information not otherwise available and of key importance in understanding the geological framework of the massive sulfide deposits.

4.2.6 List key references
*indicates key references


Cox, S.F., 1981. The stratigraphic and structural setting of the Mt Lyell volcanic-hosted sulfide deposit. Econ. Geol. 76, 231-245.


### 4.3 Styles of ore deposits

#### 4.3.1 Provide a table of tonnes and grade for major deposits (>1 million tonnes) (include economic and sub-economic or barren massive sulfides). How many additional deposits of less than 1 million tonnes are known in the district?

**Source of data:** Large (1992), Mineral Resources Tasmania, July 2000.

*The Mt Lyell field includes 22 Cu-Au deposits that form part of the one large hydrothermal system.

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Tonnes (MT)</th>
<th>Cu %</th>
<th>Zn %</th>
<th>Pb %</th>
<th>Ag ppm</th>
<th>Au ppm</th>
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<td>169</td>
<td>2.8</td>
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</table>

A further thirty or so VMS prospects of < 1 million tonnes are known in the MRV.

#### 4.3.2 What is the degree of metamorphism, deformation and recrystallisation in the ore? Does it vary from deposit to deposit in the district?

Degree of metamorphism varies from prehnite-pumpellyte facies to lower greenschist facies. Metamorphism and deformation generally decrease passing northwards from Mt Lyell to Hellyer. The shape of the ore
lenses and sulfide textures in the ores have been variably modified by deformation during the early Devonian. At Rosebery the ores have suffered firstly from early Devonian deformation and secondly from metasomatism related to intrusion of mid Devonian granites at depth (Khin Zaw et al., 1999). Further details on the effect of deformation on the ores are given in the table below.

Table 3.1: Metamorphic and textural features on some deposits in the Mt Read Volcanics.

<table>
<thead>
<tr>
<th>Ore Deposit</th>
<th>Metamorphic Grade</th>
<th>Metamorphic textures</th>
<th>Primary textures</th>
<th>Remobilised sulfides</th>
<th>Shape of orebody with respect to deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt Lyell Cu-Au</td>
<td>Lower greenschist</td>
<td>Abundant recrystallised sulfides, aligned within cleavage</td>
<td>None recognised</td>
<td>Devonian vein py-cpy-qtz-cb common</td>
<td>Elongate parallel to major cleavage</td>
</tr>
<tr>
<td>Henty Au</td>
<td>Lower greenschist</td>
<td>Abundant recrystallised sp-ga textures. Pyrite recrystallised</td>
<td>None recognised</td>
<td>Sulfides and gold remobilised into micro fractures</td>
<td>Strongly effected by deformation</td>
</tr>
<tr>
<td>Rosebery Zn-Pb-Cu-Ag-Au</td>
<td>Lower greenschist (with Devonian granite overprint to upper greenschist)</td>
<td>Annealed sp-ga textures. Pyrite recrystallised.</td>
<td>Banding in massive ore. Rare colloform pyrite</td>
<td>Coarse cpy-ga recrystalisation in places. Granite related mag-potourn overprint at depth</td>
<td>Modified by deformation</td>
</tr>
<tr>
<td>Que River Zn-Pb-Cu-Ag-Au</td>
<td>Prehnite-pumpellyite</td>
<td>Annealed sp-ga textures</td>
<td>Colloform py common. Zone sp and cpy driease textures</td>
<td>Minor, small scale</td>
<td>Strongly effected by folding</td>
</tr>
<tr>
<td>Hellyer Zn-Pb-Cu-Ag-Au</td>
<td>Prehnite-pumpellyite</td>
<td>Annealed sp-ga less common</td>
<td>Colloform py common. Primary sp and ga textures abundant</td>
<td>Minor</td>
<td>Modified by faulting</td>
</tr>
</tbody>
</table>

**What VMS deposit types occur within the belt (eg polymetallic Zn-Pb-Cu-type, Cu-Zn-type, Au-only, barite-only, pyrite-only)?** Give a cartoon model of each type present, showing simple geology, morphology of the deposit and metal zones. Do not use genetic classifications such as kuroko type or Cyprus type, but use metal content and ratios – Cu/(Cu+Zn) and Zn/(Zn+Pb). (eg. Large, 1992: ECON. GEOL. V87, p 473).

There are a range of VMS deposit types as follows:

Cu-type: Deposits in the Mt Lyell field.
Au-only: Henty deposit.
Zn-Pb-Cu-type: Rosebery, Hellyer, Que River, Hercules.
Pyrite-only: Chester.

Simplified geological cross sections of some the major deposits are shown in figure 3.1. Pre-deformation schematic reconstructions are shown in figure 3.2.
4.3.4 Are stringer zones present or economic? What is their mineralogy? Are there any deposits that comprise only stringer sulfides?

The development of footwall stringer or stockwork mineralisation is variable across the deposits.

**Mt Lyell deposits** - (eg Prince Lyell and Western Thersis) – stringer and disseminated pyrite-chalcopyrite makes up 90% of the ore. Massive sulfide lenses are rare.

**Rosebery** – stringer mineralisation is very rare. Minor disseminated py, cpy, sp occurs in the footwall alteration zone to most massive sulfide ore lenses. No stringer mineralisation is mined.

**Henty** – no stringer mineralisation. Gold ore is hosted within siliceous alteration zone.

**Que River** – pyrite-rich zinc-lead stringer is common in immediate footwall to massive sulfide. Zinc-lead stringers are common but not economic. Minor gold resource (0.5 – 2.0 ppm Au) within part of the zinc-lead stringer zone.

**Hellyer** – base metal veins are common in the siliceous core of the footwall alteration pipe immediately below the massive sulfide body. The veins vary from copper-rich to zinc-lead rich to pyrite-rich. They are commonly discrete veins and do not form a network or stockwork pattern typical of most stringer zones (Gemmell and Large, 1992). The Hellyer stringer zone is not considered to be economic.
4.3.5 What are the major textures in the massive sulfides – massive featureless, banded, brecciated? Are these textures interpreted to be primary or deformation-related. Key evidence?

Table 3.3: Textures in the ores are tabulated below:

<table>
<thead>
<tr>
<th>Name</th>
<th>Dominant sulfide ore type</th>
<th>Comment of origin of texture</th>
<th>Other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt Lyell</td>
<td>Disseminated and vein sulfides of py-cpy±bnn</td>
<td>Combination of primary stringer zone with deformation related overprint veining</td>
<td>Very minor massive py-sp-ga in uppermost ore lenses (eg Comstock)</td>
</tr>
<tr>
<td>Henty</td>
<td>Disseminated and micro veinlet sulfides in the gold zone</td>
<td>All sulfide textures are now deformation related</td>
<td>Some minor lenses of massive py and py-sp-ga commonly stratigraphically above gold zone</td>
</tr>
<tr>
<td>Rosebery</td>
<td>• massive sulfide</td>
<td>Although sulfides are recrystallised, banding is probably primary</td>
<td>Pyrrhotite and magnetite replacement occurs in deep southern end of mire related to Devonian granite metasomatic fluids</td>
</tr>
<tr>
<td></td>
<td>• banded sulfide parallel to stratification in the host volcanics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Que River</td>
<td>• massive sulfide</td>
<td>Banding in sp-ga rich ore zones is parallel to cleavage and probably related to deformation (Large et al., 1986)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• banded sulfides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hellyer</td>
<td>• massive sulfides</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• banded sulfides</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• brecciated sulfides</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Evidence for primary textures is hard to find in most deposits, but includes: clastic sulfide textures, colloform textures (may occur in massive ore or veins), and sulfide banding parallel to volcanic stratification.

4.3.6 Did most deposits form on the seafloor or by replacement below the seafloor or a combination of both? Key evidence? If sub-seafloor, how far below the seafloor? Evidence?

There is a spectrum of deposits from those that principally formed by replacement below the seafloor (eg Mt Lyell deposit), to those that probably involved both sub-seafloor replacement and seafloor deposition (eg Rosebery and Henty) to those that are dominantly seafloor sulfide deposits (eg Que River and Hellyer). At Mt Lyell, speculation by Walshe and Solomon 1981, and Corbett (in press) indicates that the disseminated py-cpy lenses may have developed up to 1km below the seafloor, with patchy alteration and mineralisation extending up to the seawater-rock interface. At Rosebery, on the other hand, the sulfide replacement may have occurred only ten's of metres below the seafloor, with related exhalation and barite-rich sulfide lenses deposited on the seafloor.

Evidence for sub-seafloor replacement is provided by replacement textures (sulfides replacing primary volcanic textures) within the massive ore lenses and especially at the margins of the lenses.

4.3.7 Did the seafloor deposits form in brine pools, or as mounds, or are both types represented, or did they form by some other mechanism? Key evidence? Is there general agreement on the mechanism of formation?

There is no general agreement in the literature or amongst current researchers about the process of seafloor sulfide accumulation at either Hellyer or Rosebery.
Most previous workers agree that the massive sulfide ores at Rosebery and Hellyer formed at or just below the seafloor (e.g. Green et al., 1981, Solomon and Groves, 1997, Allen, 1994, Gemmell and Large, 1992, McArthur, 1996, Khin Zaw and Solomon, 1999). In both cases it is considered likely that the ores formed in seafloor depressions or small basins adjacent to fault controlled hydrothermal feeder systems. However the precise nature of sulfide deposition and ore deposit evolution has been the subject of considerable debate.

At Hellyer, McArthur, (1989), Large and Gemmell, (1992), Large, (1992) and McArthur, (1996) consider that the massive sulfide orebody grew as a mound in a seafloor depression, with metal zonation developed by hydrothermal zone refining, in a similar fashion to that described for many Kuroko deposits by Eldridge et al., (1983). Solomon and Khin Zaw, (1999), on the other hand, argue that the fluid inclusion evidence suggests that the ore fluid was too dense to enable mound growth, and that the metal sulfides precipitated within a brine pool ponded within a seafloor depression.

Solomon and Walshe, (1979) and Solomon and Groves, (1994) consider that the sheet-like form, stratiform sulfide banding, large size and high Zn-Pb metal content of the Rosebery deposit sets it apart from the classical mound style Kuroko massive deposits. They argue that Rosebery is more like the large VHMS deposits in the Bathurst district, Canada, than the Kuroko deposits of Japan. In these respects Rosebery could be considered to possess some of the features of a SEDEX deposit located within a volcanic rather than sedimentary setting.

Solomon and Groves, (1994) propose that Rosebery and similar sheet-like, banded, large tonnage-grade VHMS deposits formed within a brine pool from relatively high salinity fluids which underwent reverse buoyancy on mixing with seawater. In marked contrast to this model, Allen, (1994) and Allen, (in prep) provides volcanological and textural evidence to suggest that the sheet-like form and mineral banding in some of the Rosebery ore lenses is due to sub-seafloor replacement of particularly pumice-rich units below impermeable quartz-porphyritic rhyodacitic synvolcanic sills.

In summary, the jury is still out on the exact process of formation of Rosebery and Hellyer, but most workers agree that the ores are synvolcanic and formed on, or just below the seafloor, from moderate to high salinity ore fluids (5 to 15 wt % NaCl and 160°C to 320°C, Khin Zaw et al., 1996).

4.3.8 List key references for each deposit

Mt Lyell deposits:
Corbett, K.D., in press, A field study of the hydrothermal alteration zone at Mt Lyell, Tasmania: Economic Geology.
Henty - Au
Callaghan, T. in press, Geology and host rock alteration of the Henty and Mt Julia deposits, western Tasmania: Economic Geology.


Hellyer – Zn-Pb-Cu
Gemmell, J.B., and Fulton, R., in press, Geological and geochemical characteristics of the footwall and hanging wall alteration, Hellyer VHMS deposit, Tasmania, Australia: Economic Geology.

Staff, Aberfoyle Resources Ltd, 1990, Geology and discovery of the Que River and Hellyer polymetallic sulphide ores, Tasmania: Australian Institute of Mining and Metallurgy Monograph Series no.17, p.187-196.

Rosebery – Zn-Pb-Cu
Allen, R.L., in prep, Genesis of the Rosebery Zn-Pb-Cu massive sulfide deposit, Tasmania, by sub seafloor replacement of pumiceous strata.
Fig 3.2: Some speculative reconstructions of the morphology of deposits prior to deformation.
Fig 3.1: Some typical cross sections of Tasmanian VMS deposits.

from Large et al., (1996)

from Large et al., (1988)

from Huston and Large (1989)

from Gemmell and Large (1992)
4.4 Exhalites

4.4.1 Are “exhalites” (Fe, Si or Mn, units) present at the same stratigraphic level as the ores? Are other styles of ore-equivalent horizons developed, eg; sulfide-bearing epiclastics, pyritic black shales, limestones? Are the exhalites true seafloor precipitates or simply alteration (silicification?) of tuffaceous sediments? Key criteria?

Exhalites (other than the massive sulphide ± barite bodies) are very poorly developed within the lower MRV compared to other VHMS provinces, and are absent from the peripheries of all the major VHMS deposits. All major deposits in the MRV occur in volcanic successions that are succeeded by carbonaceous shales (mostly < 1 wt. % C) that appear from C-S relationships to have been deposited in oxic ocean waters (Gee, 1970). Above the Hellyer orebody they appear to contain a small hydrothermal S component.

The upper MRV, within the Tyndall Group, contains rocks that may be exhalative, including hematite-barite-carbonate at Howards Anomaly (Eastoe et al., 1988), and possibly carbonate lenses and relict hematitic chert near the Henty Au deposit (Callaghan, 1998). Subsurface replacement and void-fill hematitic chert occurs in conglomerates at Specimen Creek, and interdigitated with Anthony Road andesite on the shores of Lake Newton (Jones pers. comm. 1996). The latter is interpreted by Jones (pers. comm., 1996) as partial replacement of volcanics within metres of the seafloor. This occurrence contains some positive Eu REE anomalies, and in many respects, including very high Fe/Mn ratios, geochemically resembles ferruginous cherts from the Mt Windsor Volcanics (Duhig et al., 1992). Like these Queensland cherts, Jones also observed fossilised microbial filaments.

These comprise thin hematitic cherts, associated carbonate alteration, and discrete fossiliferous carbonate lenses, which are isotopically inconsistent with a seawater origin for carbon and oxygen (Callaghan, 1998). It has not yet been determined if all the Si and C-rich beds are true exhalites, or formed by infiltration during diagenesis, but the fossiliferous units are evidence for some deposition at the sediment-water interface. The fossils themselves are typical Cambrian faunal assemblages rather than specialised vent fauna, and so if an exhalative association is to be sustained, it must be on the basis that the typical fauna was more abundant and preservable in the vent vicinity. This is observed around modern seafloor vents, such as the Pacmanus field adjacent to New Guinea.

4.4.2 Are exhalites developed at other stratigraphic levels above or below the ore position? How far above or below?

No, see above.

4.4.3 Can the exhalites be mapped along strike from the deposit (how far?), and are they useful for exploration? How do you distinguish ore-associated exhalites from barren exhalites?

No, see above.

4.4.4 Is there a geochemical database for exhalites in your belt (how many samples, REE data, isotope data)?

Answered above.

4.4.5 List key references

Duhig N.C., Stolz J., Davidson G.J., and Large R.R., (1992) Cambrian microbial and silica gel textures preserved in silica-iron exhalites of the Mt Windsor Volcanic Belt, Australia: their petrography,
4.5 Alteration facies

4.5.1 Have hydrothermal, regional diagenetic, and regional metamorphic mineral assemblages and textures been identified? Criteria used for discrimination?

The regionally distributed diagenetic and metamorphic alteration mineral assemblages and textures have been documented in detail in a number of recent works (Gifkins and Allen, in press). The Mt Read Volcanics were regionally metamorphosed to lower greenschist facies during Devonian orogeny. Felsic rocks were transformed to assemblages of quartz-albite-sericite-chlorite±carbonate and mafic volcanics to albite-chlorite±epidote-actinolite-carbonate. The diagenetic precursors to these assemblages are interpreted to have included clays, zeolites, k-feldspar, albite, chlorite, hematite and carbonates.

Diagenetic alteration is widespread in this dominantly submarine volcanic belt, but no regional zonation has been recognised. The diagenetic alteration has variable intensity and patchy distribution that is dependent on primary rock composition, texture (particularly permeability and proportion of volcanic glass) and physical conditions such as temperature and depth of burial.

Discrimination of diagenetic and metamorphic alteration from deposit scale hydrothermal alteration is based on texture, mineralogy, distribution and chemical composition (Gifkins and Allen, in press, Large et al., in press). Diagenetic alteration involves only minor changes in texture and chemical composition. Metamorphic alteration is likewise nearly iso-chemical, regionally extensive and usually associated with development of cleavage or foliation.

4.5.2 What (if any) is the immediate footwall alteration mineralogy and zonation? Is the footwall alteration more commonly in stratabound zones or as pipes? What is the depth extent and surface area relative to the deposit?

Footwall Alteration Zones in the MRV are dominated by quartz-sericite-pyrite assemblages with locally prominent amounts of chlorite and carbonate. They exhibit diverse morphologies and assemblages related to the variations in deposit styles.
The thin stratabound sulfide lenses of the Rosebery deposit are underlain by an extensive, stratiform, quartz-sericite-pyrite zone up to 150m thick that thins out and extends up to several hundred metres laterally beyond ore (Large et al., in press). In contrast, the mound-like Hellyer deposit overlies a vertical, elongate, concentrically zoned footwall alteration system that was focussed by intersecting synvolcanic faults in the largely coherent footwall volcanic sequence (Gemmell and Large, 1992). Chlorite-carbonate rich alteration zones exist immediately below, or envelop, ore in parts of both the Rosebery and Hellyer deposits. However, the pipe like chloritic footwall alteration zones characteristic of some Canadian deposits (eg. Noranda district) are not prominent in the MRV.

Several deposits, particularly south east of the Henty Fault, (eg. Mt Lyell, Western Tharsis) have proximal alteration assemblages that include pyrophyllite or kaolinite, or very siliceous zones with low alkali and alumina contents (eg. Henty). Recent interpretations suggest that these are magmatic related high sulfidation or hybrid high sulfidation - VHMS deposits (e.g. Huston and Kamprad, in press).

### 4.5.3 What (if any) is the extent and mineralogy of hangingwall alteration? Give morphology, dimensions and mineral zonation.

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Style</th>
<th>Footwall alteration form and extent</th>
<th>Footwall alteration zonation</th>
<th>Alteration indices and vectors</th>
<th>Hangingwall alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosebery</td>
<td>Stratiform, stratabound multiple thin lenses</td>
<td>Stratiform. Co-extensive with ore lenses and up to 150m down into footwall; thinning laterally and extending at least several hundred metres beyond ore.</td>
<td>Proximal: chlorite - MnFe carbonate ± sericite. Medial-distal: quartz-sericite-pyrite and sericite-chlorite ± carbonate.</td>
<td>Al, CCPI, Si/Na, Ba/Sr, Ti, Zn, Mn.</td>
<td>Weak, patchy: sericite-chlorite-calcite.</td>
</tr>
<tr>
<td>Hellyer</td>
<td>Single elongate mound or sub basin.</td>
<td>Discordant, vertical, elongate elliptical pipe related to synvolcanic fault. Lateral extent and shape is similar to ore body. Vertical extent &gt;550m, narrowing downwards.</td>
<td>Concentrically zoned: inner core of quartz-pyrite ± sericite ± chlorite grading outwards through chlorite and sericite dominated zones to sericite-quartz at the margins. Small chlorite-dolomite zones exist in upper part of chlorite zone immediately below sulfides.</td>
<td>Al, Na, S, base metals, Sb, Ba in muscovite, – S, – _34S, _18O</td>
<td>Complex zones extending 100m above and several hundred metres laterally beyond ore. A proximal fuchsite zone is enveloped by carbonate, chlorite-carbonate and peripheral quartz-albite zones.</td>
</tr>
<tr>
<td>Mt Lyell</td>
<td>Disseminated; minor massive sulfide lenses</td>
<td>Large, semi-concordant zone: 6km strike length, &gt;1.5km lateral (down dip) and &gt;1km stratigraphic depth extent.</td>
<td>Central zone of sericite-chlorite-pyrite (± pyrophyllite) grading out to sericite pyrite. Local upper zones quartz-pyrite.</td>
<td>No published data for entire Mt Lyell field. Western Tharsis: Cu, As, Mo, S, Ba, Sr, K, white mica (less phengitic towards ore).</td>
<td>None recorded.</td>
</tr>
<tr>
<td>Henty-Mt Julia</td>
<td>Stratabound adjacent to major fault. Massive, disseminated and veinlet style sulfides</td>
<td>Stratabound; up to 100m thick, &gt;1km strike length, ~300m down dip. Truncated up dip by Henty Fault.</td>
<td>Lenses of massive microcrystalline quartz enveloped in zones of quartz-sericite-pyrite grading out to quartz-sericite-chlorite-pyrite.</td>
<td>Intense texturally destructive quartz-albite alteration, stratabound up to 100m thick immediately above ore and thinning laterally up dip.</td>
<td></td>
</tr>
</tbody>
</table>

The thin stratabound sulfide lenses of the Rosebery deposit are underlain by an extensive, stratiform, quartz-sericite-pyrite zone up to 150m thick that thins out and extends up to several hundred metres laterally beyond ore (Large et al., in press). In contrast, the mound-like Hellyer deposit overlies a vertical, elongate, concentrically zoned footwall alteration system that was focussed by intersecting synvolcanic faults in the largely coherent footwall volcanic sequence (Gemmell and Large, 1992). Chlorite-carbonate rich alteration zones exist immediately below, or envelop, ore in parts of both the Rosebery and Hellyer deposits. However, the pipe like chloritic footwall alteration zones characteristic of some Canadian deposits (eg. Noranda district) are not prominent in the MRV.
Hangingwall Alteration zones are not prominent in the Rosebery deposit but are well developed at Hellyer and Henty. Quartz-albite zones exist above and lateral to ore at both these deposits, although they have very different hangingwall volcanic sequences (mafic and felsic, respectively) (Gemmell and Fulton, in press; Callaghan, in press). The mafic hangingwall volcanics at Hellyer contain zones of fuchsite, chlorite, carbonate (calcite), quartz-albite and sericite above the orebody. Empirically, it seems that hangingwall alteration is most prominent in deposits associated with synvolcanic faults.

4.5.4 What particular alteration indices (vectors to ore) have been tested or proposed?

Alteration Indices and vectors have been identified by an extensive CODES-AMIRA research project (P439 - studies of VHMS related alteration: geochemical and mineralogical vectors to mineralisation, 1995-1998). A number of wholerock major element based indices have been shown to be effective as deposit scale exploration vectors in footwall alteration zones. These include $AI = \frac{100\times(MgO+K_2O)}{(MgO+K_2O+CaO+Na_2O)}$, $CCPI = \frac{100\times(FeO+MgO)}{(FeO+MgO+K_2O+Na_2O)}$, and $S/Na_2O$.

An innovative graphical combination of the AI and CCPI (Large et al., in press) enables discrimination between diagenetic and hydrothermal alteration and mineralogically distinct zones associated with VHMS deposits. Ti, Sb and Ba/Sr are useful trace element vectors to zinc rich deposits including Rosebery and Hellyer but not in the Cu-Au systems. Ti and Sb exist at anomalous levels for up to several hundred metres above the deposits and 2km laterally and therefore are geochemical vectors that can be applied in district scale exploration.

4.5.5 Has a single database of alteration geochemistry been compiled for the district? (number of samples?). By whom? and is it available?

A Geochemical Database was compiled by CODES-AMIRA project P439, 1995-1998. The database includes approximately 3927 samples analysed for wholerock major and trace elements.

4.5.6 Is there a database of whole rock oxygen isotopes? (number of samples?) Is data available on H or C isotopes?

An Isotopic Database is currently being compiled in a CODES-SPiRT research project. The database to date contains approximately 210 wholerock and 100 silicate $^{18}$O analyses. Also approximately 400 paired $^{18}$O and $^{13}$C analyses of carbonate minerals. There are practically no hydrogen isotopic data. This database remains confidential to the project sponsors until 2003, but much of the data has been published or reported elsewhere.

4.5.7 Have deep semi-conformable alteration zones been identified? What is their dimension, mineralogy, and chemical characteristics? Is there evidence for metal depletion?

Deep semi conformable alteration zones have not been mapped out or identified to date except for those associated with syn-volcanic intrusions (see section 8). However alteration containing epidote-quartz, albite, quartz, hematite and disseminated chlacopyrite, sphalerite and galena have been identified in lithologies approximately 600 m into the footwall below Hellyer. A similar alteration assemblage, without the base metal sulphides, is observed in andesites/dacites approximately 1 km below the mineralised horizon in the Rosebery district rocks.

4.5.8 Is alteration geochemistry used to assist exploration in the district?

Alteration lithogeochemistry and isotope geochemistry has been used in VHMS exploration for about the past 15 years (e.g. Green and Taheri, 1992). The techniques have been applied mainly in prospect scale, rather than regional, exploration programs (eg: Boco, White Spur, South Henty).
4.5.9 List key references


Note: A Special Issue of Economic Geology concentrating on hydrothermal alteration in Australian VHMS deposits is due for release mid 2001.

4.6 Hydrothermal geochemistry

4.6.1 Are there systematic published studies on the mineralogy, mineral paragenesis and mineral chemistry of the ores and altered host rocks. Which deposits?
Various studies have been conducted on the deposits in terms of these aspects.


4.6.2 Are the temperature, salinity and chemistry of the ore fluid well constrained from deposit data? What is the quality of primary fluid inclusion data?
Temperature, salinity and chemistry of ore fluids have been well constrained for the Hellyer stringer system applying microthermometry, laser Raman spectroscopy, microprobe SEM/EDS and proton-induced X-ray Emission (PIXE) techniques (Khin Zaw et al., 1996). The Hellyer VHMS deposit has three synmineralisation vein stages. The primary nature of the Type I, liquid-vapour inclusions in the vein stages are evident by the occurrence of these inclusions along growth planes of crustiform quartz crystals or within colour banding of zoned sphalerite. These inclusions are 10-15 µm in size, and yielded homogenisation temperatures of 170-220°C in early 2A veins, 165-322°C in main-stage 2B veins and 190-256°C in late-stage 2C veins. These data suggest a waxing and waning thermal history. However, the average salinity remained between 8 and 11 NaCl equiv. wt % in all Stage 2 veins. Chalcopyrite-bearing primary fluid inclusions have been also recognised in the Stage 2B veins. Some temperature-salinity data were recorded in Solomon and Khin Zaw (1997).

The presence of CO₂ (<1 mole %) in the Stage 2B veins has been also confirmed by Laser Raman spectroscopic analysis. Semi-quantitative SEM/WDS microprobe analyses of fluid inclusion decrepitates indicate that the Hellyer ore fluid was enriched in potassium and calcium but depleted in magnesium relative
to seawater. PIXE microanalysis of fluid inclusions in quartz indicates the presence of significant base metals in the Stage 2B ore fluids compared to the Stage 2A veins.

At the South Hercules deposit, Khin Zaw (1991) and Khin Zaw and Large (1992) recognised two groups of fluids: a low temperature (125°–210°C), low salinity (<4.2 NaCl equiv. wt %) fluid, and a variable temperature (125°–300°C), higher salinity (up to 15.0 NaCl equiv. wt %), CO₂-bearing fluid. The low-temperature, low-salinity fluids are texturally associated with early Type I, two-phase fluid inclusions and are interpreted as Cambrian fluids of volcanic origin.

Offler and Whitford (1992) recorded homogenisation temperatures of 220-310°C from two-phase, primary fluid inclusions in quartz from the alteration zone of the P/Q lens, at the Que River deposit, but no salinity data were given.

Inclusions in quartz from the Chester mine ranged in homogenisation temperature up to 373°C (but most are between 115 and 160°C), with salinities between about 14 and 18 wt. % NaCl equivalent (Boda, 1991).

4.6.3 Is there any evidence for fluid boiling, give details?

Detailed petrographic investigation indicates no unequivocal fluid inclusion evidence of fluid boiling during the development of the VHMS deposits in the Mt. Read volcanic belt. Fluid inclusion studies at the Hellyer deposit (Khin Zaw et al., 1996), Que River deposit (Offler and Whitford, 1992) and the VHMS deposits in the Rosebery-Hercules area (Khin Zaw, 1991; Khin Zaw and Large, 1992) note no evidence of fluid boiling (e.g. co-existence of vapour-rich inclusions and liquid-rich inclusions in the same healed fracture). Vapour-rich inclusions that homogenise into vapour phase have also not been found.

4.6.4 What hydrothermal thermodynamic modelling has been attempted? What modelling software was used (if any)?

Walshe et al., (1981) has undertaken thermodynamic modelling of the Mt Lyell Cu-Au system, with temperature constrained by chlorite chemistry. Green et al., (1981) attempted preliminary thermodynamic modelling of the Rosebery VHMS. Modelling to explain base metal and gold deposition for Rosebery was carried out by Huston and Large (1988, 1989). Schardt et al., (in press) has undertaken the first detailed thermodynamic modelling of fluid/rock interaction in the hydrothermal alteration pipe below the Hellyer deposit. Schardt reproduced the alteration zonation at Hellyer by reacting a hydrothermal fluid with andesite using the CHILLER software package.

4.6.5 What additional information is required to develop robust geochemical models?

Further research on mineral paragenesis, mineral zonation, fluid inclusions and stable isotopes is required in all deposits in order to develop robust thermodynamic models. This work is limited by the effects of later deformation and recrystallisation of the ores. The best deposits for further thermodynamic modelling are Hellyer, Rosebery K lens and Western Tharsis (Mt Lyell).

4.6.6 List key references

Offler, R. and Whitford, D.J., 1992, Wall-rock alteration and metamorphism of a volcanic-hosted massive
4.7 Source of fluids, sulfur and metals

4.7.1 How extensive is the S isotope database on ores, sulfates and host rocks (numbers of analyses)? What is the range of del 34S? Do the massive sulfides and stringer zones have the same mean value and range? What is the interpreted source(s) of sulfur?

The sulfur database is perhaps the largest of any isotope database collected in the MRV (n = 1661). However, it is strongly biased towards the known deposits and prospects (Solomon et al. 1998), with only a small population of hostrocks, and these are probably altered. No KIBA extractions have been undertaken on MRV volcanics, which might yield primary igneous compositions from fresh rocks. A background variation of 4–8‰ for felsic rocks is inferred by comparison to compositions in analogue basins. Instead, the background variation in acid soluble sulfur has been established away from deposits, and been found to be highly variable (-20→+26‰), reflecting a range of fractionation processes (biological reduction, deep inorganic sulfate reduction, etc) operating during diagenesis and fluid flow. All of the quoted data is inferred to be Cambrian in origin; there is little evidence of alteration of sulfur isotope compositions during Devonian deformation or magmatism.
Table 1.1:

<table>
<thead>
<tr>
<th></th>
<th>Small systems</th>
<th>Henty-like</th>
<th>Henty</th>
<th>Hercules</th>
<th>Rosebery</th>
<th>Mt Lyell-like</th>
<th>Que River</th>
<th>Hellyer</th>
<th>Background</th>
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<tbody>
<tr>
<td>Pyrite S</td>
<td>100</td>
<td>41</td>
<td>58</td>
<td>13</td>
<td>49</td>
<td>177</td>
<td>131</td>
<td>140</td>
<td>179</td>
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<td>(total S n = 1661)</td>
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<tr>
<td>Barite S</td>
<td>12</td>
<td>10</td>
<td>1</td>
<td>15</td>
<td>48</td>
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<td>(n = 159)</td>
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<tr>
<td>Pb (n = 603)</td>
<td>410</td>
<td>36</td>
<td>1</td>
<td>3</td>
<td>18</td>
<td>107</td>
<td>12</td>
<td>17</td>
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<tr>
<td>C-O (n = 376)</td>
<td>58</td>
<td>50</td>
<td>71</td>
<td>7</td>
<td>90</td>
<td>6</td>
<td>9</td>
<td>49</td>
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</tr>
<tr>
<td>Barite Sr (n = 23)</td>
<td>3</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>5</td>
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<td>Host-rock Sr</td>
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</table>

Gemmell and Large (1993), Green et al. (1983), and Davidson et al. (2000) have all shown that stringer veins in VHMS systems in the MRV mainly have similar isotopic ranges to overlying massive sulfide lenses. However, the isotopic composition of disseminated and vein footwall pyrite which occurs lateral to distinct alteration, or is paragenetically later than main-phase ore veins, can be significantly heavier than ore sulfide (up to 45‰).

Barites in VHMS systems have $\delta^{34}$S values $\sim 10\%$o or higher than coeval Cambrian seawater, which has been attributed to an origin by partial reduction of seawater in the deep circulatory system (e.g. Green et al., 1981). Such reduction also occurred in and marginal to shallow footwall alteration at Hellyer, Que River and Rosebery (Gemmell and Large 1993; Davidson et al. 2000), with pyrite values more positive than that of the upwelling fluid. These pyrites are inferred to form within marginal circulation cells that were sites of partial reduction of Cambrian seawater sulphate.

Barites within parts of the Mt Lyell system have $\delta^{34}$S values $\leq 30\%$, thought by Solomon et al. (1988) to have been derived by leaching and oxidation of previously precipitated sulphides, but possibly of direct magmatic origin.

The two dominant sources of sulfur in the MRV province are thought to be igneous, derived by leaching of hostrock sulfur or from reduction of magmatic SO$_2$, and reduced Cambrian seawater sulphate. Although there is evidence for circulation of seawater-derived fluids into the basement (see below), there is no direct evidence as yet for contributions of sulfur from this source.

4.7.2 How extensive is the Pb isotope database on ores and host rocks (number of analyses and range of 206/204Pb and 207/204Pb ratios on ores?). What is the interpreted source of metals?

Lead isotopes have been extensively applied in MRV mineral exploration, following the pioneering work of Gulson and Porrill (1987) and Gulson et al., (1987) in differentiating Devonian from Cambrian galena. The database of 603 values is therefore dominated by the compositions of small systems (410 values total), analysed to determine their affinities and suitability for further work by mineral exploration companies. There is a strong spatial variation in the isotopic composition of the systems from north to south, with Hellyer-Que River at (Pb$^{206}$/Pb$^{204}$ = 18.3–18.4; Pb$^{207}$/Pb$^{204}$ = 15.58–15.65), compared to the most southern explored MRV prospects (Elliott bay) with (Pb$^{206}$/Pb$^{204}$ = 18.05–18.26; Pb$^{207}$/Pb$^{204}$ = 15.56–15.65). All MRV deposits have ‘incorrect’ Pb model ages of ~300 Ma (Gulson et al. 1991), which is an atypical characteristic for Australian massive sulfide deposits. Gulson et al. (1991) concluded this to be evidence that Tasmania was not joined to mainland Australia in the Cambrian, and suggested that Pb isotopes would be useful for placing Tasmania in a tectonic context. It is not clear if MRV deposits have anomalously young ages because MRV hostrocks have high $\mu$ values, or whether this is a feature of basement that was incorporated into the deposits following deep fluid circulation. The north to south trend is likely to reflect systematically varying
mixing of two components, as has been inferred for Lachlan foldbelt isotopic compositions generally by Carr et al. (1995).

4.7.3 Is there any other isotopic data (Os/Ir, Sm/Nd, Sr) that may assist in determining the source of metals?

Limited Sr data is available for the MRV (Whitford et al. 1992), and provides an important constraint to fluid circulation. Although numbers of samples are not quoted, initial ratios (calculated at 500 Ma) for felsic volcanics (CVC; \(^{87}\text{Sr}/^{86}\text{Sr} = 0.7070–0.7094\)) and mafic-intermediate volcanics (Que-Hellyer sequence; \(^{87}\text{Sr}/^{86}\text{Sr} = 0.7063–0.7080\)) are provided. The Sr isotope compositions of barites in the major deposits exceed both these values (give \(^{87}\text{Sr}/^{86}\text{Sr}\)), and also the composition of Cambrian seawater. Whitford et al. (1992) concluded this to be evidence for circulation of hydrothermal fluids into the basement to leach old continental Sr sources.

4.7.4 Is there any evidence for magmatic fluid/metal input? If so what is the key evidence?

The high salinities recorded in fluid inclusions from Hellyer (Khin Zaw et al., 1996) and Chester (Boda 1991) indicate a magmatic source for the halides, because there is no evidence that evaporites existed in the deep footwall rocks during fluid circulation associated with VHMS mineralization (Solomon, Gemmell and Yang, in prep.). The high REE contents and presence of apatite in the disseminated Prince Lyell ore at Mount Lyell may also indicate a magmatic source (Large et al., 1996).

4.7.5 What further research is required to determine the source of fluids, sulfur and metals?

Determine Sr,Nd and other isotopic ratios in the fluid inclusions from the Hellyer vein sequence. Investigate alteration and mineralization associated with intrusion of Cambrian plutons apparently coeval with VHMS deposits. More detailed analayses of fluids in the Hellyer and Chester deposits.

4.7.6 List key references


4.8. Subvolcanic intrusions

4.8.1 Have syn-volcanic intrusions been identified and are they associated with VMS deposits? What is their composition and are they composite?

A series of granite sill-like intrusions occur at depth along the eastern margin of the Mount Read Volcanics. Research in the 1970’s and 1980’s by Mike Solomon and his students (Solomon, 1976, Polya et al., 1986, and Eastoe et al., 1987) proposed a relationship between syn-volcanic granite emplacement, district scale alteration, seawater accumulation and massive sulfide formation. More recently Large et al., (1996) suggested the possibility of a direct input of magmatic fluids carrying gold, copper, iron and phosphorous to form the copper-gold VHMS deposits in the Mt Lyell district.

Geophysical evidence (magnetics and gravity) indicate that the granite(s) form a narrow discontinuous body about 60km long and 2-4km wide toward the base and eastern margin of the volcanic pile that hosts the deposits (Large et al., 1996, Fig 4 attached). The two outcropping parts of the elongate composite granite body (the Murchison and Darwin granites) are strongly altered, high K, magnetite series granites. The Murchison granite varies in composition from diorite to granite (58-78 wt% SiO₂, Polya et al., 1986) while the Darwin granite is composed of two highly fractured phases (Jones, 1993) with SiO₂ content from 74-78 wt%.

4.8.2 Classify them as shallow (<1000 m from the lowest VMS horizon), epizonal (1000-3000 m) or deep (>3000 m). Is there more than one level present? What is their geometry and dimensions.

The depth of the granite below the lowest VMS horizon is difficult to determine due to later structural events. Various reconstructions place the granites at a depth of 3 to 7km below the ore horizon. As stated above the granite is sill-like and discontinuous for 60km along strike with a thickness of 2 to 4km.

4.8.3 Are they hosted by comagmatic volcanics? Underlying basement?

The granites are hosted by comagmatic volcanics.

4.8.4 Are they identified as comagmatic to VMS-hosting strata by: a) geology; b) igneous geochemistry, and/or c) geochronology?

The co-magmatic nature is based on geology (Polya et al., 1986, Corbett, 1992, Jones, 1993), geochemistry (Crawford et al., 1992, Wyman, 2000) and geochronology (Perkins and Walshe, 1993). The age of the granite is 508±6 compared to the age range of the MRV of 501 to 510±7 (Perkins and Walshe, 1993).

4.8.5 Are they related to district-scale alteration zones? Key evidence?


Well-developed zones of hydrothermal alteration have been mapped around the margins of the Murchison and Darwin granites. Polya et al., (1986) noted that the Murchison Granite has suffered potassic alteration, chloritisation and late calcite-edidote alteration. They recorded a zonation in alteration mineralogy from the
western margin (top?) of the granite, up through the volcanic section to the Farrell slates (about 2.5km of stratigraphic section) as follows: potassic zone (K-feldspar, chlorite, epidote, calcite, pyrite, magnetite); epidote zone (epidote, chlorite, calcite, magnetite); chlorite zone (chlorite, sericite, albite, calcite); sericite zone (dominantly sericite, quartz). Eastoe et al., (1987) and Jones (1993) record potassic, chloritic and sericitic phases of alteration in the Darwin Granite and the Central Volcanic Complex to the immediate west and north of the granite. Although no clear regional zones of alteration were defined, Eastoe et al., (1987) notes that the alteration assemblages are similar to those around the contact of the Murchison Granite, and are considered to be related to hydrothermal fluid circulation associated with granite emplacement and cooling. Magnetite and tourmaline veins and breccias are localised within and adjacent to the Darwin Granite, demonstrating that magmatic-hydrothermal fluids were exsolved from the granite during crystallisation.

At the Jukes Pty prospect 12km south of Mt Lyell a minor zone of k-feldspar-magnetite alteration around the margins of the granite is overprinted by a more extensive zone of chlorite-magnetite±K-feldspar±pyrite±chalcopyrite, which gives way to an outermost zone of sericite±chlorite alteration which extend vertically and laterally away from the granite (Doyle, 1990, Large et al., 1996). Large et al., (1996) proposes that the chlorite-magnetite and sericite alteration zones around the granite are related to, and probably connected to, chlorite-magnetite-apatite, and related sericite alteration zones around the Mt Lyell type Cu-Au deposit.

4.8.6 Do they contain extensive areas of alteration? Do they contain base-metal and/or gold occurrences?

The granite themselves are extensively altered, especially along their margins. Early K-feldspar-magnetite alteration is commonly overprinted by chlorite-magnetite±pyrite alteration. Minor Cu-Au prospects are associated with the second stage chlorite-magnetite alteration (Wyman, 2000), in the Darwin-Jukes area to the south of Mt Lyell.

4.8.7 List key references


4.9. Hydrogeological modelling

4.9.1 Are there any published or unpublished hydrogeological models for the district or for individual deposits? What software package was used?

Qualitative convection experiments using a Hele-Shaw cell were used in an attempt to explain the spacing between the major and minor Mount Read deposits (Solomon et al., 1987). The major deposits are not less than 20km apart, those of about one order of magnitude smaller tonnage lie within a few km of the major, and smaller deposits are even more closely spaced (e.g. between Rosebery and Hercules). Solomon et al., (1987) found in experiments that during development of large convection cells there were periods of increasing duration in which smaller cells operated, their magnitude and period of stability increasing with time.

There are no formally published hydrogeological numerical models that are directly related to VHMS deposits in the Mount Read Volcanics. However, two recent conference papers are closely relevant. Jianwen Yang and Jocelyn McPhie (2000) investigated the influence of typical volcanic facies architecture in the Mount Read Volcanics on hydrothermal fluid migration. Mike Solomon and Jianwen Yang (2000) established a computational model to explain the variation in VHMS from the likely role of fractures, deep footwall permeability and rock buffering capacity. In addition, Christian Schardt is currently working on his Ph.D. project entitled hydrothermal fluid migration in volcanic facies architecture: implications to massive sulfide deposits. All these modelling studies have employed our own developed finite element computer software (Yang et al, 1998).

4.9.2 Are there any data on the original porosity and permeability of the volcanic and sedimentary facies in the succession?

No data on the original porosity and permeability except some limited qualitative estimates.

4.9.3 Have regional or local hydrothermal fluid pathways been defined? Using what data or criteria?

It has been speculated that the major longitudinal (?) rift faults (Henty Fault, Mt Lyell Fault and Rosebery Fault), and associated transfers (which are poorly defined) have acted as fluid conducts.

4.9.4 Have any heat sources or fluid driving mechanisms been defined?

Seawater convection was first proposed for the Mount Read and other ores by Solomon (1976), and the granitic bodies that crop out on the eastern margin of the Mount Read province (e.g. Darwin, Murchison granites) were later suggested as the heat sources (Solomon, 1981). Study of the alteration in volcanic rocks overlying the Murchison Granite (Pоля et al., 1986) failed to establish flow paths. A significant magmatic component for the fluids responsible for mineralisation at Mount Lyell, derived from the Darwin Granite, was proposed by Large et al., (1996). The identification of saline fluids in the veins beneath the Hellyer deposit indicate a magmatic source (Khin Zaw et al., 1996), and radiogenic Sr in the barite of this orebody, combined with S, C and O data of ores and footwall rocks suggest fluid flow penetrated the basement beneath the Mount Read Volcanics (Solomon, Gemmell and Yang, in prep.).

4.9.5 What research is required to develop robust hydrogeological models? What computer codes are suitable and available? What computer code developments are needed to better constrain 3D heat and fluid flow modelling?

Our own developed finite element computer software can simulate 2-D and 3-D time-dependent groundwater fluid, heat and solute transport in discretely fractured, arbitrarily-shaped earth structures. This code can deal with fluid migration driven by buoyancy force, topography and magma pumping. To simulate sediment compaction, a 2-D finite element software RIFT2D is available, which was originally developed by Mark Person of the Johns Hopkins University.
However, extensive efforts are still required to develop robust numerical models, especially in the following aspects: (1) need to better define the equations of state (i.e., fluid density and viscosity as explicit functions of temperature, salinity and pressure under extremely high temperature and pressure conditions), and (2) need to couple geochemical reactions into the hydrogeological models.

4.9.6 List key references


Solomon, M., 1976, 'Volcanic' massive sulphide deposits and their host rocks—a review and an explanation. Handbook of Stratabound and Stratiform Ore Deposits, v.6, p.21-54.


Solomon, M. and Yang, J., 2000, Explaining variation in VHMS ores (e.g., Hokuroku, Hellyer and Mt. Lyell): the likely role of fractures, deep footwall permeability, and rock buffering capacity, Australian Geological Congress, Sydney, Australia, July, 2000.


4.10 Exploration criteria

4.10.1 How were the known deposits found? Provide a list with dates and the key methods (eg. outcropping gossan, gravity, magnetics, soil geochemistry etc).

Mt Lyell; 1883
In 1881 gold was discovered in the Lynch Creek area approximately 10 km south of Mt Lyell. This attracted prospectors to the area and in 1883 S Karlson and the McDonough brothers located the Au-rich gossan of the Iron Blow (the Mt Lyell deposit), by following Au dispersion in drainage. Further prospecting (often by sinking shafts) located the majority of the 15 orebodies in the Lyell field during the 1890's. Modern exploration, diamond drilling of combined IP and EM targets, led to the discovery of the Crown Lyell 3 and Cape Horn Orebodies in 1956 and 1957 respectively.

References: Blainey (1954), Reid and Meares (1981), Reid (1975)

Rosebery; 1893
Rosebery was discovered by T. McDonald who located alluvial gold and boulders of Pb-Zn ore. Trenching then resulted in the discovery of the sub-cropping massive sulphide orebody. The orebody gradually grew by drill testing down-dip extensions of the host horizon. Early deep (approx. 1 km below surface) drill tests, on >300m spacing, were unsuccessful and led to the assumption that the orebody did not continue at depth and that the ore position at the north end of the mine was truncated by the Rosebery Fault. This coupled with a lack of suitable underground drill sites and surface access restrictions discouraged deep drilling attempts. However, in the late 1980's declining ore reserves and re-interpretation of the geology led to a revitalised deep drilling program which was successful in intersecting K lens in 1991, P Lens in 1993 and W Lens in 1996 as well as several smaller lenses at the south end of the orebody. The orebody is still not closed off and deep exploration continues.

Blainey (1954), Reid et al. (1993), Berry et al. (1998)
Hercules; 1891/1894
Following the discovery of alluvial Au in the Ring River in 1891 prospectors traced the dispersion to a gossan (on L-M lodes of the Hercules orebody) on the flanks of Mt Hamilton, a discovery attributed to A. Conliffe. Base metal mineralisation was discovered in 1894 by J. Will who located an inch wide seam of gossan overlying massive sulphide. The South Hercules Deposit (250m south of N lode at Hercules) was prospected in the 1890’s (Williams shaft) and base and precious metal mineralisation were recorded, however, no further serious exploration, apart from 5 diamond drill holes, was completed until 1972 when a Turair survey focussed interest in the area. IP surveys and an Hg soil geochemistry led to increased interest and a 21 DDH program in 1973 led to the discovery of the precious-metal rich lens, however, it wasn’t until the increase in precious metal prices in the 1980’s that the deposit was drilled out.


Que River; 1974
Prospecting by T. McDonald; alluvial Au and partly decomposed sulphide boulders found in creeks, 6m shaft sunk at Gold Hill – 500m north of Que River (1922)
Regional – 20# stream sediment geochemistry (1972)
Airborne EM McPhar H400 (1972)
Recognition of coincident AEM and stream sediment anomaly near old workings at Gold Hill (1973)
Drilling (1974): DDH QR1 intersected the sub-cropping S lens (11.44m @ 2% Cu, 5% Pb, 7% Zn and 105 g/t Ag). DDH QR2, designed as a test of the broad Pb in C horizon soil anomaly and a deep test of the QR1 intersection, intersected the shallowly buried P Lens (3.81m @ 0.86% Cu, 13.72% Pb, 22.03% Zn, 371 g/t Ag and 3.8 g/t Au).

References: Webster and Skey (1979), Anon (1986), McArthur and Dronseika (1990)

Hellyer; 1983
Following the discovery of Que River and subsequent orientation surveys, the target volcanic stratigraphy (Que-Hellyer Volcanics) was covered by detailed AEM, geological mapping, C Horizon soil sampling and dipole-dipole IP with no success (1975-1981).
Trials of available deep search EM systems completed over Que River; UTEM selected (1979-1982)
During 1983 a substantial part of the prospective stratigraphy was covered with UTEM. A UTEM anomaly, recognised as being intense as that over Que River, was detected on the northernmost line of this grid (100m north of previous drilling). The survey was extended and located a 400m strike length conductor, coincident in part with baritic and fuchsitic alteration (also associated with mineralisation at Que River) and a Pb soil anomaly at surface. The first hole of a three hole program, HL3, intersected 24.4m @0.3% Cu, 4.4% Pb, 12.6% Zn, 157 g/t Ag and 1.9 g/t Au at 125m below surface.


Henty; 1974-1984
Systematic exploration for Rosebery Type VHMS commenced in 1968.
A Grid was established then mapped and covered by ground EM and magnetics with no significant results. An old shaft with Cu-mineralisation and several zones of pyritic quartz-sericite schist were located. The grid was infilled with further mapping and a gradient array IP survey that located 17 anomalies (1972-1973).
A program of pole-dipole IP, soil geochemistry (C horizon), costeansing and diamond drilling commenced to test the IP anomalies. In late 1973 costeansing over an IP anomaly, associated with a weak soil anomaly on line 49N exposed a 1.5m bedded semi-massive sulphide (1.67% Cu, 1.68% Pb, 0.2% Zn, 95 g/t Ag and 1.6 g/t Au). Hole HFZ5 drilled to test 120m beneath the costean intersected weak Cu-Pb-Zn mineralisation, but, significantly was not assayed for Au. A further drill hole 125m to the south also intersected 0.6m of massive sulphide, with 2 g/t Au. At this stage (1974) work on the prospect was abandoned.
In 1982-1983 the geology of the prospect was reviewed in detail; and a further three holes were drilled (HFZ9-11). These holes intersected further narrow massive sulphides, with 1.3-7 g/t Au and one hole intersected a separate 1.1m thick Au-rich (5.1 g/t) sulphidic chert – this program marked the start of routine assaying for Au.
In 1984 HFZ5 (drilled in 1974) was re-assayed for Au and returned 4m horizontal width @ 10 g/t Au.
major program of diamond drilling was commenced which culminated in the discovery of the deep (300m below surface) Zone 96 in 1989 (HP96A, 8.5m @ 107 g/t Au).


4.10.2 Currently, what are the key methods used by companies to identify 1) prospect areas, and 2) drill targets?

Key methods used to identify prospect areas:

Stratigraphy: Economic mineralisation appears restricted to quiescent intervals (fine to medium grained volcaniclastics, often overlain by shales) at the top of the Central Volcanic Complex or in the Lower Tyndall Group.

Structure: Syn-volcanic Cambrian structures that may be related to mineralisation are defined by volcanic facies changes and gravity/magnetic data (for deep structures) and/or using fault orientations derived from detailed 3D studies of orebodies.

Geochemistry: Regional stream sediment coverage may highlight areas of interest, Pb isotopes are used to differentiate Devonian and Cambrian mineralisation in outcrop and/or soils.

Geology: Locate areas of footwall (Sericite-pyrite-silica) or hangingwall (sericite-carbonate) alteration.

- drill targets

Geophysical: Ground EM (UTEM), DHLEM, IP, CSAMT for direct targeting.

Geochemical: Partial leach soil geochemistry. Total digest soil geochemistry where it may represent leakage up structures that intersect mineralisation. Lithogeochemical data (alteration index, Tl/Sb content etc) from nearby drill holes or outcrop.

Conceptual: Potential host stratigraphy adjacent to interpreted Cambrian structures or suitable inflections in Devonian structures (Henty Style).


Regional data sets available from relevant government departments:

Aeromagnetics: Whole belt covered at a line spacing of 201-500m. More recent high quality data, line spacing <200m, available for majority of central (Mt Lyell–Hellyer) part of belt, although some significant areas are still closed file (confidential)

Gravity: Coverage of whole belt on a 1 km station spacing available. More detailed close spaced data (down to <100m spacing) available for central part of belt, although, some significant areas are still closed file (confidential).

EM: All surveys recorded in database (TASEXPLORE giving coverage, technique etc.) and available in hard copy through open file reports. Only more recent data (post approx. 1995) available digitally. Majority of belt has been covered with modern (post-1983) airborne and/or ground EM surveys

Stream geochemistry: Data compiled digitally by MRT and available on a sheet (1:25,000) by sheet basis. Whole belt covered at an average density of >5 samples/sq km, using a range of methods, but, mainly – 80#.

Soil geochemistry: Currently not available digitally, except for data provided to MRT as part of relinquishments (generally post-1996) but, majority of data available in hard copy through open file reports. Extensive modern (post-1970) data, both total and partial digest, covering the entire belt generally on 200m line spacing.

Rock Chip geochemistry: Data compiled digitally by MRT and available on a sheet (1:25,000) by sheet basis. Not sure of completeness – less rigorous compilation than stream sediment data, but, samples have been collected from entire belt. Very wide range of elements analysed.

Geological mapping: Interpretative maps. at 1:25,000 (data collected at 1:10,00; 1985-present) are available digitally for approximately 70% of the belt. The remainder of the belt is covered by older 1";1 mile and 1:50,000 sheets. Some of the earlier sheets are in need of partial review/re-mapping in the light of more recent advances in stratigraphic understanding of the belt.
4.10.4 What percentage of the volcanic district is under shallow cover? Have any deposits been discovered in the covered areas?

Approximately 53% of the belt is under shallow cover (defining shallow cover as >10m of post-Cambrian sediments/volcanics). This cover comprises largely quaternary glacial deposits (to 100m thick), tertiary flood basalts and associated sediments (highly variable thickness, to 350m) and the siliciclastic Cambro-Ordovician Owen Conglomerate (up to >800m of cover). No deposits have been found under shallow (>10m) cover.

4.10.5 What exploration methods need to be considered or further researched in your district?

The consensus is that no economically significant mineralisation remains undiscovered in the depth range 0-150m. All exploration is now focussed on finding buried, and probably blind mineralisation at >150m. On a regional scale improved 3D understanding of the structural and stratigraphic architecture of the belt is required to locate deep targets. Improved deep search geophysical techniques (e.g., EM, CSAMT, seismic?), and interpretation routines are also required. Application of partial leach soil techniques may prove useful, however, considerable research into techniques suitable for Tasmanian conditions is required. Considerable isotopic data is available scattered through the literature, but, a complete compilation and interpretation, of all data from the belt has not been completed to date.

On a local scale improved techniques and interpretation routines (lithogeochem., isotope systematics, DHEM etc.) are required to increase the value of information obtained from every drill hole.

4.10.6 List key references

4.11 Research strengths for your VMS district

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1 = Adequate database and extensive interpretation of data  
2 = Adequate database but little interpretation  
3 = Extensive interpretation but inadequate database  
4 = Moderate database and interpretations (needs improvement)  
5 = Inadequate database and little interpretation

4.12 List of ten key references

List the major references, even if the interpretations differ from those generally accepted. The key references should include those that have the major geological, geochemical etc data (maps and tables) and also those that contain important discussions and interpretations. Make sure the titles of key maps or map series are included. List key unpublished references (eg. theses) especially if they contain critical data not available elsewhere.


Other Important Publications


