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METALLIC MINERAL DEPOSITS OF THE PIEMAN-GORDON REGION AND THE LIKELIHOOD OF NEW DISCOVERIES

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ABSTRACT

The metallic ore deposits of western Tasmania occur in Lower Palaeozoic rocks which appear to represent two tectonic phases or cycles, described here as the Tyennan and Ordovician-Devonian phases. Reconstructions indicate that during each phase Tasmania formed part of Andean-type continental margins flanking the Australia-Antarctica craton. Comparisons with the mineralization of the Andean and similar orogenic belts imply a potential in western Tasmania for porphyry coppers magnetite skarns polymetallic veins, massive sulphides, tin-silver, and carbonate-lead-zinc deposits. Post-Palaeozoic erosion probably reduces the list to the last three ore-types, each of which is already recognised. The probability of further discoveries is reviewed, particularly in the light of new ideas on the genesis of massive-sulphide deposits.

INTRODUCTION

This article is designed to review the pattern of mineralization in the Pieman-Gordon region of western Tasmania and attempt a qualitative assessment of its long-term potential for metal mining.

The first approach is to identify in general terms the tectonic style of the region and then to compare the known mineralization with that in similar tectonic regimes elsewhere; this could reveal a potential for types of deposits not yet recognised in Tasmania. The second approach is to use our knowledge of the genesis of the known or potential types of deposits to predict their size and frequency of occurrence.

GEOLOGICAL SETTING

The geology of the Pieman-Gordon region and its ore deposits has been reviewed in several recent articles in "Economic Geology of Australia and Papua New Guinea" (e.g. Williams *et al.* 1976), the 25th International Geological Congress Guidebook for Excursion 31 (e.g. Solomon *et al.* 1976), and this volume. To keep the following discussion as brief as possible, papers cited in these articles will generally not be referred to.

In the Early Jurassic, Tasmania was probably joined to Antarctica, Australia and New Zealand (fig. 15, after Griffiths 1974). At this stage Tasmania clearly lay within the Tasman orogenic zone or belt, a complex Palaeozoic feature that extends northward into Malaysia and southward into Antarctica. How long this configuration had persisted before the Jurassic is not clear. For example, there is some evidence that at least the western half of Tasmania may have been further west relative to the mainland, in the Ordovician-Silurian period (Crawford and Campbell 1973).

The history of the Tasman orogenic belt in Tasmania extends from the Cambrian to the Devonian and in this period, two major tectonic phases can be recognised. The first ranges from Early to Late Cambrian and will be referred to here as the Tyennan Phase, and the second ranges from early Ordovician to mid-Devonian and will be referred to as the Ordovician - Devonian Phase. The term Tyennan Phase is almost synonomous with the definition of the Tyennan Orogeny given by Carey and Banks (1954) and thus is only a slight departure from common usage.

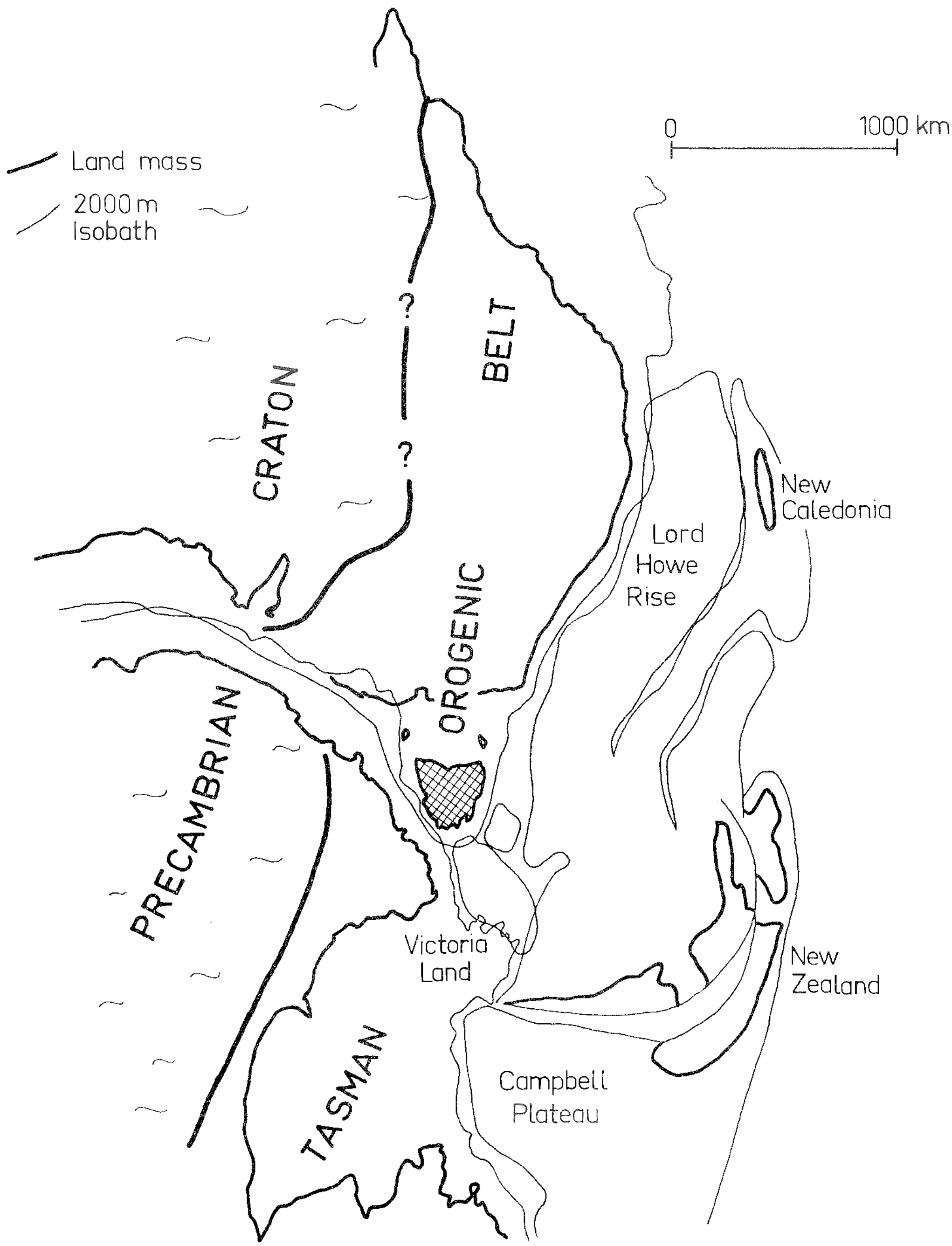

FIG. 15. - Reconstruction in the Early Jurassic of Australia, Antarctica, New Zealand and neighbouring sialic masses (after Griffith 1974).

The Palaeozoic rocks of these phases are now underlain, probably continuously, by late Proterozoic rocks but very little is known of the tectonic history of Tasmania at this stage.

The Proterozoic

The quartz schists and phyllites of the Tyennan Nucleus are the most severely deformed rocks of the Precambrian and are assumed to be the oldest. They contain insignificant mineralization. Those of the Rocky Cape Nucleus, the "Younger Precambrian", appear to be shelf sediments and may have formed on the eastern margin of the Proterozoic Australian craton. They include a zone of deformed rocks (the Arthur Lineament, fig. 16) which was probably active during sedimentation. Within this zone there is a sequence of mafic volcanic and intrusive rocks which in the Savage River area contains lenses of magnetite-pyrite ore. With our poor understanding of the tectonic setting in the Proterozoic, predictions concerning the distribution patterns of this mineralization are not yet possible.

The Rocky Cape rocks are supposedly about 750 m.y. old. Apart from the overlying Smithton Dolomite, also of Proterozoic age (Griffin and Preiss 1976), the next youngest dated rocks are Middle Cambrian. Rocks conformably underlying this Cambrian sequence may well extend into the Lower Cambrian but at this stage there appears to be very little material to represent the period from about 600 to 750 m.y. Whether this reflects non-deposition or erosion is not known.

The presence of pre-Middle Cambrian ophiolitic bodies in the Dundas Trough suggests an early Cambrian or late Proterozoic ocean or sea in that area.

The Tyennan Phase

The tectonic interpretation of the Cambrian in Tasmania hangs to a large degree on the nature of the Mt. Read Volcanics, which extend in arcuate form around the Tyennan Nucleus (fig.16). They are highly altered spilitic or keratophyric rocks, supposedly of calc-alkaline type. They are dominantly felsic and pyroclastic, and appear to be similar to suites of the Taupo volcanic zone of the north island of New Zealand, and to volcanics in Mexico, Chile and the Carpathians (see references in Solomon and Griffiths 1974). If these comparisons are correct they indicate the existence of an Andean-type, continental margin in Tasmania at this time. Possibly similar volcanic rocks occur in western New South Wales (Schneibner 1974) and Queensland (Kirkegaard 1974), perhaps indicating the existence of a volcanic belt throughout much of eastern Australia at this time. The Mt. Read Volcanics contain several small granitoid stocks of similar composition to the adjacent volcanics.

Extrapolation of plate-tectonic theory to the Cambrian indicates the presence of a trench and ocean margin to east or west of the Mt. Read Volcanics, and the presence of pre-Middle Cambrian ophiolites in the Dundas Trough suggests a spreading centre existed west of the Mt. Read Volcanics. However, lack of polarity in the volcanics and uncertainty about the age of the ophiolites and the tectonic setting of the related sediments, has led to a variety of speculative interpretations (Solomon and Griffiths 1972; 1974; Corbett *et al.* 1972; Rutland 1973; Schneibner 1974). The occurrence in Victoria Land (Antarctica) of late Cambrian - early Ordovician granitoid plutons and an outlier of Cambrian sediments (the Bowers Group), suggests the continental margin at this time may have included this region and extended eastward from the Antarctic-Australia craton. The Cambrian reconstruction shown in figure 17 with a thin, discontinuous sialic crust, is highly speculative but provides a loose framework for comparison with other regions.

The Ordovician-Devonian Phase

The Tyennan Phase appears to have given way, with only a limited period of deformation and mountain building (e.g. the Jukesian Movements), to the succeeding phase. From the Early Ordovician to the Mid-Devonian, western Tasmania was the site of unstable shelf sedimentation without volcanic activity. The flysch-like (continental rise) sequences of eastern Tasmania (the Mathinna Beds) are probably faulted against the shelf facies (Williams *et al.* 1976) but similar rocks may well have lain to the east of the

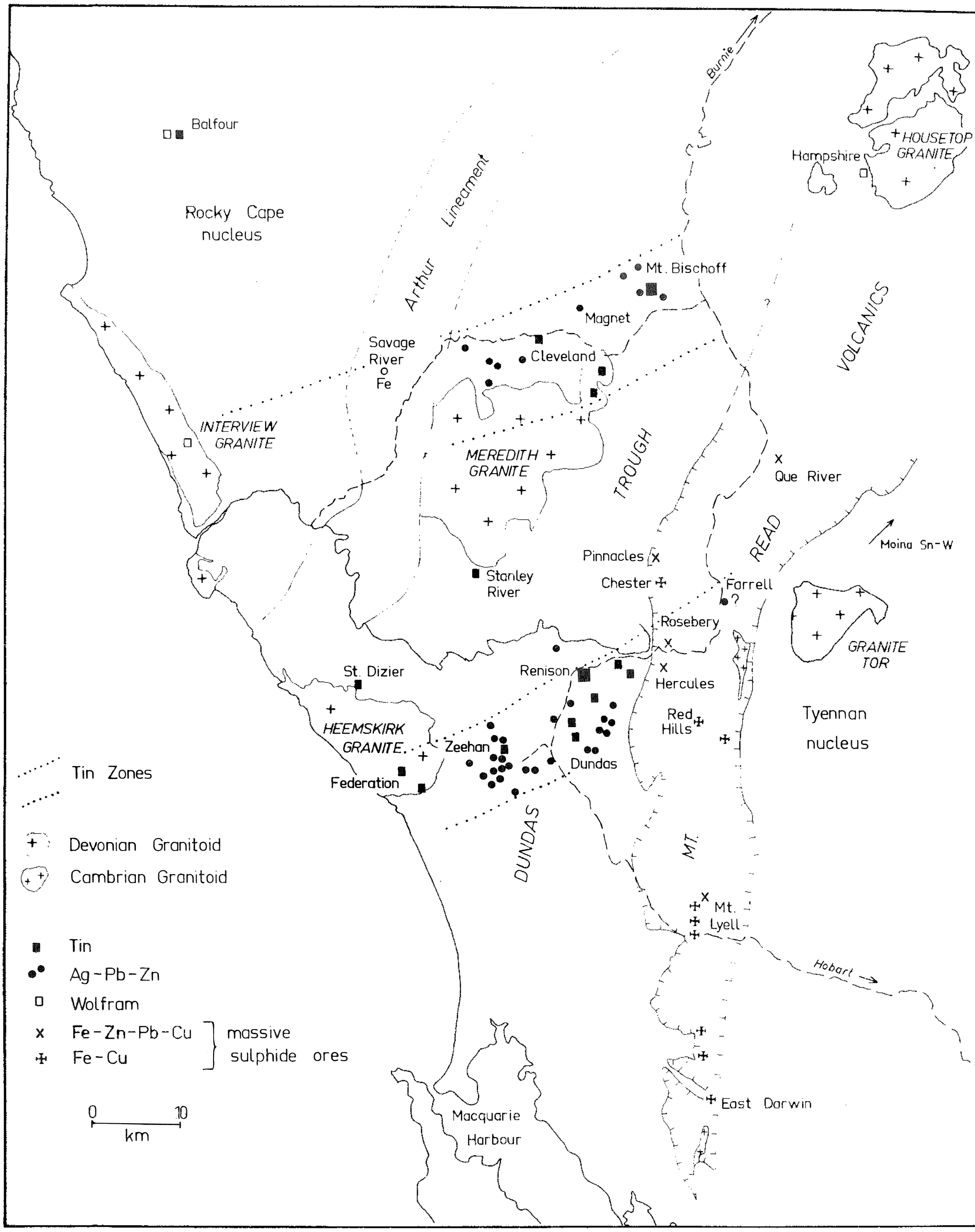

FIG. 16. - Generalised sketch map of Western Tasmania, based mainly on Tasmanian Geological Survey 1 : 250,000 maps of Queenstown and Burnie.

shelf facies, as shown in the proposed reconstruction for this period (fig. 17). In eastern New South Wales a north-south, Ordovician-Silurian, "orogenic" volcanic belt has been recognised (Schneibner 1973) and it is suggested that this may well have extended southward and lain east of present Tasmania. Thus the Ordovician-Devonian locus of sedimentation and volcanic activity appears to have shifted east relative to the Tyennan Phase.

As in adjacent sections of the orogenic belt, Tasmania was invaded by many granitoid intrusions, particularly towards the end of the Ordovician-Devonian Phase. In Tasmania these range in age from 400 to 340 m.y. and tend to be younger in the west (J. Cocker, in Solomon *et al.* 1976).

From the Late Devonian, Tasmania formed the eastern edge of the Australia-Antarctica craton, and the locus of tectonic activity and sedimentation again moved eastward (Solomon and Griffiths 1972).

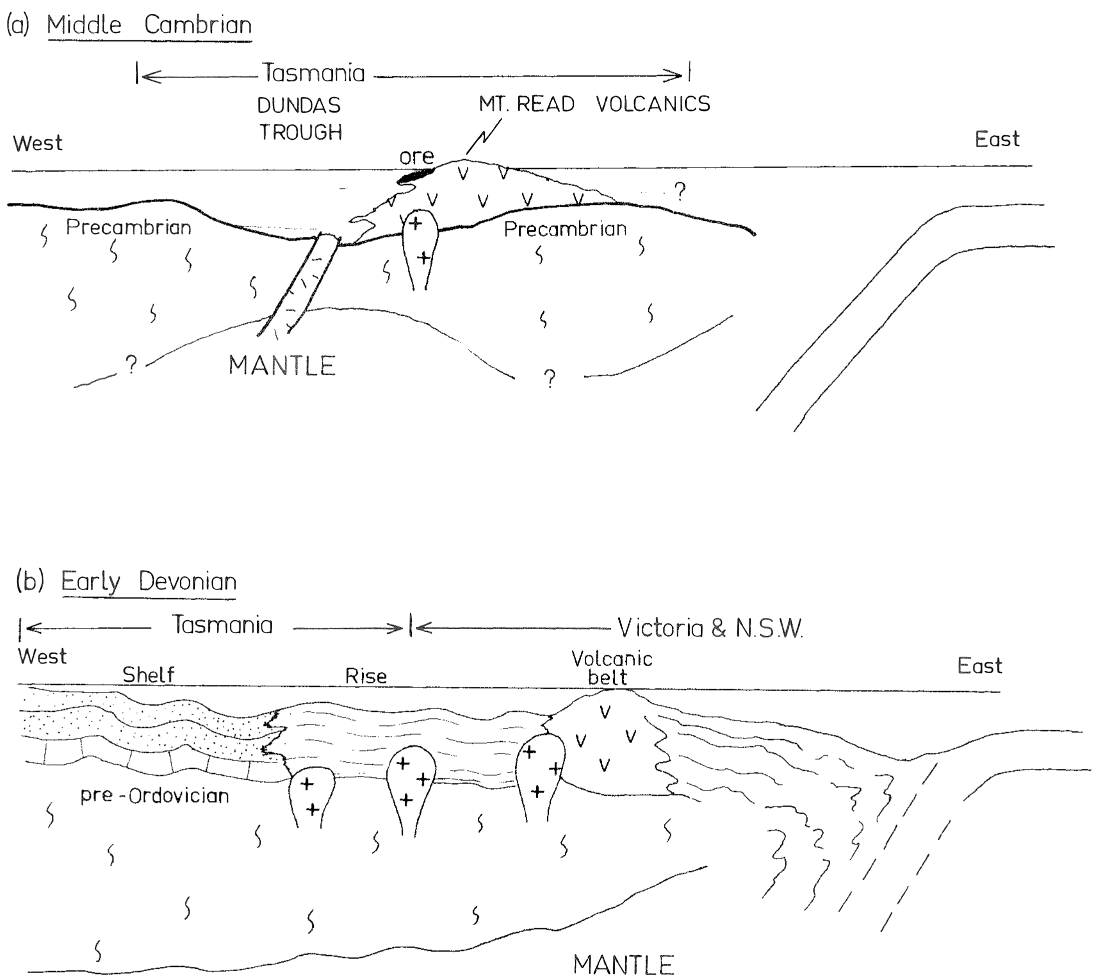

FIG. 17 (a) - Speculative east-west cross-section of the Tasmanian region reconstructed for the Middle Cambrian.

(b) - Speculative east-west cross-section of the Tasmanian region reconstructed for the Early Devonian.

Table 11

TASMANIA - METAL PRODUCTION TO JUNE 1975

	Tonnes		Kilogrammes
Tin	196,000 (30%)	Gold	96,000 (10%)
Wolfram	22,000 (30%)	Silver	2,800,000 (?)
Copper	845,000 (50%)	Osmiridium	1,000 (90%)
Zinc	1,250,000 (90%)		
Lead	773,000 (55%)		
Magnetite	15,000,000 (80%)		

(%) very approximate percentage of production from whole of the Tasman Orogenic Zone.

Production figures from statistics made available by the Department of Mines, Tasmania.

MINERALIZATION

The intensity of mineralization in Tasmania (mainly in the west and north-west) compared to the rest of the Tasman orogenic belt is remarkable. Table 11 illustrates the total Tasmanian production to mid-1975 and also shows the approximate proportion which this represents of total production from the Tasman belt between Cooktown in northern Queensland and Queenstown in Tasmania. It is suspected that this disparity in value of production per km^2 is a function of exploration success rather than any fundamental differences in geology.

Proterozoic

The only significant Proterozoic mineralization is in the southern end of the Arthur Lineament where there are several areas containing lenses of magnetite-pyrite rock within mafic volcanic successions. At the Savage River mine there is some evidence that the lenses represent a dismembered, stratiform,syngenetic deposit (or deposits) and the ore is now regarded as "oxide facies" of a massive sulphide-type deposit. Mineralization does not extend south of the Pieman River.

A number of small haematite bodies occur in the Penguin area in Proterozoic rocks and may be of late Proterozoic age (Burns 1961).

Tyennan

Massive Sulphides These are the most important types of ore deposits of this phase. Two major varieties are present - the pyrite-sphalerite-galena-chalcopyrite ores of Rosebery, Hercules and Que River, and the pyrite-chalcopyrite-bornite ores of the Mt. Lyell field. While the Rosebery and Hercules deposits are like many other massive sulphides (e.g. Captains Flat and Woodlawn in Australia and several of those in the New Brunswick area of Canada), Mt. Lyell is unusual (if not unique). It consists of several separate orebodies in about 10 km^3 of altered rock and while some ores are typical massive sulphides (e.g. the Blow, and Tasman and Crown Lyell) the majority are low-grade, disseminated, replacement lenses. A tentative reconstruction of the geology at the time of ore deposition is shown in figure 18. The diagram is highly speculative in that it suggests all the orebodies formed during one, probably protracted, phase of mineralization within a sequence of volcanics about 1 km thick. As the succession and structure are not yet firmly established the reconstruction must be regarded merely as a useful working hypothesis. The footwall rocks are mainly altered rhyolitic or dacitic pyroclastics and the alteration extends at least to the limits of sulphide mineralization. This is currently interpreted as due to lateral dispersal, with concomitant secondary circulation, of the rising ore solutions as they penetrated the top km or so of the volcanic pile.

The ore lenses at Rosebery have been tentatively interpreted as representing disrupted fragments of two or three (Braithwaite 1973; Green 1976, fig 4) individual ore lenses within a tuff-shale horizon in the Mt. Read Volcanics.

Minor deposits (e.g. Chester, Pinnacles) north and south of Rosebery and the larger deposit at Hercules may well be at approximately the same stratigraphic horizon, and all the minor deposits south of Mt. Lyell occur in one volcanic unit (the central lavas of Corbett *et al.* 1974, or the Intercolonial volcanics of White 1976) which may possibly be approximately equivalent to that at Rosebery (Solomon *et al.* 1976). It is suspected, though cannot yet be proved, that prominent zones of folding and faulting at Rosebery (north-south) and Mt. Lyell (north-south and east-west) may well have been important ore-solution channelways in the Cambrian.

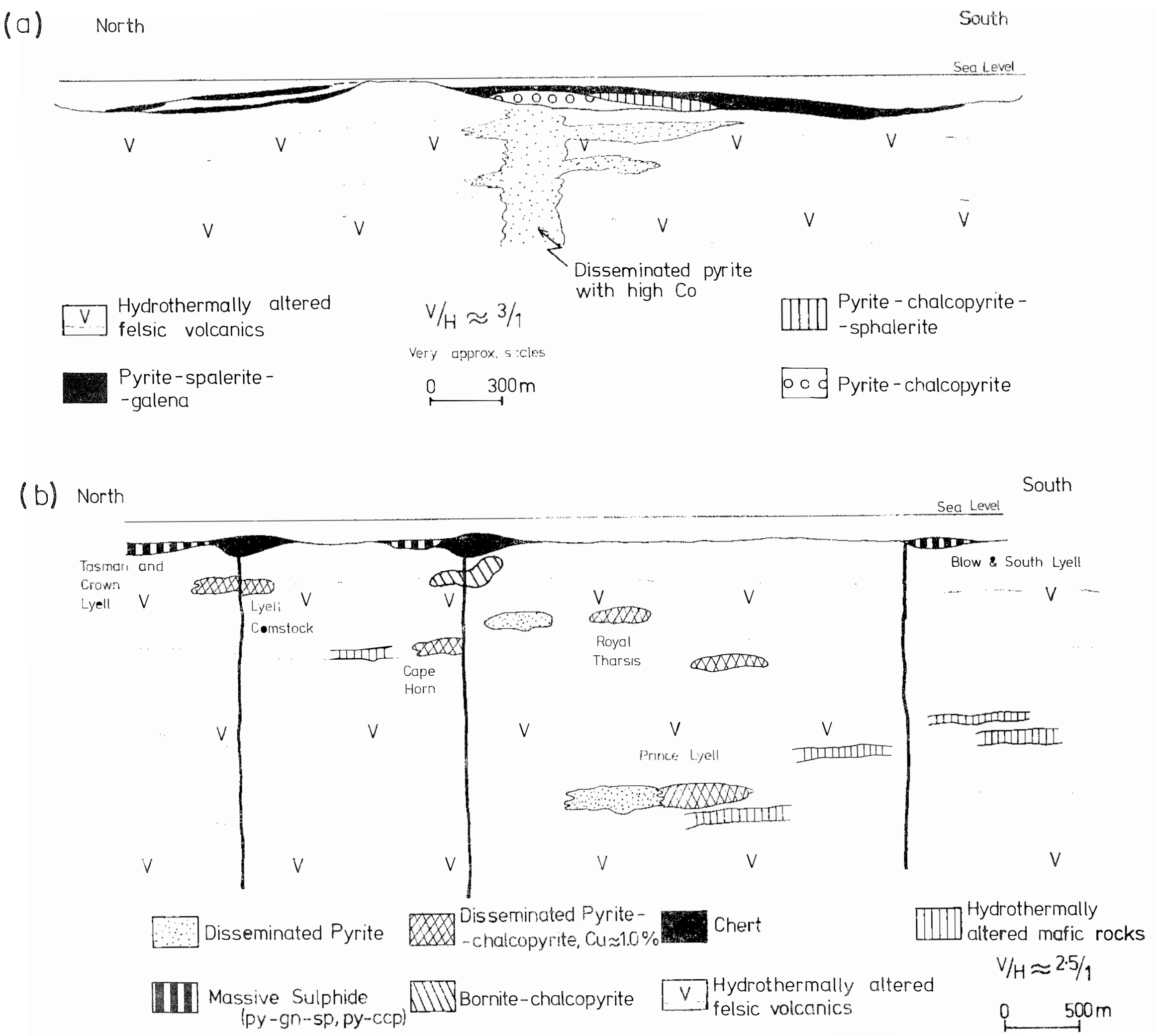

FIG. 18. - (a) Tentative reconstruction of the Rosebery massive sulphide prior to deposition of the borite lode, drawn by G.R. Green.

(b) Speculative reconstruction of Mt. Lyell field at the close of ore deposition, based on Reid (1976), Solomon (1976) and earlier workers.

The Mt. Farrell-Stirling Valley line of deposits lie in a slate-tuff unit (the Farrell Slates) or in underlying pyroclastic rocks. Their origin is not known with certainty though some may well be massive-sulphide deposits. They also occur in a strongly faulted zone and could lie at about the same stratigraphic horizon as Rosebery and Mt. Lyell.

The relatively common occurrence of ash-flow tuffs and breccias in the Mt. Read Volcanics (particularly in the footwall and hanging wall rocks of Rosebery and Hercules and in the sequence at Mt. Lyell), together with the paucity of well-bedded rocks, has led several workers to suggest the palaeogeography during ore formation was one of a chain of volcanic islands flanked to the west by an extensive marine basin (the Dundas Trough). The island chain probably contained ephemeral inlets and lagoons, particularly on its western margin where it merged to the ocean, and many of the massive sulphide deposits probably formed in these shallow basins during a pause, or pauses, in volcanic activity (Braithwaite 1970, Solomon *et al.* 1976).

Nickel sulphides. A Cambrian gabbroic sill at Cuni, near Zeehan, contains lenses of megnetite-pyrite-pyrrhotite-chalcopyrite-pentlandite ore and pyrite-chalcopyrite-millerite ore (Hughes 1965). The lenses are small and the geology is not well known. Minor occurrences of heazlewoodite and pentlandite occur at Trial Harbour and Bald Hill but these appear to be largely secondary features related to Devonian (?) sulphidization of ultramafic rocks.

Ordovician-Devonian

Mineralization during this tectonic phase was dominated by cassiterite-pyrrhotite-pyrite deposits associated with crudely-defined haloes containing minor argentiferous galena-sphalerite lenses and veins (fig. 19). All the significant known mineralization of this type is confined to two NNE-trending zones, one including Cleveland and Mt. Bischoff and the other Zeehan and Renison Bell (fig.16).

The geology of the Mt. Bischoff and Renison deposits is very similar and it seems probable that the host rocks are of similar age (cf. Williams *et al.* 1976). The mineralization occurs in sandstone-mudstone-dolomite sequences in which the dolomite has been replaced by pyrrhotite, pyrite, arsenopyrite, cassiterite, etc. The replacement extends out from fractures (Renison) or from quartz porphyry dykes and sills (Mt. Bischoff). A similar mineralogy is found in associated steeply-dipping lodes which may be of fracture-filling and/or replacement origin. The quartz-porphyry dykes at Mt. Bischoff probably originated from underlying extensions of the Meredith Granite, and though only a few dykes occur at Renison, granite has been located in drill-holes beneath the mine. A tourmalinzed quartz porphyry plug crops out at Pine Hill, about 2 km south of the mine.

The Cleveland mineralization differs in being relatively rich in stannite (which contains about 10% of the tin), and having a lower total sulphide content. It appears to be a replacement of carbonate and mudstone. No felsic igneous rocks occur in the immediate vicinity.

Other iron sulphide-cassiterite-stannite lenses occur at Zeehan (Queen Hill), east of Renison Bell, and near Dundas (fig. 16). Tin has also been won from cassiterite-quartz-tourmaline lodes and greisen lenses near the margins of the Heemskirk and Meredith Granites (fig. 16).

Both the Cleveland-Bischoff and Zeehan-Renison tin zones contain minor vein deposits dominated by sphalerite and argentiferous galena, with variable tetrahedrite, jamesonite, etc. A few chalcopyrite-rich vein deposits also occur in these zones (e.g. the old Mt. Stewart and Ring Valley mines). The Zeehan field is the most important of these Pb-Zn haloes. Using the analytical date of Both and Williams (1968) it can be seen (fig.20) that the highest Ag values (in galena) group around the zone that includes not only the cassiterite ores of Queen Hill but all the stannite occurrences and the six major silver producers (accounting for 89% of the field's production). In addition to this pattern there is a pronounced east-west variation in the gangue composition, from pyritic to sideritic, and the reasons for this are not well understood.

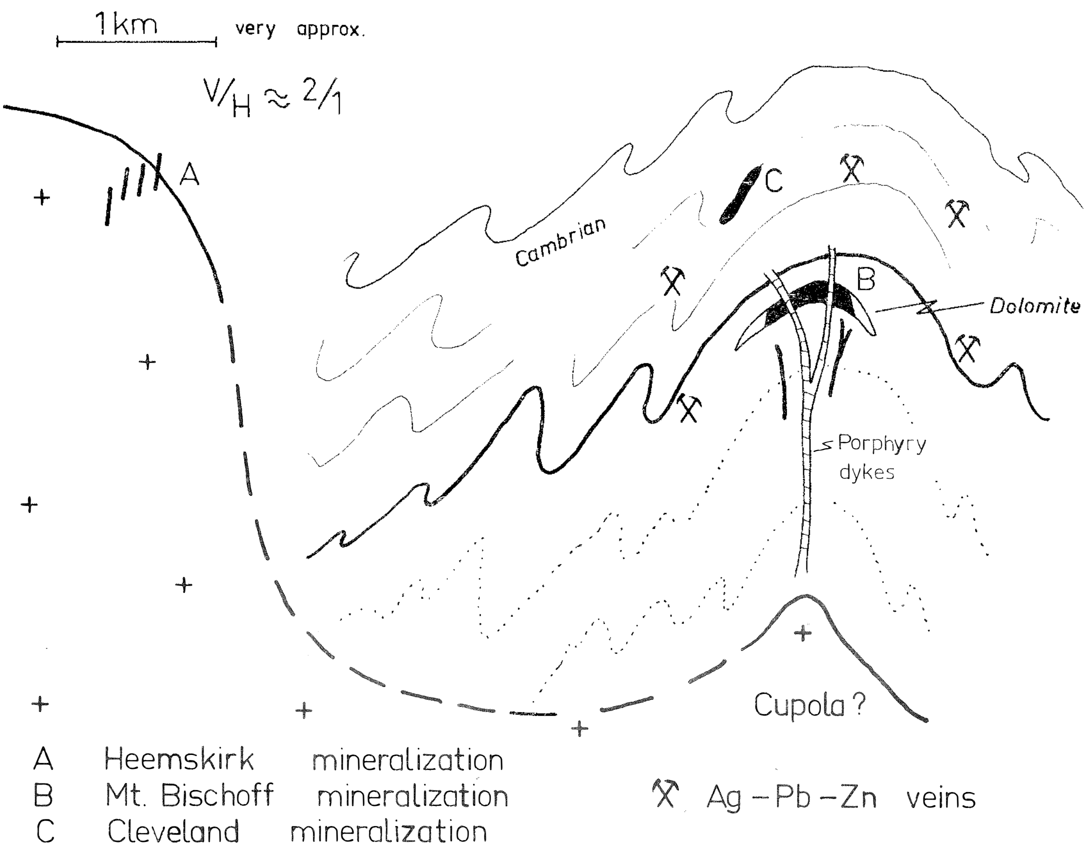

FIG. 19. - Sketch to illustrate the spatial relationships of some tin deposits in western Tasmania to their source and host rocks.

The enigmatic silver-rich galena-sphalerite lodes of North Mt. Farrell are similar in many respects to the argentiferous Zeehan ores and could represent another centre of Ordovician-Devonian mineralization along an extension of the Zeehan-Renison zone.

Although the granitic plutons are mineralized, most of the tin mineralization is of extra-magmatic type. It is suspected that the major tin ores overlie cupolas or centres of late-stage dyke emission and that these are centred over north-east ridges or ledges of granitic rock as shown in the speculative reconstructions of figure 19 In the Cleveland-Bischoff district the ridge appears to be a ledge on the northern flank of the Meredith pluton. Cassiterite-tourmaline and greisen-type mineralization of intramagmatic type is irregular, dispersed, and of relatively minor economic significance.

Wolfram mineralization is invariably within, or much closer to, the parent granitoid than most tin mineralization. Only minor wolfram mineralization occurs on the west coast but it may be significant that two of the occurrences (Interview River and near Hampshire) lie on possible extensions of the Mt. Bischoff-Cleveland zone (fig.16).

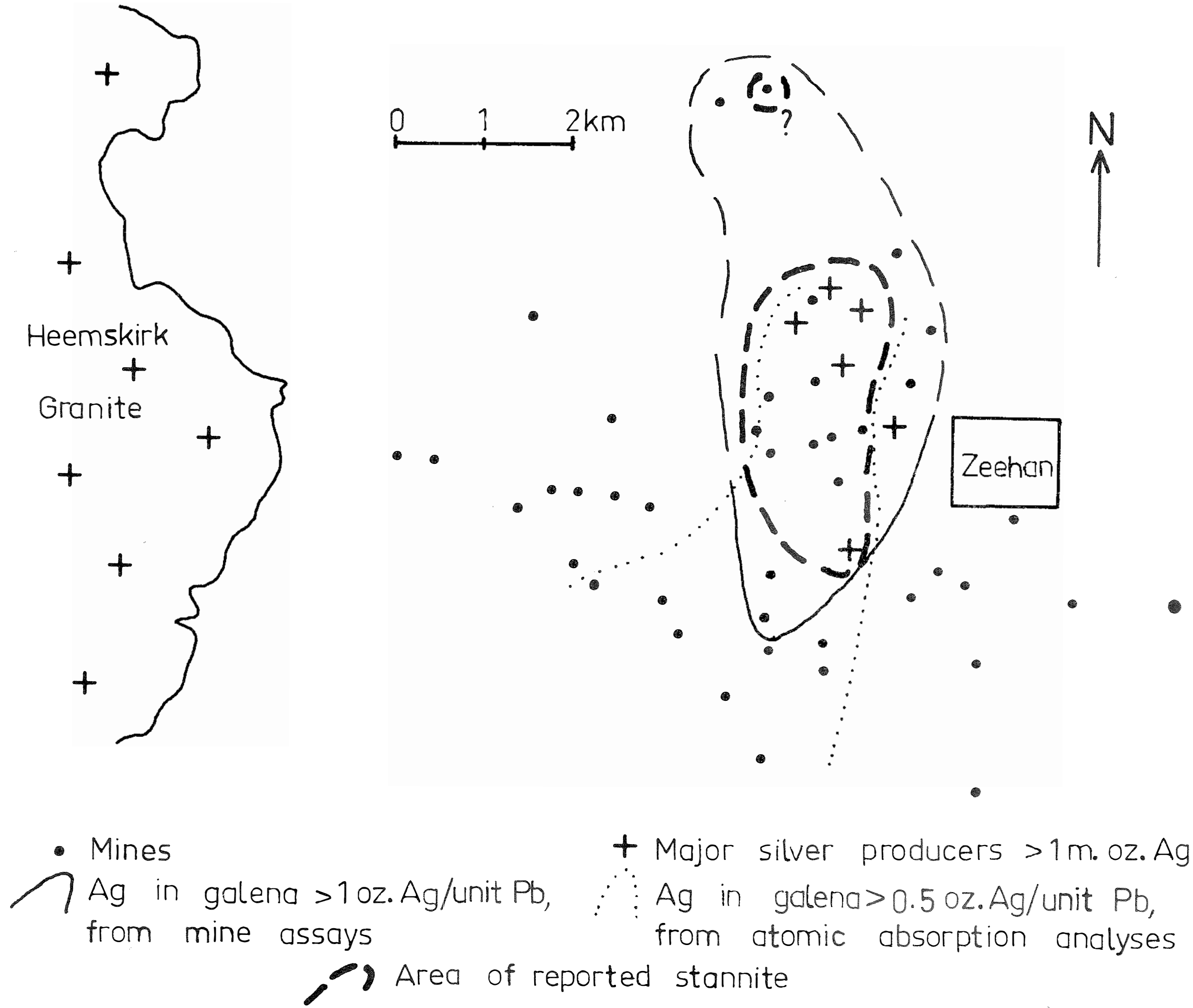

FIG. 20. - Map of the major deposits of the Zeehan tin-lead-zinc-silver field showing stannite occurrences, distribution of silver content of galena, and the major silver-lead producers (after Both and Williams 1968; Green 1973). Note that in plotting the Sylvester mine, a minor stannite occurrence, horizontal fault displacement as indicated by the Cambrian/Proterozoic boundary has been removed.

The only other occurrences are near Moina and these lie on an eastward extension of the Zeehan-Renison zone.

Sulphide-cassiterite occurrences north of the Heemskirk Granite (St. Dizier) and south of the Meredith Granite (Stanley River) might represent an additional north-east tin zone.

The linking of ore occurrences to linear features is a favourite occupation of economic geologists and can be fruitless and misleading without adequate data points. However it is worth noting that this north-east element to the Devonian mineralization now looks even more significant than when it was first noted by Hall and Solomon (1962).

Other Tabberabberan Mineralization. Cassiterite and wolframite occur in veins west of Balfour in a small area of copper mineralization (Ward 1910; fig. 16); and gold-quartz veins occur in Siluro-Devonian sediments west of Queenstown (e.g. the Florence Mine).

Galena-sphalerite-barite-calcite-quartz veins and splashes occur in a downfaulted block of Ordovician limestone at Bubs Hill, 1.8 km east of Queenstown. This is the only known example of Mississippi Valley-type mineralization in Tasmania.

MINERALIZATION IN THE ANDES AND OTHER OROGENIC BELTS

If the tectonic reconstructions for Tasmania are valid then it is pertinent to compare Tasmanian mineralization patterns with those in other continental margins. Probably the best preserved mineralization is that related to Mesozoic-Tertiary igneous activity in the southern Peru-northern Chile-southern Bolivia region. This region contains four distinctive but discontinuous zones of mineralization approximately parallel to the coastline (Ahlfeld 1967; Sillitoe 1972a; Rutland 1974 and others; fig. 21). The zones from east to west, are as follows:

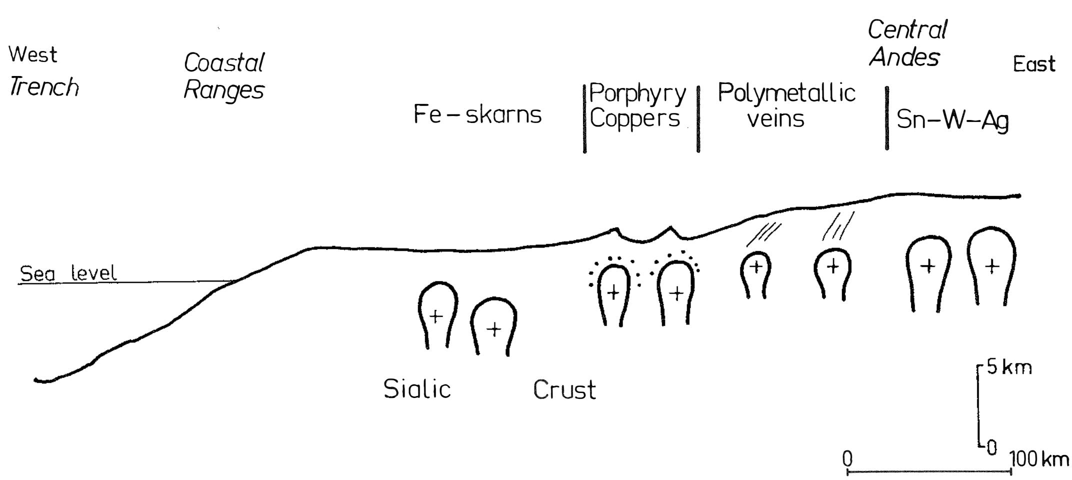

FIG. 21. - Simplified cross section of the Bolivian Andes, showing zonation of mineral deposits.

(a) magnetite-rich, contact-metasomatic skarn deposits;
(b) porphyry copper deposits with molybdenum (and also gold in the western part) and minor peripheral lead-zinc deposits;
(c) sub-volcanic polymetallic vein deposits with lead, zinc, silver, copper, cadmium and locally, antimony; this zone also contains "red bed"-type copper deposits in molasse-type sediments (e.g. Ljungren and Meyer 1964);
(d) tin-wolfram deposits of varying form with peripheral lead-zinc-silver veins (the Bolivian tin province).

The porphyry copper districts around the western Pacific, like those in the Andes, lie fairly close, and parallel, to trench zones but those of the Cordilleran region of western U.S.A. are more dispersed and their tectonic setting is uncertain (Hollister 1975). Tin deposits in orogenic belts generally appear to follow the Andean pattern, lying well away from trench, or inferred trench, zones and generally within the craton or close to its margins. This appears to be true in each of the three major tin-wolfram epochs in the Tasman orogenic belt of mainland Australia (Solomon and Griffiths 1974).

Sillitoe (1974a) has pointed out that these Andean mineral zones are not continuous along strike, making direct comparisons with small areas like Tasmania difficult. Further complications arise in making comparisons because removal of the top 3 km of the present Andes by erosion would eliminate most of the observed mineralization (Sawkins 1972). Porphyry coppers in general have a frequency-time distribution that suggests they are susceptible to erosion (fig. 22). It would appear that there is little or no chance of finding Cambrian examples but a better chance of finding them in Devonian rocks. The Bolivian tin deposits are also probably related to high-level granitoid stocks but ore deposition appears to have extended to greater depths below surface compared to porphyry coppers (Sillitoe 1973; *et al.* 1975). This is reflected in the frequency-time chart for tin ores of orogenic belts, which shows tin ores persisting from the Precambrian (fig. 22). Note that the tin deposits related to alkalic plutons in stable cratons (Sillitoe 1974b) may have a different time distribution.

Massive sulphide deposits are rare in the Andes, probably in part because many of the exposed rocks formed in terrestrial conditions while massive sulphides typically require a marine, or at least aqueous, environment for their deposition and preservation. The volcanic chains of older orogenic belts are characterised by the presence of massive sulphides, commonly within or near calc-alkaline volcanics (e.g. the western cordillera of Canada and U.S.A., the Appalachians, the Caledonides, etc.). It is suspected that erosion of the Andes to about sea level would expose many more massive sulphide deposits, particularly in the early phases of the volcanics associated with the present porphyry copper belt. Massive sulphides also occur in sediments flanking volcanic belts but are relatively rare.

Massive sulphides of pyrite-chalcopyrite ± sphalerite type are commonly associated with the lavas of ophiolites, and ophiolitic material is commonly found in thrust slices and diapiric structures within orogenic belts. Well-known examples of such mineralization occur in Newfoundland and other areas (Sillitoe 1972b), and low-grade mineralization of this type has been described from New South Wales (Ashley 1974).

Another style of mineralization seen in eroded belts is that of gold-quartz veins in folded flysch-like sediments, as developed in the Bendigo and Ballarat fields of central Victoria, and to a lesser degree in the Mathinna Beds of eastern Tasmania. Much of the vein gold may well be concentrated from the local sediments during cleavage folding (Ceplecha and Wall 1975).

A further variation of relevance is the occurrence of dominantly lead-zinc deposits in shelf-type carbonate successions of Carboniferous age along the northern margins of the Hercynian orogenic belt. Typical examples are the Lower Carboniferous ores of Eire(Russell 1968) which include those composed of sphalerite, pyrite-barite, galena-sphalerite-chalcopyrite and sphalerite-galena-chalcocite-bornite-chalcopyrite-tennantite (producing copper, silver and mercury). The fluorite-barite-sphalerite-galena ores of the Pennines in England also occur in Lower Carboniferous limestones but are probably of Late Carboniferous age. Ore deposition in these areas may well be closely related to mafic igneous activity and/or tensional faulting related to continental break-up (Russell 1973).

Nickel sulphide mineralization rather similar to that found in Tasmania is found elsewhere in eastern Australia (e.g. Ashley 1975) and in other orogenic belts (e.g. the Pride of Emory mine east of Vancouver, British Columbia, Little *et al.* 1970) but is of little economic significance. Important primary nickel mineralization in orogenic belts appears to be largely in rocks of Archaean age.

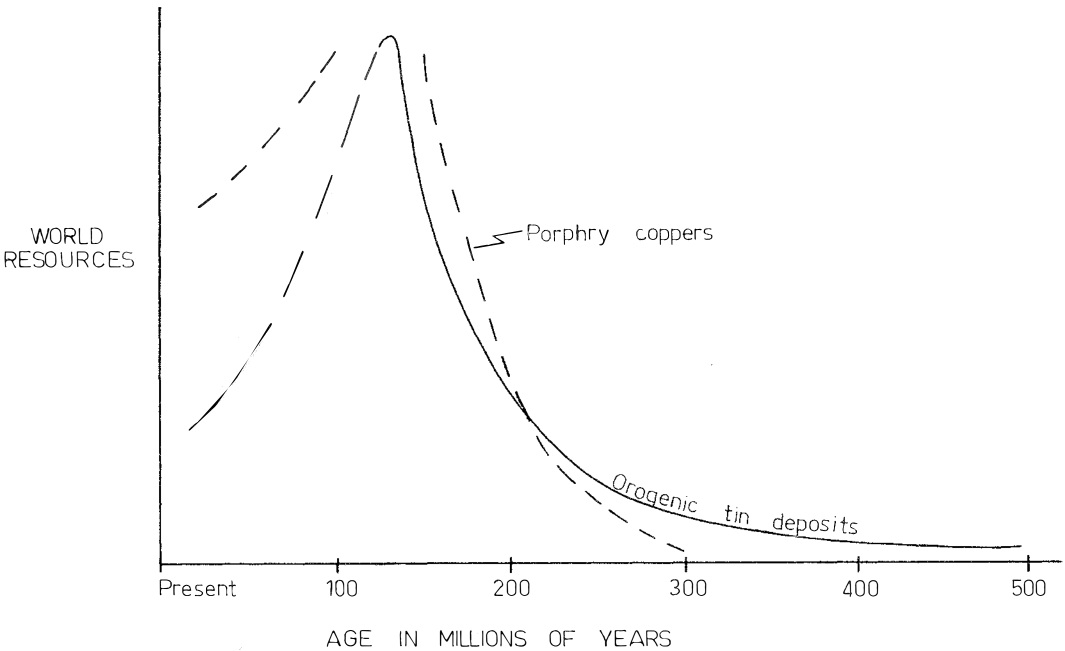

FIG. 22. - Generalised curves showing time distribution in time of porphyry copper and primary "orogenic" tin deposits. The tin curve is based on Itsikson (1960).

MINERAL POTENTIAL OF THE PIEMAN-GORDON REGION

Tyennan Phase

The previous outline review of mineralization patterns, and the supposed tectonic situation or Tasmania in the Cambrian, allows the following conclusions to be drawn:

(a) there is obvious potential for massive sulphides, particularly in the Mt. Read Volcanics of the ophiolite bodies, and to some extent in the sediments of the Dundas Trough,

(b) the Cambrian age of the calc-alkaline volcanics virtually eliminates any chance of finding porphyry-copper deposits,

(c) the chances of finding significant nickel-sulphide mineralization are small.

If the Victoria Land - Tasmania reconstruction is correct then tin ores related to near-craton granitoids might be expected in Antarctica, though the Cambrian/Ordovician age of the granitoids reduces the probability of significant tin occurrences.

The greatest interest lies in the chances of finding more massive sulphides in the Mt. Read Volcanics, and recent theories for the genesis of these deposits allow some tentative predictions to be made. As indicated in a review by Solomon (1976) there is increasing evidence that massive sulphides in volcanic piles originate by convective circulation of sea water during protracted pauses in volcanic activity. Critical prerequisites for ore formation are an adequate heat source, relatively stable conditions, and suitable sites for deposition and preservation. Faults probably assist in providing chennelways and local depositional basins.

Some of the strongest evidence for such widespread sea-water circulation has come from the mafic rocks of Cyprus which are hydrated and have undergone $^{18}O/^{16}O$ and $^{87}Sr/^{86}Sr$ changes compatible with exchange between rock and considerable volumes of sea water (Spooner and Heaton 1976).

Of particular relevance to exploration geology is the pattern of the convective circulation. Theoretical and experimental studies indicate that in an infinite horizontal permeable medium, heated from below, the flow patterns should take the form of polyhedral cells arranged in plan in a regular manner and having a diameter related to the depth of the medium by a factor which appears to vary between 2 and 3 (Elder 1965; Lapwood 1948; Combarnous and Bories 1975 fig.23). Such regularity is unlikely in nature because flow paths tend to be distorted by faults and horizontal layering of rocks with different permeabilities. The tendency for massive sulphides to lie on fault zones indicates their importance in controlling the cell patterns.

Despite the high probability of upsetting the ideal pattern there is some evidence in well-established and relatively undeformed ore fields, like those of Cyprus and the Hokuroku basin (northern Honshu), of regularities in the distribution patterns (Solomon 1976). In these areas the deposits tend to occur in clusters covering areas of a few km^2 and separated by distances of at least several km. The clusters have their own fairly regular internal distribution pattern. In very general terms, the larger the amount of ore in the cluster the greater the separation between clusters, a feature seen in several orefields and also predicted by the convection hypothesis. In Tasmania, for instance, Mt. Lyell is the largest cluster of orebodies, and the nearest neighbouring deposit, which is very small, is 10 km distant. Presumably this indicates a cell size of *at least* 10 km for Mt. Lyell. At Rosebery, on the other hand, with about a quarter of the tonnage of sulphur, the nearest significant neighbour (Chester) is only 7 km away. Similarly on Cyprus there is no mineralization within about 12.5 km of the main ore group (Skouriotissa-Mavrovouni - Aplika) but the smaller ore groups are closer together (Solomon, 1976). This is very speculative treatment, particularly in Tasmania where the ore horizon is faulted, folded and partly eroded but nevertheless the grouping may well be providing useful data on cell sizes.

The presence of volcanics or ophiolites does not in itself necessarily indicate an ore province as the conditions critical to ore formation may not be met. However, the number of deposits between Tullah, Rosebery and Mt. Darwin indicates that convective circulation was active throughout this part of the volcanic belt. Hence it is reasonable to suppose that further orebodies could be present in the major gaps in the present distribution pattern, though the total potential tonnage would not appear to be much more than that already discovered (i.e. about 15 million tonnes of sulphur). The discovery of the Que River massive sulphide deposit indicates convection was active north of Rosebery and thus there would appear to be considerable scope for further orebodies in that area.

The degree of alteration (both mineralogical and isotopic) should prove a useful guide to the degree and pattern of sea water circulation and indeed in a mineralized province it should be possible to "map" the cells by studying variations in mineralogy and isotopic composition. Work of this nature has not yet been undertaken in Tasmania, making further prediction difficult.

Ordovician-Devonian Phase

Tasmania's tectonic situation during this phase indicates potential for:

(a) tin-wolfram and associated silver-lead-zinc deposits.
(b) lead-zinc-copper deposits associated with carbonate shelf sediments.

Gold potential in the flysch facies would be confined to eastern Tasmania.

There is no way of predicting tin-wolfram occurrences other than by using empirical extrapolation, and obvious areas of potential are the known north-east zones and indications of parallel zones. Within these zones there would appear to be better

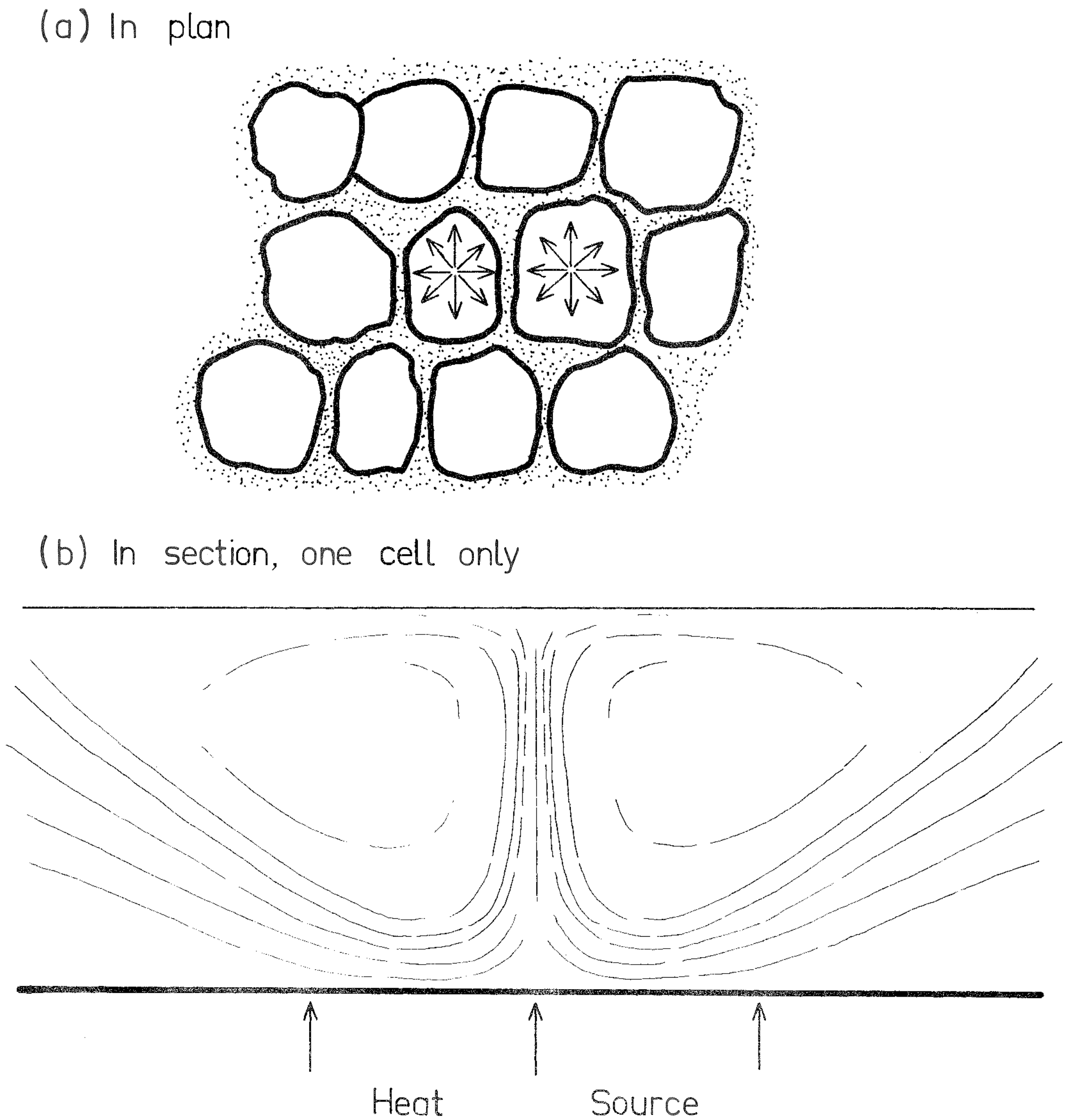

FIG. 23. - Sketches showing the geometry of convection cells developed in laboratory experiments simulating a horizontal water-saturated permeable medium uniformly heated from below and covered by water (after Elder, 1965; Combarnous and Bories 1975).

chances of substantial deposits well away from outcropping granitoids (thus lowering the potential of the St. Dizier and Stanley River deposits) and within carbonate beds.

The search for carbonate-lead-zinc-copper deposits would clearly be concentrated on the Gordon Limestone which outcrops intermittently over a wide area of western Tasmania. The presence of minor mineralization is significant but three factors downgrade the potential for discovery, viz:

(a) the limestone is considerably deformed in the Pieman-Gordon region (though less deformed elsewhere).
(b) there is no concomitant igneous activity, a possibly significant factor in the Hercynian cases, even if it is only a source of heat.
(c) there is no evidence of continental break-up at this time in Tasmania, though Late Ordovician movements are recorded on mainland Australia.

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