
Finding Cambrian keys: An essay in controversy, prospectivity and tectonic implications

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ABSTRACT

There is a need, in terms of Tasmanian geology, to consider a bigger picture and preserve appropriate perspectives. Failure to do this may lead, and has led, to false or limited conclusions. We blithely talk about orogenies and so on but rarely consider the entire sequence of events involved, their impact on mineralising processes and how such events might be flagged today, or their final result. We need to think in terms of evolved and inherited structural and sedimentological controls, lateral and vertical dislocations, and concealment of indicators. When we think of mineralising controls or sources, whether at faults, margins, in volcanic piles and so on, it is easy to look locally and superficially and miss the real setting. Further, the entire fragment examined may not be in its original or relative setting.

Petroleum explorers have developed many sound ideas for sequence and structure evolution but they force simplicity on their exploration by considering mainly the relatively undeformed parts of evolved basins. Mineral exploration often must treat the "unprospective" part of a petroleum explorer's section. But the issues and controls, in structural terms, are inseparable and we must take both the shallow and deep views into our thinking.

All this applies to Tasmanian mineral exploration — and Cambrian events. If we are looking for granitoid-related Devonian mineralisation styles then we need to seek out only the granitoid and roof controls. In many cases these, and the methods required, are well defined. We may seek targets directly. Cambrian targets are more like needles in an evolved and complex haystack. Appraisal depends on knowing what belongs where, where it was at the time of mineralisation, what has happened since, and where the controlling elements were. What if our beloved Mt Read Volcanics are affected by all this? Indeed, were they formed as key indicative elements of a developing structural package?

This essay asserts that a realistic perspective of Tasmanian geology and its development cannot be established without taking a broader view which shows that western Tasmania is not unique and that any concepts based solely upon that region will be misleading. Past concepts have overlooked the multiple mélangé-like nature of Tasmania, the repeated thrusting regimes and the significance, and exploration use, of the Lower Cambrian mafic rocks.

A concept involving long-term extension processes with modern and ancient analogues, punctuated with wrench-compressional events, can account for the evolution of the Tasmanian crust from the mid Proterozoic to the Jurassic (and with variants to the present). Critical or key elements in this evolution are penetrative crustal structures. While occasionally recognisable at surface, crustal geophysical methods must be used to properly confirm these structures. If other, local, characteristics of such special sites are also observed nearby then an exploration target has been defined.

Mineralised sites can be associated with primary penetrative structures, however these may have been modified with time provided the original crustal setting has been recovered. Rock suites such as the Mt Read Volcanics can be shown to occupy particular crustal settings within an evolving extensional regime, and are not limited to a single province such as western Tasmania. The associations between early Palaeozoic structures, mineralisation, volcanic sequences and Devonian overprints reflect persistent and inherited controls. Above all, such associations show that the mineral potential of the entire Tasmanian continental mass is very great indeed. It is up to us, as explorers, to fully lift the lid on this cornucopia.

PROLOGUE

Before considering the issue of how to find a Cambrian key it is first necessary to define the keys and their characteristics, explain why Cambrian sites are important, and why they appear so difficult to find. Some aspects of these definitions and comments strike to the very heart of the many major

controversies and issues in Tasmanian geology which must be seen afresh. The recent explosion in understanding and the removal of many forms of blinkered vision forces wholesale review of all previous concepts and the demolition of several — along with many assumptions. Yet, it will be argued, only the exploration approach is really at issue — and it must now be seen in a STATEWIDE perspective and not restricted only to a well-known mineralised belt in

western Tasmania. There is, in principle, no difference in exploration approach required regardless of location, whether western, central, northern or southern Tasmania.

The Cambrian mineral potential of Tasmania is wide open. Only one part of the province — that of central western Tasmania — has been considered to date and it will be shown that this amounts only to surface scraping in considerable ignorance. This region and the remainder of the island have yet to be explored seriously, and yet Tasmania is already a world-class base metal province!

INTRODUCTION

Metallic mineralisation in Tasmania is intimately associated either with Devonian granitoids or Cambrian volcanism or tectonism (including mafic rocks). Although the Devonian-related prospectivity is clearly important it may be argued that the Cambrian province is the more important — and its structural elements certainly controlled the Devonian evolution — to the extent that the younger mineralising event was a sideshow in comparison. This perspective accounts for the use of the word Cambrian in the title of this paper.

But, assuming the possible existence of a number of large, mineralised sites of Cambrian age, just how does one find them? These are the key sites. A few have been found already, but most are locked away and concealed by at least two major deformations and related dislocations, or post-Carboniferous cover. This essay examines some of the issues involved and some of the techniques which might be used to find the keys which unlock these sites for detailed exploration.

CAMBRIAN CONTROVERSIES AND PREVIOUS CONCEPTS

In order to appreciate the basis and implication of the concepts proposed here it is essential that some elements of Tasmanian geology be clarified or placed in perspective.

The recently published (1988) volume *Geology and Mineral Resources of Tasmania* provides several discussions dealing with the Lower Palaeozoic tectonic history and conflicting theories — including rifting, plate motions and mafic allochthons.

This was summarised by Corbett (1989) but all such discussions are fatally flawed if they emphasise only those relationships seen in western Tasmania. Do these represent the beginning and end of the Cambrian story in Tasmania or beyond? Not at all. They are barely representative of the total condition when viewed on a larger scale (below).

Each of the previous concepts involves presumptions about the origin of the various igneous rocks and their original setting based on an array of geochemical indicators, which leads to some absurdities. Corbett essentially concludes that either something is wrong with various of the assumptions or a new conception is required. But many of the presumptions about arcs, back arcs, oceanic sources, subduction zone needs, continental collisions and so on, are unproven arm waving and may evaporate, especially if we are dealing with a multiply-compressed mélange in which the pieces do not always preserve original relationships or

crustal locations. In short, the geochemical-petrology-environment arguments are interesting but may often be irrelevant to finding exploration keys. There has been too much re-arrangement, and this is the first thing which has to be recognised. We have to step back and take a longer view — both in time and space — and not necessarily assume that all modern oceanic processes are relevant to the late Proterozoic.

The second thing is to admit that the exposed rocks of western Tasmania are not special, or unique, in any way. Not in composition, structural evolution or provenance. If it could be shown that rocks of the late Precambrian through to the late Ordovician, say, exist in other parts of Tasmania, or elsewhere, then many special theories used to account for the Mt Read Volcanic "arc" would have to be reviewed (scrapped, actually). Note that my time range fully encompasses the Cambrian.

Some of the enigmas presented by current published thinking relate to the Penguin Orogeny, the relationship of the volcanic rocks and the Tyennan Precambrian boundary, the role and origin of the various Precambrian blocks scattered around northern Tasmania, the placement and development of "rift-ocean" floor settings at the scale implied, and the apparent narrowness of the volcanic belt itself when compared with similar belts.

Every one of these enigmas can be resolved.

SOME ADDITIONAL FACTS

Reappraisal of Tasmanian geology depends on three datasets. All are incomplete, but sufficient is known to extract a consistent story. The Tasmanian gravity database converted into a residual form (fig. 1*, 2) provides the foundations for understanding the larger components within the Tasmanian crust. The columns of the temple of understanding are supplied by the many fragments of aeromagnetic data including the Midlands survey (e.g. fig. 3). The embellishments on the cornice are provided by the repeatedly inherited impressions of older structures which have influenced events since their genesis. These are evident even in modern topography, with or without Mesozoic or Cainozoic dislocation, and surface mapping can be interpreted in terms of them.

When exposed Cambrian rocks are examined it is always difficult to separate Devonian and older influences. The younger influences always appear more important or less ambiguous.

The gravity map reveals several important elements including the scale of the Devonian granitoids, their distribution and differences between west and eastern Tasmania, and the Tertiary basins. But the most significant features are strongly positive. Only one is now reasonably coherent. In western Tasmania such a belt extends SSW and then south from Bass Strait and has one side along the Arthur Lineament. The eastern side passes east of Waratah, through Dundas and south via Birchs Inlet. The bending is sympathetic to the entire northern portion of the so-called Tyennan core near Cradle Mountain and the wrap around of the volcanic arc. Is there a relationship in this pattern? Note the Cambrian grain near Boco (fig. 4). Similar positive effects may be observed in the central north of the island and

* NOTE: Figures 1 and 15 are located in the pocket at the rear of this Bulletin

throughout the central plateau region, but the pattern is more disrupted. The gravity field also demonstrates the existence of regular and huge fracture systems within the Tasmanian crust.

NNW trends can be recognised from the far northeast to the West Coast and block out the central core. Many gold deposits in Northeast Tasmania are related to one of these.

Leaman (1988a, *d*) proposed at least two deep troughs (rifts) incorporating late Precambrian materials within the Tasmania region, based on such data. If we consider the materials which are exposed and associated with the western anomaly we see that the rocks of the Burnie and Oonah Formations fall within this zone — and nowhere else. Units such as those of the Success Creek and Crimson Creek Formations and their correlates tend to overlap and be more widespread, typical mature basin sag onlaps. The large tracts of mafic volcanic rocks have similar dispositions. All these materials offer the required property contrasts and imply crustal penetration of the contrasts for up to ten kilometres. There can be no doubt that the margins of this western anomaly represent first-order structures of probable deep rift or trough form. And they have been largely preserved as we should expect — if the roots of the troughs have not been dislocated, and horizontal offsets are at shallow depths with respect to the modern surface.

This is clearly not the case in central Tasmania from the north coast to the Maydena–Adamsfield region. The gravity field shows that similar materials and patterns persist, but they are much disrupted.

The combination of the gravity and magnetic data sets beneath the Derwent valley system and in southern Tasmania shows that elements of the western pattern have been retained. Sequences with similar properties capped by thick mafic accumulations occur in the lower Midlands and south of Huonville to the south coast. These piles are up to 7 km thick with pronounced penetrative margins (figs 10 to 12).

All this information shows that these pre-Lower Cambrian rocks are universal within the Tasmania region and not restricted to a part of western Tasmania. More importantly they accumulated in deep, narrow trenches. The total number of such gape trenches is uncertain pending further work. Stacking during the Devonian orogenies has terminally disrupted and repeated significant elements of the overlapped and more (originally) widespread units (fig. 8). This stacking is important for its ability to repeat critical parts of the sequence — including volcanic piles.

This view of the late Precambrian rocks implies that they formed part of a giant basin many times wider than present-day Tasmania. The parts we now see clearly simply represent the deeper rift axis cores or “pop-ups”, while the onlapped and thinned (relatively) portions are often shuffled into thrust stacks. This makes better sense of the involvement of the Precambrian blocks in all parts of the crustal structure.

Again, one must be careful — about timing. The distribution and styles of the Devonian granitoids show that large parts of the sequence, including apparently very large Precambrian blocks, were still mobile until the late Devonian and earliest Carboniferous. This is the only way to explain the granitoids of the King Island, Rocky Cape and South West regions (Leaman and Richardson, 1992). The same principles apply to the entire north coast region north of Deloraine and Cethana.

We should therefore presume a greater generality for the rocks said to be afflicted by the Penguin Orogeny if that orogeny is taken to affect the Burnie and Oonah Formations. I note that there is a possible conflict in definitions of this event within the literature. If an event occurred at about 700 Ma then it is the Penguin Orogeny. But note that the rocks affected may not then have existed, or been any part of what is now Tasmania, given the allochthoneity which can be demonstrated for most parts of the Precambrian blocks.

If we distinguish between an older and younger Precambrian sequence, with the latter in basin initiation gapes as suggested above, then we must define a new orogeny. I think the Heazlewood Orogeny to be an appropriate name. The time? Late Lower Cambrian. The recently-formed Burnie, Oonah, Success Creek and Crimson Creek Formations were deformed. Given the likely evolution of the gross extensional basin containing this sequence (compare fig. 5) it is probable that the gape fill rocks were more seriously deformed and parts may now show textures and structuring not unlike some of the older rocks that they onlapped.

My Heazlewood event introduced quite large volumes of ultramafic and mafic materials. Berry and Crawford (1988) have proposed broad-scale allochthonous coverage of pre-existing materials. This option cannot be denied but realistic alternative possibilities include emplacement of several slabs of material — as indicated by the amply documented process described by Middleton (1984) (fig. 6). Part of this material may be intrusive and part detached. Evidence for this option is based on the location and distribution of deep or massive accumulations of the material. Even near the largest accumulation, at Heazlewood, there is evidence of the material having been drawn upward and outward along the old deep trough margin for more than 30 kilometres. Gravity and magnetic data imply this (Leaman, 1988a, *d*). At least three other deep centres (N Boco, S Penguin, W Deloraine and possibly SW Bridport) can be identified magnetically in northern Tasmania.

In every other case the ultramafic bodies are now thin but extensive stringers. Magnetic data show these to be ubiquitous and to occur throughout all parts of Tasmania (e.g. fig. 3). Several occur wholly within Precambrian blocks. It is difficult to separate original relationships from younger tectonic re-emplacements during late Cambrian or Devonian events. These bodies extend into the eastern Mathinna Beds and granitoid province and clearly form part of the basement to these materials. This is consistent with the Devonian uplift of such materials, with Precambrian rocks, in thrust blocks moved from the east, as at Beaconsfield.

This type of evidence, in association with the gravity and magnetic maps, shows that the crustal construction of Tasmania is of west Tasmania style — no matter what materials happen to be exposed at surface. There is no evidence for a gross crustal suture (or ‘terrane change’) in the Tamar region. There are other explanations — such as a structural nappe front (below). The concept of a Tamar Lineament is not supported by any crustal data set (see also Wellman, 1989) and the term should be dropped. The largest change in physical character extends from East Devonport to Sorell — within the western ‘terrane’.

Other Cambrian units are also ubiquitous. Mt Read-type volcanic rocks occur on the eastern side of the Tyennan “core” of the island at Golden Valley, the Den and near Hobart. They may be inferred to occur in a belt south to Cynet from Hobart (Leaman, 1990a). In all cases they

appear to occur on a shelf of Precambrian rocks which was either exposed or thinly covered at the time of volcanism. All this really means is that they were deposited in elevated regions, rather than in the trough basins. The associated sedimentation, such as the Dundas Group, is undoubtedly also common, and this was placed in the depressed zones nearby — probably as direct time correlates and facies variants.

If we attempt to recreate the old basin cores then it seems likely that the volcanic accumulations were either quite common and perhaps covered a wide area, or were accumulated near a particular set of old primary margins. In either solution there is a sense of ubiquity. At no stage is there any need for collisions or subduction (see also Middleton, 1984). The Late Cambrian and Ordovician rocks were also clearly general. Shelf deposits covered the entire Tasmania region by the late Ordovician. But why not before? The latest Cambrian sediments prior to the conglomerates may also have done so — as the Success Creek and Crimson Creek Formations may have done long before them. The thick conglomerates imply dramatic events and revitalisation of structures. In every case these occur marginal to the older structures of crustal scale. None of these were listric.

The direct implication of all this is to suggest that the same processes have operated across a large area, involved large volumes of material, and have generated a sequence of extensional environments with short compressional periods of wrench origin caused by slow rotation of the continental mass (with evolving basin) against the extensional stress field.

If we were to consider this as a basin history and viewed it in terms common to petroleum exploration (e.g. fig. 5) we would have no difficulty with its origin, nor with its scale — probably many hundreds of kilometres across. The rocks of Tasmania's late Precambrian to Carboniferous represent a series of basinal developments with symmetrical and asymmetrical extensions punctuated by wrench-based compressions and an ultimate multiple sag phase. The entire environment is one of extension. Even the Permo-Triassic deposition can be seen in this context as a further sag phase before the effects of continental splitting altered the regional environment. The Triassic itself suggests the grand scale of the evolution — far larger than modern Tasmania.

In each of the wrench phases leading to the ultimate compressions of the Devonian orogenies, pre-existing structures have controlled events and the formation of new structures. Thus structures like the Henty and Great Lyell Faults, which are old, may now display a range of conflicting motions or reversals or rotations, and may now no longer be quite in their original positions. This recognition is important for exploration, especially if we seek Cambrian targets some of which may be concealed, dislocated or relocated.

Devonian deformations have been important in two ways; the introduction of large granitoid bodies (especially in the eastern portion of Tasmania which was clearly closer to the axis of later deposition) and re-arrangement of pre-existing structures. Note also that roof effects above or around the plutons may add to the structural complexity if the story is read from the top down.

This entire scenario carries several important implications, and it does not have to be perfect for these to be applicable. The Cambrian key elements will not be readily inferred from surface evidence, as these will be confused by younger

effects and it is probably unlikely that any reliable story will ever be extracted for the rocks older than about 600 Ma due to the extensive rearrangements. The depositional and structural sequence implies a large basin development with important local elements — all determined by previous features. Further, prospective Cambrian materials are not restricted to western Tasmania. They are not now, and never were. We should expect similar histories, correlations, styles and provenances in western Victoria, Antarctica, New Zealand and, perhaps, South America beneath the Andes. Of all these sites the crucial elements are most accessible in modern Tasmania.

The stress field did not change greatly with time. This can be shown from the persistence of sub N-S trends from the late Precambrian structures to the late Devonian granite margin of eastern Tasmania (Leaman and Richardson, 1992). In such an extensional environment in which stresses may have swung no more than 45° either side of north, sub E-W transforms should be common. These are recognisable and also ubiquitous and effective right into the Jurassic. More local stress fields within the rifts of the basins, at early stages, did deviate (see fig. 4). Modern analogues show this to be common. Wrenching and inversion follows such variations.

Within the N-S rifts we might expect, following the wrench phases, some subsidiary rotations of axial trend — within the primary trough axis — and these may be observed. I propose that it is these relationships which account for the common near-NE and NW trends. Deposition and rifting within the Dundas Trough north of Rosebery and south of the basalt cap of northern Tasmania follows application of such wrenching and internal extension. This pattern may be observed across northwestern Tasmania NW of Cradle Mountain, while the conjugate can be observed to the south within the trough — but now largely concealed by the numerous detachments and reversals such as represented by the Rosebery Fault.

Large scale bending of the old trough axis, marginal faulting and volcanic rocks are related to Devonian deformation.

This entire sequence of events fully explains the setting of onset of deposition of conglomerates and features such as the Haulage Unconformity. These are normal components in active basin development.

CLARIFICATION OF PROPOSED CONCEPT

I want to be very clear about what is being proposed.

The basic model or analogue used to explain the various components of the proposed history from the late Proterozoic to the present is well known to petroleum geologists and interpreters of seismic records, although such workers usually limit their interest to the upper and younger parts of such sections. The common denominators of basin evolution can be recognised in structures and deposition back to the Archaean and, with only minor variation — well within the options and local controls applying to any given basin — may be recognised in modern structures.

This model requires no special pleading, complicated tectonic processes or assumptions such as involved in subduction or collisional models. I accept no such assumptions. I do argue that modern oceans date only from the Mesozoic on planet Earth, and that before this waterways and deep seas occupied the axes of subsidence related to basins. The basin model requires tension only — an extensional regime in the long term. Anisotropies and

rotations have induced the wrench and compressional effects evident at many stages. Igneous activity is related to the mantle causes which initiate the tension. Any ultimate expulsion or inversion of the basin is also related to these causes and mantle transformations generated during the extension process. Plutons, nappes and related features are side effects of first order inversions.

This story, in Tasmania, begins with generation of some deep gapes which clearly invite mantle changes (Middleton, 1984) and then mafic volcanism. These gapes appear as subparallel or *en echelon* features at least 100 km long, 25 km wide and 10 km deep (Leaman, 1988a, d). They may have been essentially symmetrical in section and were well filled and probably overlapped by the time of Success Creek Formation and associated deposition and volcanism. The structures were fully covered by the Crimson Creek Formation. This sequence of units represents fill of active troughs, continuing extension to half grabens (style of Baillie and Pickering, 1991), and finally thinner but generous sag fill coverage of a large area. Several breaks in deposition and possibly rotation, erosion and volcanism may be inferred. At least two of these elements are always present in evolving systems of this type when viewed at continental scale. The younger units may not have exceeded 5 km in thickness but the total section may have been more than 15 km near the original gapes. The deep sections will also have become dense, compact, perhaps locally metamorphosed and stressed by events. The entire package will be extremely variable with an array of unit relationships. All normal in a basin.

One could offer Bass Basin as an example at this point. The deep gape, Jurassic in age, is largely filled with mafic volcanic rocks and related products and is then overlapped by a broad spread of half grabens containing Cretaceous and basal Tertiary units with some patchy volcanism. This entire sequence is then covered by a several-stage sag phase Tertiary succession with unconformities, volcanic horizons and erosional breaks. No significant inversion has yet occurred, as the basin remains in tension. The adjacent Gippsland Basin has borne the effects of wrenching and local inversion. Note that the time frame for the Late Precambrian basin development and Bass Basin is similar, about 150 million years. It may be noted that in all such basins — other well documented examples surround Britain — volcanic products may be substantial but spatially and temporally restricted. These relationships and their origin are crucial to our appreciation of Cambrian volcanism in Tasmania (below).

Although this history begins with deep gapes, it is worth considering the rocks which were extended. These were essentially siliceous arenites and lutites initially deformed during the Penguin Orogeny (termination of the sag phase of their basin evolution). What underlies these rocks is unknown but this old sequence, now variably metamorphosed, was at least 5 km thick. These comments imply that the process, which is focused about the Cambrian in this essay, is of long standing.

During or after deposition of the Crimson Creek Formation the now extended and locally very thin crust was wrenched and rearranged. Thermal changes may also have forced uplift, as the basin-crust-mantle proportions would have become very unstable isostatically if we assume an original crustal thickness of only thirty kilometres. I define this as the Heazlewood Orogeny.

The result of the uplift, wrenching(?) and deformation was to reverse many of the listric elements of the structure and emplace slices of the transformed upper mantle. Associated effects would have included uplift and shuffling of blocks of now variably metamorphosed old basement and deep gape fills. The ultramafic rocks of the Lower Cambrian and their probable coverage of large tracts date from this event. Original gape structures or wrench zones will have survived this deformation because of their scale and penetration — as would any older elements of similar type. Uplift, erosion and further extension followed, but these forces were now applied to an homogenised sequence containing an array of materials, metamorphic grades and relationships.

No deep gapes have yet been identified in the third extensional period, and the extension seems to have evolved from the half graben phase. This unstable period, with its variable volcanism localised near particular structural elements, produced the Mt Read Volcanics and its trough-fill associates of the Dundas Trough. In western Tasmania we see only a part of a much larger extensional environment. Similar products occurred across a wide area but the patchy development reflects the frequency and relief of the relative horsts and basement slabs and their association with older, penetrative structures. The style of this period is suggested in Figures 4 and 5.

This regime was catastrophically reversed in early Upper Cambrian (Delamerian) times. The extensional blocks were inverted and the "basement" was reshuffled. The Tyennan core became emergent. The violent activity of the period is marked by the deep, half graben fills of conglomerate (molasse). More extension! The half graben fills reversed the form of earlier structures and many can be linked to older penetrative structures.

Two things should be noted here. Penetrative structures can only be identified with any certainty by crustal geophysics, not surface geological methods. At all stages after the burst of the Lower Cambrian the isostatic balance of the affected crust remained critical and very sensitive to applied stress, loadings, water depth and upper mantle changes.

The major mineralising events are related to this active multiphase extension and volcanism of the extensional period preceding the active inversion of the Late Cambrian. I infer this to mean an appropriately differentiated mantle core beneath the basin and both suitable transmission paths and thermal conditions. This stage and style can be recognised in other basins, and an example from the Ordovician of western Britain is indicated in Figure 5.

After a settling period, further half graben rotation, and more mature deposition, the sag phase of the basin was reached and persisted from the Early Ordovician to the Middle Devonian. At least some of the units of this stage were very widespread shelf-type deposits (e.g. Gordon Limestone). It should be assumed that all younger units were basin wide — perhaps 1000 km. The seaward axis was to the east of "Tasmania" and included at least 4 km of deep, marine, turbiditic facies (flysch).

It was hardly surprising that this giant basin should become unstable along the axis to the east because of the great thickness of sediment and depth of water — especially if the axis were related to older gape and cover fills. Even so, the basin required two major events before termination of this stage.

The first began near the axis and included uplift, inversion, thrusting to the west and serial granitoid intrusion on a major scale. Granitoid compositions are consistent with melts from the inferred "west Tasmania-type basement". This primary event shattered many of the older Precambrian blocks, already disorganised by two previous events, and spread nappes of the axial turbidites towards the western side of the basin. The bounding front of this cover has been termed the Tamar Lineament, even though it really occurs near Devonport, some 50 km west of the River Tamar (fig. 7 and 8). The gross orientations of the plutons and batholith front reveal a persistent east-west extension or stress field throughout this process (fig. 2).

Thirty million years later this process infected the zones lateral to the old basin axis, now inverted. This was a region now patchily exposed across most of Tasmania. Relatively minor plutons were emplaced and various marginal elements of the original basin were overthrust to the east. The Rocky Cape and Cape Sorell blocks are of this type (Leaman, 1986; 1988b; 1990b). Each carried its basin cover eastward. The now disparate older basement and evolved younger rocks were finally pinned together by the isolated plutons of western Tasmania (Leaman and Richardson, 1989a; 1992). Every one of these bodies intrudes Precambrian (or pre-Heazlewood Orogeny) rocks which must therefore have been mobile and active elements of the inversion. Some deformation must also have been localised around these plutons. Each of these Late Devonian to Early Carboniferous events may have been related to developments further north in the Lachlan Fold Belt.

The eastward motions of many blocks now in western Tasmania and granitoid emplacement has transformed elements of many old margins and penetrative structures — including the Arthur Lineament. Only parts of the transformed zone are exposed. Some are covered by the overthrust Rocky Cape Block (Leaman, 1992). The history of this margin is not as auspicious for base metal deposits, as it was less involved in the Middle Cambrian volcanic events and extension. The gold near the lineament may well, however, be related to the older ultramafic insertions along the lineament. Widespread copper occurrences are the challenging anomaly in the Rocky Cape Zone. Near Balfour I have linked these to distillation from overthrust mafic volcanic rocks of the Smithton Trough by Devonian granites (Leaman, 1988c). But is this a general solution?

The Devonian–Carboniferous events produced the fourth or fifth (depending on how these are counted) significant deformations of the deeper or oldest sequences. The result was renewed homogenisation, uplift and erosion. But the ruling extensional control was little affected.

Insufficient work has been done to assess Lower Permian formations but these may have been deposited in etched structures reflecting older features, or to have filled half grabens of low relief. But, by the Upper Permian, a broad sag phase is recognisable. This continued sagging resulted in at least 2.5 km of sedimentation by the early Jurassic. The ultimate axis of this sagging is no longer recognisable but the sedimentation was widespread and extended into Antarctica. Its spread is almost certainly of similar scale to the mid Devonian deposition.

The developed crustal history of the basin essayed here doubtless laid the foundations for the Jurassic volcanism, mantle upwelling and continental separations to follow. A completely new cycle appears to have begun during the early

Jurassic with the formation of deep, very narrow and isolated grabens. These were intruded by dolerite and predate the intrusions (Leaman, 1975). The feeders and grabens are not randomly located, as concealed major structures can be identified wherever appropriate analysis has been completed (e.g. Leaman, 1990a, fig. 12). Recent reprocessing of Fingal Tier gravity data has also revealed that established dolerite feeders lie on a continuation of the Mathinna–Alberton gold-bearing structure (R. G. Richardson, pers. comm.).

This sequence of events and evolved relationships accounts for the large scale of all events and sequences to this point — when the original gape in the Bass Basin began to form, and the elements of Gondwanaland decided upon divorce. These developments resulted in a multi-component extension (still extension!), rotation of some blocks and relative application of the stresses, and sympathetic uplift with further erosion in Tasmania. The uplift produced our modern fault mountains with a relief of about two kilometres. Some older structures, such as the thrust fronts near the Tamar and the Western Tiers, pulled apart; others deformed into new half grabens imposed on the older and narrower Jurassic gapes. This entire process from the Cretaceous is an exact re-run, with volcanism, of events which had occurred at least twice before. Gapes, asymmetric basins, onlaps and transforms.

The post-Cretaceous basins and developments are of interest in that they show where and how the volcanic rocks occur or are preserved. No mineralisation is associated and the products are very limited in compositional range. These young sequences do show how volcanic rocks and related products can be widespread and patchily preserved in times of depositional hiatus. Vents are associated with deep, concealed, penetrative older structures. Is there a lesson here for our Cambrian searches?

While common denominators and subtle, inherited variations may be recognised throughout this proposed history, only one active period is distinct. The conditions and, perhaps, compositional evolution of the Earth have never been repeated. The period is the Middle Cambrian.

RESOLUTION OF SOME ENIGMAS

Some of Corbett's (1989) enigmas may now be dissolved.

The Penguin Orogeny has been confused. The late Precambrian rocks must be built into the sequence with an early Cambrian deformation. They are a deep gape rift sequence leading to a quiet phase prior to wrenching. This was a violent event and introduced ultramafic materials in its culmination. Events prior to 700 Ma, including the Penguin Orogeny, cannot now be readily discerned but are preserved in the variably metamorphosed remnants of oldest Precambrian rocks.

This pattern of events, with Devonian thrusting, can account for the similarities between the rocks of the Smithton Trough, within the Rocky Cape Block, and the rocks of the Arthur Lineament at least partly beneath it. The marginal deformations, additional stress and contrast with less deformed and probably thinner parts of the sequence from elsewhere complete the picture.

The apparent trough shapes, as seen today, are largely irrelevant due to the highly compressed and distorted slicing which took place during the latest Cambrian and Devonian. The bending of the northern zone near Cradle Mountain is

an artifact of these developments and sequence overlapping or ramping. Any significance previously ascribed on the basis of west Tasmanian relationships dissolves when it is realised that these are not unique.

There is no special significance to the Precambrian blocks around the perimeter of the northern coastal region. These simply reflect the jumble of facing thrust stacks generated up to the late Devonian, and the effect of transforms offsetting earlier rift axes. Each of these Precambrian blocks is allochthonous and overlies parts of the late Precambrian to late Ordovician sequence. (This has important ramifications for Tasmanian petroleum exploration because the Gordon Limestone is a proven source for oil seepages and many apparent seeps occur in Precambrian exposures). More complete outlines of thrust patterns have been given by Leaman (1986, 1990c, 1992) — including their role in the Zeehan area — as well as many, presently confidential, company reports which also show that the Mt Read Volcanics have been caught up in some structures. Figures 8, 9 and 14 suggest some general relationships.

Concepts of rift-ocean-arc settings based on local relationships and geochemical indicators are not well founded nor necessary if a continental and large basin scale is applied. The west Tasmanian region represents only a fragment of such a basin and pieces within it cannot therefore be considered exotic without considering a total assembly. Conflicts on the basis of such implications are non-existent. Classical relationships, including correlations, provenance, and onlaps, are more diagnostic than trace chemical indicators for which many assumptions must be linked and which cannot be properly controlled for an evolving mantle.

The apparent narrowness of the Mt Read volcanic arc is also an illusion, since the environment may have been very much larger and is now structurally sliced, heaped and repeated. In either case the 'arc' appears much more like other analogues (such as the Andes). Other occurrences will occur in similar zones within the basin and may be expected (e.g. Western Tiers, Glenorchy).

Differentials exist in the nature and grade of regional metamorphism within most units older than Middle Cambrian. In the case of the Precambrian rocks it is possible to imply (as did Turner, 1989) that local history and stresses may account for the differences, even when applied to similar lithologies. This would be quite consistent with a uniform, extended basement now locally stressed and evolved and thrust diapiroically into and across the orogen created from the original basin developed (also fig. 6).

There is no doubt that many details remain to be worked out but I believe this style of evolved basin evolution is consistent with known relationships and demonstrable basin styles of other ages or locations. Tasmania remained within the evolving basin zone throughout a long period but was ultimately located near the active axis. The massive scale of the eastern batholiths shows that the final and largest movements occurred east of present day Tasmania, and that the aftershocks occurred in what is now western Tasmania. This is reflected by the ages of the granitoids, with the youngest being in western Tasmania.

Structures and boundaries have persistently evolved and been rejuvenated. It will not be possible to understand the oldest controls until superimposed elements have been unscrambled. Only fundamental crustal lineaments can remain recognisable.

SITING OF MINERALISATION

What are the implications for exploration of such an evolved history? In a word, encouraging. In another, complex. It means that the entire State is prospective for Cambrian mineralisation providing the complicating issues of structural confusion and concealment of various types are treated. Fortunately these problems can be recognised and resolved. The only debit will be that in some areas the target rocks have either been removed at some stage, or are now too deep for mining. These are normal risks in any province.

We have to seek the large and penetrative structures. These will be the elements of the rifts which passed into or carried wrench motions, or which were steep and not listric, or which were reactivated and perhaps reversed and transformed into penetrative structures. Transforms within the rift system form the second class.

If we are seeking sites with Cambrian mineralisation then we need to find those sites in which the above fracture types were active at the appropriate time and, most crucially, were held in tension for a long period. Known mineral deposits do not occur continuously along any fracture system; there must be nodal or special local conditions. The intersections of primary rift and transform faults can provide such conditions since the first provides half of a tensional environment and the second, by acting as an effective shear within the rift environment, but normal to it, can maintain and amplify the local extension to create gape sites (fig. 15).

Such sites are required if we are to achieve the fluid flows normally considered to be required for deposition of a large ore body. These properties are also consistent with sites in modern volcanic areas in which there are high rates of passage and deposition. Note that deposition occurs in the fracture system and may close it very rapidly unless it can be held in tension and continuously re-opened.

We should also expect to find these sites using geological induction. There should be greater alteration, a range of anomalous deposits, and probably more intrusive rocks than normal. Or, at least, a wider range of local compositions in volcanic rocks. This is consistent with vent conditions.

Other, more universal, indicators are described below. Preservation of deposit, however, may depend on some stagnation in order to concentrate it (and not disperse it either in solution or sediment) coupled with active but periodic venting.

Can any of these patterns or indicators be recognised at Mt Lyell, Hercules, Rosebery, Que River or Hellyer? Indeed.

All lie within about 2 km of a demonstrable Middle Cambrian rift marginal fault (defined crustally). Any offset between its ancient, or crustal, location and modern surface position is due to subsequent reversals and displacements. Thus the proto-Henty Fault now underlies the Jack Fault directly at Hellyer. The position of the modern Henty Fault is irrelevant in terms of Cambrian targets. Henty Gold Prospect is a special case in which old and new overlap with a corner of a Devonian granite pluton.

Rosebery and Hercules are more complicated, and confidentiality forbids further discussion here.

All are associated with variable vent volcanism AND intrusion which are locally distinctive. This demonstrates

active venting. All lie on 80° transforms — as preserved in both deep crust or in local detached blocks elsewhere. Even the Devonian granitoids of western Tasmania were largely controlled by these structures. All are also associated with shale and fine-grained rocks. This suggests a slower, stagnant environment which avoids dispersal. Many can also be linked to erosional breaks in volcanic sequences. The Rosebery transform was first identified by Leaman (1986). The likely effective rift line lay to the east of Rosebery where it is possible to project an extension of the proto-Lyell Fault. The Mt Read and Mt Black volcanic piles now lie beside and astride (due to reverse flower motions) this structure.

The evolved nature of the transforms and their control of later structures is very evident in the Lyell region.

This view of western Tasmania is only possible with the combined use of crustal geophysical data sets (gravity and magnetics) and a coherent geological integration at surface. Use of any one set, such as geological — as has been the case until recently, cannot resolve the many issues involved. Nor can any other techniques for shallow penetration or low lateral resolution. This excludes use of most electrical methods due to resolution (mainly) or cost factors.

The gold deposits of northeast Tasmania may, like those near the Arthur Lineament in the west, be related to granitoid intrusion in, or partial remelting of, western Tasmanian (pre-Heazlewood) sequences including at least one large and several smaller pieces of ultramafic rocks. The general distribution of pre-Middle Cambrian materials, as described here, and the magmatic and structural history implied for various regions, indicate a greater base metal and gold potential than previously believed. See also the Little Den Goldfield discussion below. Gold potential in eastern Tasmania may be comparable to central Victoria and for the same reasons proposed there.

THE KEYS

It is now clear just what the keys are. But we need to express them fully in classical geological terms. Within the deep crust the key sites are long-lived zones of extensive fracturing held open by applied and active tensions related to the system providing the host sites.

The geological indicators of such sites include:

- the rift margin or primary rift faults
- fault history data to prove that the structure was active (in terms of being a magma path, or changes in deposition — facies or thickness)
- unconformity relationships to establish activity before, during or after formation of host sequence
- a steadying of deposition or erosion at the key time
- transverse or transform fracture systems
- a range of intrusive and extrusive compositions, or vent complex, to establish source location foci
- review of evolved structure to verify existence of crustal scale changes at depth
- lineament patterns, or fracture frequency determinations, may also assist but care must be taken to ensure

consistency with data sets of crustal value, as sliced blocks may be misleading.

It should also be noted that many of these elements may be preserved WITHIN a large allochthonous slice and many of the characteristics may imply a target. This possibility inevitably means, in a region with Cambrian sequences as disrupted as in Tasmania, that a number of apparent key sites will lack the bulk of any mineralisation deposited. It may then be necessary to review the home site by unravelling the slices or avoid those sites which lack any of the primary criteria. Note that displacement will offset crustal and intra-slice structures.

Further, these criteria will apply to the entirety of Tasmania not intruded by granitoid plutons irrespective of the nature of present cover, whether Tertiary basalt as in northwest Tasmania, Permian-Jurassic as in central and southern Tasmania, or Mathinna Beds in eastern Tasmania. A corollary of the latter is that the Devonian gold of the vein deposits of NE Tasmania may have been derived from the Cambrian rocks which underlie the region at modest to mid-crustal depths (above).

FINDING THE KEYS

The above discussion describes a very complex geological picture which can easily disguise some very large golden eggs. So how might we find these rich targets? We can judge the potential richness on the basis of the few sites we know about. Sites which can be mined, and expand in reserves, for up to a century and which contain an array of metals.

It is not the purpose of this paper to spell out in detail how this can be done, but Leaman (1990a) provides a detailed example for southeast Tasmania.

The southeast Tasmania example allows appraisal of the implications and methodology — and the key criteria — free of the presumptions which abound in the (presumed) better-known western Tasmania where all the materials crop out. It is because they crop out, and the forest cannot be seen for the trees, that problems have arisen. It is simply too easy to focus on the very local or very detailed issues and lose the sense of scale required. Large ore bodies imply large controlling structures.

The fragmental preservation of all elements of sequence and structure, without clear correlative controls due to paucity of mappable units or fossils, and the abutment by structural inversion or dislocation of disparate elements of the evolved basins, also tends to blind purely geological methods.

The keys cannot be found without the use of geophysical methods with high lateral resolution and crustal range capacity. Only two methods are cost effective in Tasmanian conditions — gravity and magnetics. Magnetotellurics or seismic reflection may assist, or be useful elsewhere, but the former lacks much lateral resolution and is far from easy to evaluate, and the latter can be blinded by the broken nature of the section and high velocity capping materials.

The recommended methods cannot themselves be used in isolation but the gravity method can define gross structure and scale while the magnetic method can define patterns, suggest the nature of dislocations, and provide selective support to the gravity method. Each technique can only be appraised in terms of evolved or impressed structural indications to identify the critical structures.

The magnetic method derives much of its usefulness, in Tasmanian conditions, from the fact that there are so few strong magnetic sources. These strong sources include the Crimson Creek Formation and its correlates, the ultramafic (not mafic) rocks, the Cambrian granitoids, the Jurassic dolerite and the Tertiary basalts. The effects due to the latter two sources are readily discriminated upon analysis. The combined effect of the first two is to provide an effective magnetic basement which marks the end of the first Cambrian deformation (Heazlewood). Disruption of this time marker is reflected by the distribution of anomalies which are largely produced by the rocks at or below it. Thus the rifts and troughs of the Middle Cambrian can be clearly defined as NE-SW and E-W gaps within a gross N-S frame.

This coupling of structural scale, provided by the gravity data, and the post-Lower Cambrian dislocation information in so far as it affects Cambrian rocks, as provided by the magnetic data, goes far towards defining the required keys.

Figures 10 to 12 provide an extract of the geological evaluation of southeast Tasmania (from Leaman, 1990a). This shows how the geophysical data base was used, with minor support from various geological observations, to generate a view of the upper crust and its contents. The analysis was able to demonstrate continuity between mafic suites exposed from the south coast towards the Weld River and Adamsfield; the inclusion of an ultramafic-bearing zone; differentiation between basement types; and distinction between rocks comparable to the Mt Read Volcanics (drilled at Glenorchy) and the mafic or thick underlying sequences comparable to the Oonah Formation and Mainwaring Group of western Tasmania.

The scale of the sections is comparable with those known in western Tasmania. Although the gravity and magnetic models hint at dislocated Precambrian blocks, the limited seismic data available confirms a major change in the Bruny Island–Storm Bay region at about 3 km depth and that a strongly stratified section occurs at depth beneath the homogeneous (seismically) Precambrian units. In every respect this pattern is similar to those which can be inferred at Beaconsfield or Rocky Cape (Leaman *et al.*, 1973; Leaman, 1990b; see also figs 7, 8).

The primary trend patterns can be directly associated with modern drainage and terrain features, even though there are few recent (post Carboniferous) faults with these orientations. There are many older structures with the required trends and it is clear that many of these are impressed, in modified or subtle ways, on subsequent units or developments. These quantitative methods, incorporating comprehensive array modelling, are able to indicate general rock distribution and relationships beneath the cover of post-Carboniferous rocks.

If we consider the setting of the well-known gold deposits at Cygnet we find a number of interesting features. Although some gold was mined *in situ*, most gold recovered has been alluvial. The gold has been associated with the Cretaceous alkaline rock suite (dykes, small sills) but most gold is found in the calcareous country rocks about the dykes. These igneous rocks are not chalcophile and yet sulphides are abundant in some areas. Up to 1% Pb is known in some samples. Names such as Copper Alley are very suggestive.

What is the source of this mineralisation?

It is clear that the alkaline rocks are not sources but may be temporary carriers (R. J. Ford, pers. comm.). The gold mineralisation, while concentrated south of Cygnet, is not tightly restricted and occurs in three zones which fan from the head of Port Cygnet. The sulphides occur in a more limited zone, at higher grades, south of Cygnet. This area contains some of the larger alkaline bodies and a probable dolerite feeder. Pyrrhotite is very common in this zone. Review of Figure 12 will show that the location of the Cygnet mineralisation is almost directly above the eastern margin of the southern trough, which is an important and dominant feature. Dolerite has intruded this structure just east of Cygnet — probably its original position — and the alkaline bodies have also occupied a similar site, bowing the materials above a laccolithic mass.

Although the thickness of the basal Permian tillite is not known it is unlikely to exceed a few hundred metres. Both dolerite and syenites have parted and intruded near the unconformity. If these intrusive rocks have occupied a zone previously mineralised then either may have removed part of the ore. Chemical transfer occurred at the first feasible hosts — carbonates of the Lower Permian. I believe we should take such sites seriously as flags of hidden mineralisation. Two further examples are given below but each is associated with the nominal criteria defined above for key sites. The older rocks at Cygnet clearly occupy a key site.

Although the depth of any mineralisation could be as much as 5 km below surface, given the structure, it seems likely that any target lies just below the Permian unconformity or any thin Ordovician cover on the Cambrian rocks where the intrusives have been stepped or edged. Note that the Cambrian materials are an extension of the altered acid-intermediate suite found at Glenorchy. Major sub E-W trends are also visible in gravity data in the southern part of Port Cygnet (fig. 1). This means that all the criteria for finding key sites are represented here, together with definite evidence of mineralisation. Figure 12 also shows an asymmetry in second-stage basins, with the key margin near Port Cygnet. The margin as interpreted (for petroleum purposes) is kinked or stepped near Port Cygnet and this effect is restricted to the second stage (Cambrian) basin. Masked sub E-W (WNW to south–ENE to north) features bound Port Cygnet. Further refinement of the interpretation is possible.

Several sites have been reported throughout central and southern Tasmania in which gold or sulphides are present. Most of these observations date from the turn of the century when many sought gold and were unaware that they should not expect to find it in the post-Carboniferous cover. In each case sulphides, usually pyrite, are present in abundance and are often in Jurassic dolerite — near contacts and near a feeder system. Do such sites, which often lack gold, actually mark a naturally drilled ore or mineralised system? We should not immediately start laughing when a farmer tells us of the sulphides on his property when little more than dolerite or Triassic sandstone are present.

One such site at Neika, west of Hobart, is known to be within a dolerite feeder. This is a particularly interesting site. Figure 13 presents a structural diagram for this part of the Hobart area. No rocks older than Lower–Middle Permian are exposed. Attention may be drawn to the location and orientation of Tertiary structures, Jurassic dolerite discordant sheet limbs and feeders, and Tertiary basalt centres. Post-Permian faulting is also focused and there are major offsets and transfers of motion from the Cascades to the Fern

Tree area. Jurassic and Tertiary motions have been reversed and offset in this zone, and the Tertiary structures are hinged in the same region. A monocline within the Permian rocks is also offset. The monocline directly overlies the primary change in basement structure noted above at Cygnet, and is shown in Figures 12 and 13. The Glenorchy bore hole, with its Cambrian extrusive rocks, lies immediately below or to the east. The folding is almost certainly a rejuvenation of this much older structure. There is a correspondence of association with many sites in western Tasmania.

If the fault and intrusive patterns are examined it will be seen that these align within a narrow corridor not more than 1.5 km wide which is oriented a little north of east. Regional data show that this extends eastward to Dunalley and Marion Bay on the east coast of Tasmania. Dolerite feeder systems are offset along the corridor, yet there is no direct evidence of shear motions in any exposed rocks. There is only one conclusion possible. A zone of structural weakness, subsequently intruded by the dolerite, was offset prior to deposition of the cover. This structure has clearly affected the Cambrian basin developments from the time of the Crimson Creek/Mainwaring Group equivalents, was almost certainly active during later volcanism, and could easily have carried mineralisation near the intersection with the primary N-S structures near Neika. It is, therefore, conceivable that the dolerite feeder, occupying the same weakness, could have ripped away part of any such mineralisation. A part of it was frozen into the intrusion. Such a site satisfies all the criteria for a key site — beneath the Permian cover. Note that in both cases the cover, or cover content, is irrelevant. It is possible to make direct inferences through it by careful use of geophysical data or by examination of the implications of evolved younger structures and landforms. In the Neika and Cygnet cases the focus is a little blurred, but in each case the target has already been defined — without any detailed analysis (feasible with extant data) — within an area little more than one kilometre square.

This method of accepting all clues, unwrapping or unscrambling young structural implications, and combining crustal geophysical implications can be extended to the small fragments of exposed Cambrian(?) rocks known to carry gold near Connorville. Figure 14 presents a fragment of a regional structural study of the pre-Permian rocks, coupled with a surface geological map. The reason why the streams present the orientations observed becomes immediately apparent — as does the cause of the offset in the alignment of the terrain and local small faults. Gold-bearing veins in the region also lie near this intersection of shears, which can be shown to extend great distances. These are crustal features. ENE elements dominate the vein system.

It may be argued, in view of the stacked nature of the concealed structuring (fig. 8), that such relationships should not be apparent. Much may depend here on whether the gold is Cambrian or Devonian in age. We may infer Devonian as it can be shown that the offset pattern of the Ben Lomond Granite (figs 1, 2), which is the youngest of all the eastern plutons, is 'offset' by the same regional trend.

The Little Den Goldfield example illustrates the use of evolved structures to infer and approximately locate large concealed structures and controls, but also to separate the issue of which age of involvement is predominant at the site (fig. 14). This area also illustrates the effect of pull apart (compare fig. 8).

The coupling of these principles and criteria will work in western Tasmania and one example is offered; Hellyer.

Regional geophysical data suggest that the Hellyer site is located close to the margin of a Cambrian trough. We may call this the 'Proto Henty Fault' and it is several kilometres west of the present position of the fault. The Jack Fault represents a rejuvenation of this structure and overlies it at a very acute angle. These structures are intersected by an 80° degree transform defined in gravity and magnetic data sets — at Hellyer. We may say that the site is selected, within the regional resolution of the data sets, as an area of about a square kilometre. If we then examine the nature of the volcanics, and intrusive rocks, in the area, and changes in thickness of other units consistent with active margins, then the site fulfills all criteria. Note that the geological factors alone are quite inadequate to provide target focus, as these cannot "see" the big features and fundamental controls.

This broader approach is essential in other parts of western Tasmania where structural complexity has disrupted the section so much that it is rarely possible to confirm or deny changes in rock compositions or patterns, or demonstrate the localisation of any major thickness changes. The gravity data set is not so blinded and this information is retained — it sees the big picture, deep in the crust.

CAMBRIAN POTENTIAL

It is clear from the foregoing discussion that the already well-established potential of the Cambrian rocks of western Tasmania represents only the tip of an iceberg. Other sites, concealed or not yet evaluated, must exist. Many transform structures were inferred by Leaman (1986, 1987) and the rift structures extend for more than 100 kilometres (exposed).

This essay, however, suggests that this environment — or more strictly fragments of it — extend far more widely and that the entire State has potential for these styles of mineralisation.

Many may argue that away from western Tasmania the potential targets are too deeply buried. This remains to be seen. It should be noted that the Mt Read correlates (?) at Glenorchy were at a depth of only 600 m, and that depths of this range are now routinely drilled in western Tasmania. Not only may target depths be less in some areas of central Tasmania but may be much more in western Tasmania where thrust slices have repeated parts of the sequence. This is a trap few have yet allowed for.

Potential exists for an array of possibilities. All require the usual exploration cautions and specification parameters of grade, depth and region or risk.

DEVONIAN OVERPRINTS

Devonian tectonic and igneous events have been superimposed on all previous effects. Consideration of just what these events might have been indicates that we should expect several results. The granitoids of Tasmania were not intruded as a single event, rather as two separate sequences with a time differential of about 30 Ma. We would expect to see a variety of developed structural changes associated with this process and a range of rejuvenations, compressions near the roof-wall elbows, and extensions in the roof. All of this will be overprinted upon the regional compressive or shearing events. If the granitoids have occupied two time

frames then it is also likely that such events will occupy similar time frames.

This sequence may well account for the intra-deformational nature of many quartz veins and the cross over or opposing thrust stacks identified in W and NW Tasmania by Leaman (1986, 1988*b*, 1988*c*). Many granites follow the 80° trend and may show passive or fracture punch emplacement.

This complex history has two negative effects and two positive results. The positive results are simply the remobilisation of some pre-existing mineralisation, and perhaps economic accumulation as well as the primary emplacement of large amounts of gold, tin, tungsten and perhaps lead-zinc. The negative effects are the possible remobilisation of large Cambrian deposits and redeposition in less attractive forms; a situation which must be discriminated if it occurs in Cambrian rocks which have been extensively intruded in all parts of Tasmania, or a total rewriting of structural surfaces and styles. The latter effect is the most destructive for geological and exploration analysis as it leaves the observer with only the most recent and often ambiguous view of the structures and the forces at work.

The superimposition problem has been alluded to many times above. It is very difficult to remove Devonian–Carboniferous effects from a structural analysis when the rocks are examined at outcrop scale. Some of the conflicts possible can be illustrated by listing some of the recognised shear patterns in western Tasmania north of Queenstown to Bass Strait. This incomplete list includes recognition of shears at about 40°, 80°, 290–300° and 325°. It may be argued that the 40° and 290° set are dextral and sinistral respectively on the basis of outcrop observation (D. Selley, pers. comm.). However, if we consider the structures in regional terms, based say on magnetic patterns or gravity shifts of margins — large scale effects, we find that the 40° set may not always be dextral, that the 300° or 325° features may be either sinistral or dextral, as may the 80° structures. The latter appear to be usually dextral.

It may be admitted that small-scale judgments may be clouded by the most recent motions and that large-scale judgments may be rendered uncertain due to feature correlation problems. The point to be made, however, is that great care and all data sources must be considered if a realistic structural sequence is to be deduced; especially if the conditions pertinent to Cambrian key sites are the focus of interest. What we see today, by looking closely, is not especially or immediately of benefit in determining this (fig. 15).

It is for all these reasons that the presence of post-Permian cover may sometimes be an asset. We cannot be misled by the most recent structuring, and the methods which must be used tend to focus on the largest elements of the concealed structure. And it is these which are relevant to exploration of Cambrian sites. The examples above illustrate this for central and southern Tasmania; but the principles apply even when we believe we can understand or decode the exposed sequences in western Tasmania.

CLUES FROM TODAY

The case histories provided for central and southern Tasmania illustrate the persistence and inheritance of many structural controls — regardless of their concealment by thrust stacks or more recent sedimentation. Subtle fracture regimes from zones of fundamental weakness continue to be

expressed — even if no direct and obvious faulting occurs — such that modern drainage and coastal patterns can still reflect these trends. This also means that trend or lineament analysis may also yield useful information.

Where such analysis involves use of geophysical data, with some potential for deep probing, care must be taken to assess the likely depth range or depth of the sourcing effects, as it is possible to recognise, in magnetic data for example, alteration effects which appear marked but which are restricted to only one slice of the structure. The fundamental and original position of the feature may be elsewhere; the Devonian shifts strike again! This relationship, or the possibility of resolving it, will only be recognised geophysically in most cases because normal geological methods are blinded by surface issues (fig. 15).

Other useful clues may be provided by direct indicators of mineralisation or mineralising processes. Thus surface identification of alteration, magnetic inference of the altered volumes (e.g. Leaman, 1987), or the suggestion of the presence of sulphides — even if in rocks which are neither carriers nor hosts — provide important clues. Much modern exploration has already been based on the first of these three approaches but it, in isolation, lacks the discrimination offered by the second in terms of true scale. While the second is viable in all conditions, the first can only be used in parts of western Tasmania where the target rocks are actually exposed.

If it is good enough to use the content of conglomerates or breccias as an indicator of local sources during deposition or wall rocks to magma passage, then the record of abnormal materials in other rocks should also be taken seriously, even if we do not know precisely how they were carried or survived the journey. We should be grateful for these flukes of geological history and treat the neighbourhood of the occurrences of sulphide concentrations as potential targets. If these fall into regionally credible sites in terms of the concealed rocks, then the only unknown is depth of target. If we consider what we do know about the relationships in western Tasmania then we may infer that the mineralised sequence is not near the base of any large trough structure; it will lie high in the sequence or on the marginal lip. I infer that most of these oddities have been derived from sites at or near the covering Permian unconformity, where the intrusive energy is transformed from vertical to sub-horizontal motion (dolerite) (Leaman, 1975) and where various phase changes may also be emphasised due to approach to the surface (depth range of 1 to 3 km maximum).

What these relatively rare sites in central Tasmania prove, however, is the general possibility of extensive and interesting mineral terranes across the entirety of Tasmania.

The thickness of cover would appear to present various types of obstacle to exploration and development of this potential. Four types of cover sequence may be defined in terms of Cambrian targets: Tertiary basalt; Permo-Triassic sedimentation with Jurassic dolerite; Mathinna Beds; and Precambrian rocks. There may also be patches of Ordovician to Devonian cover but these appear thin and patchy on present information and analysis. The presence of the third and fourth classes is likely to preclude any economic development because of the thickness of the overthrust slabs. The first and second rarely exceed 300 or 1500 m respectively, and may be rendered transparent with appropriate methods (Leaman, 1986; 1990*a*; Bendall *et al.*, 1991). The thickness of the second class is also misleading,

as it is commonly much less than 600 to 1000 metres. Evaluation of those regions in which the cover is less than, say, 500 m, where key structures may be inferred, is a high priority in terms of general research and exploration.

CONCLUSION

The Cambrian rocks of Tasmania must be seen as part of a much larger province and to have had a relatively normal basin development. The depositional environment over a very long period was extensional with wrench-related compressive punctuations. Mineralisation and volcanism in this setting have been related to certain of the rift and transform faults which produced generally orthogonal control patterns at critical or key sites. Marked activity on these structures had ceased by the latest Cambrian, and most acid volcanism is related to a period in which basin development was very advanced, and deep.

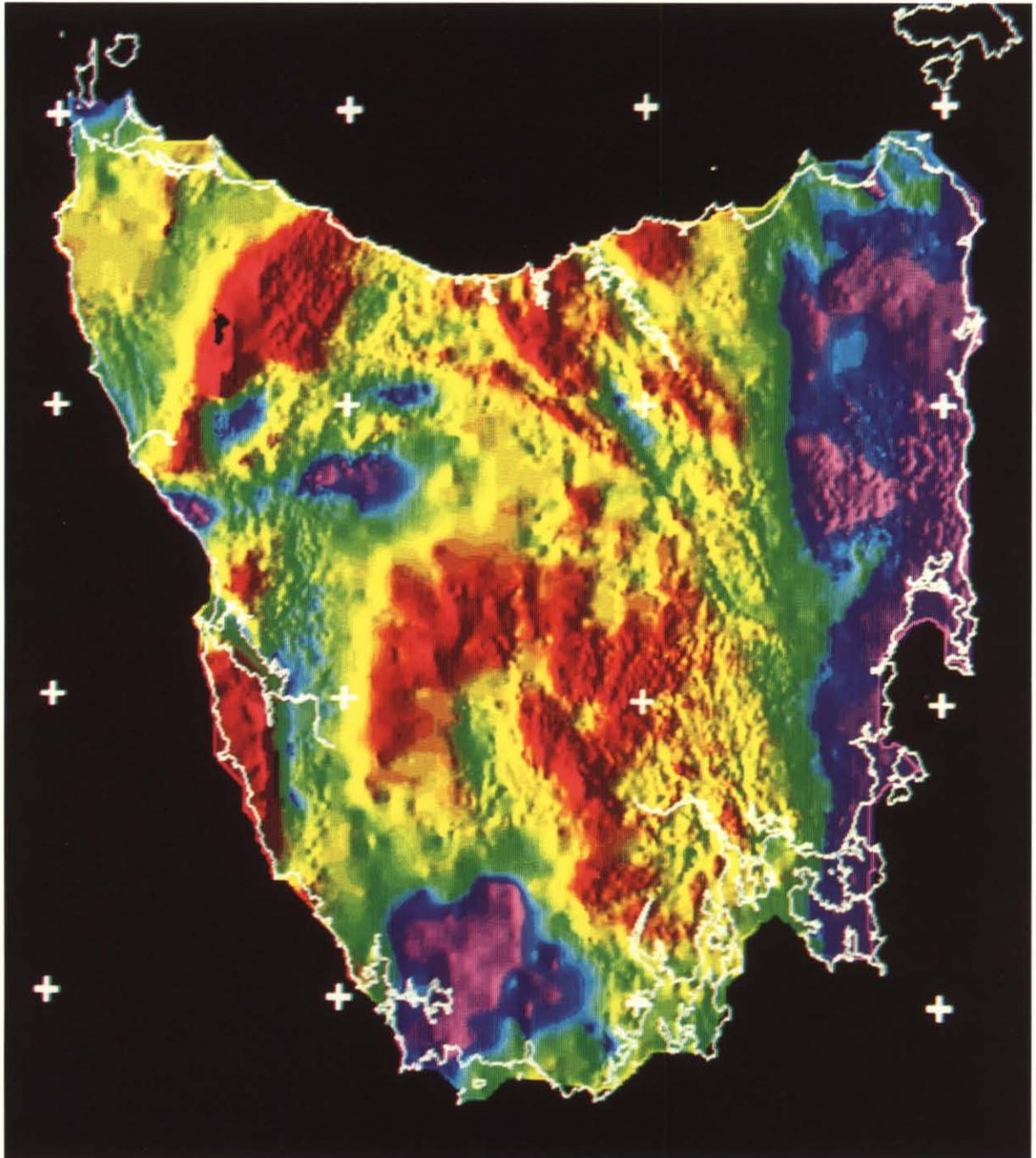
Had these structures been peripheral to the basin or the ultimate application of granitoids and primary compressions upon uplift, we should have little difficulty conceiving the key sites, or perhaps, finding them. We might have an "Irish" situation in terms of structural simplicity, if not precise style. Unfortunately, the massive uplift forces were applied directly to the Tasmania region — which clearly lay near the basin axis at the crucial time. This has led to major structural rearrangements, confusion in correlation, multiple stacking of parts of the section, and intrusion of large granitoids. Appraisal of this chaos has not been helped by the broad-scale post-Carboniferous cover.

The apparent down side of this evolution, which has made things very difficult to decode structurally due to dominance of the latest effects, is that the appraisal and exploration of Cambrian rocks and the critical sites within them is no longer simple. The up side falls in several classes which outweigh the down side views. Firstly, the Devonian activity introduced much mineral potential of its own. Secondly, the Cambrian province is much larger than previously thought, and even in western Tasmania where the rocks are exposed there is greater potential than would appear from any sighting of a geological map. Thirdly, it is possible to infer the approximate positions of key sites regardless of cover or structural conditions which have concealed or complicated many regions.

It is possible to conceive an area-exploration scale graduated in terms of cover thickness, content, risk and potential which encompasses the entire island. I am not sure that western Tasmania would rank as the long-term optimum zone for investment on this scale. We may conclude from this that if Tasmania is already a world class Cambrian base-metal province based on the visible materials which form only a fraction of what is actually present, then this island SHOULD have a long and prosperous future given the indications of current work.

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5 cm

Figure 1.
(D. E. LEAMAN — *Finding Cambrian keys*)

Residual Bouguer Anomaly map of Tasmania. Based on Mantle 91 model method (Leaman and Richardson, 1989*b*). Bouguer density 2.67 t/m^3 .
(Image courtesy M. Roach, CODES).

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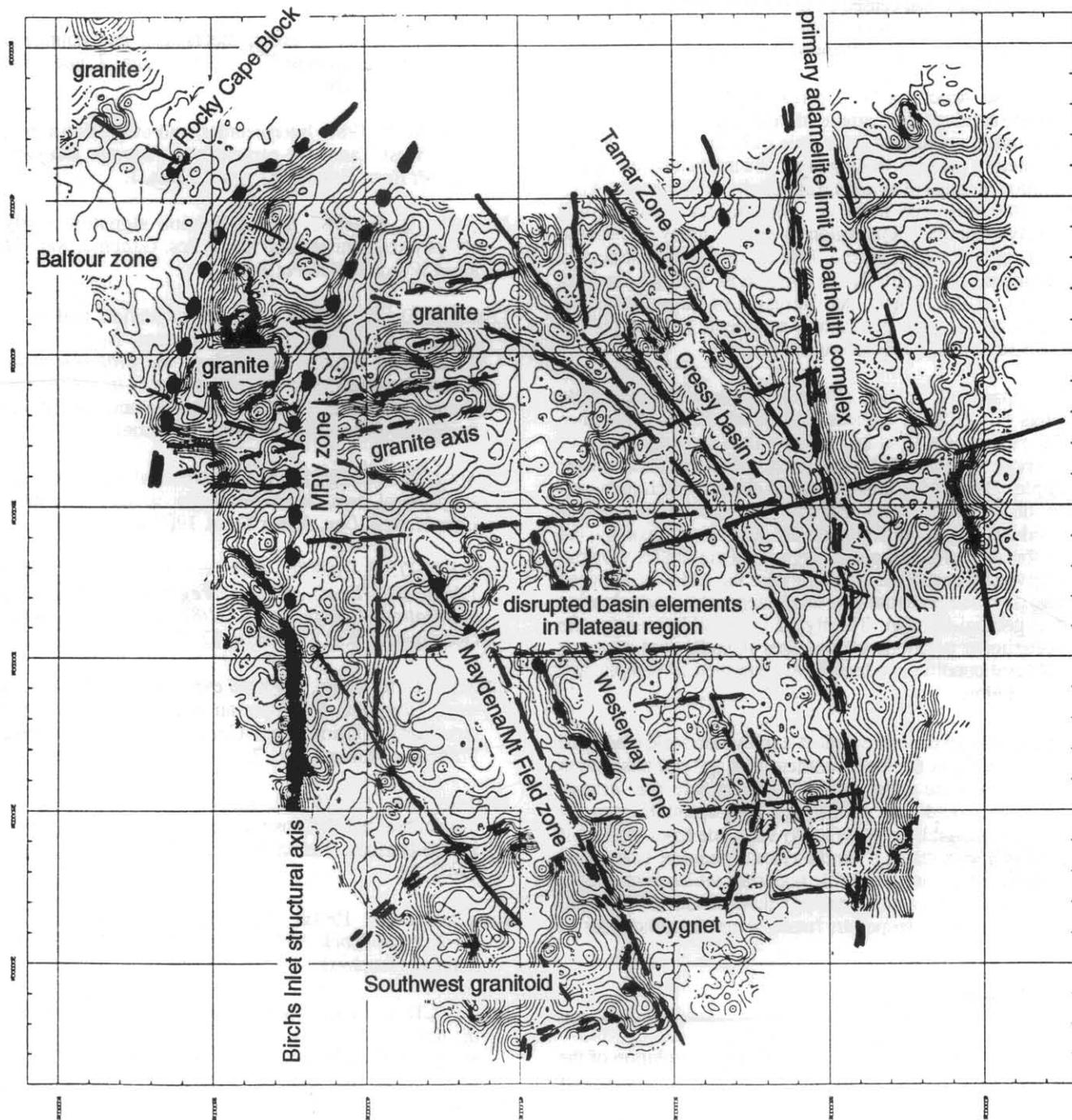


Figure 2

Residual Bouguer Anomaly and some labelling of features. attention is drawn to contrasts involving pre-Lower cambrian rocks and some major offsets and granitoids. Note the general distribution of granitoids.

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Figure 3

Part of the regional aeromagnetic survey across the midlands. Data courtesy of Conga Oil. Note the extended grain of many features with trends related to, and extending from, exposed ultramafic rocks (as at Beaconsfield). Magnetic data do not reflect post-Jurassic elements in the Tamar region. There is no evidence for a Tamar suture or lineament or terrane join. See also Wellman (1989).

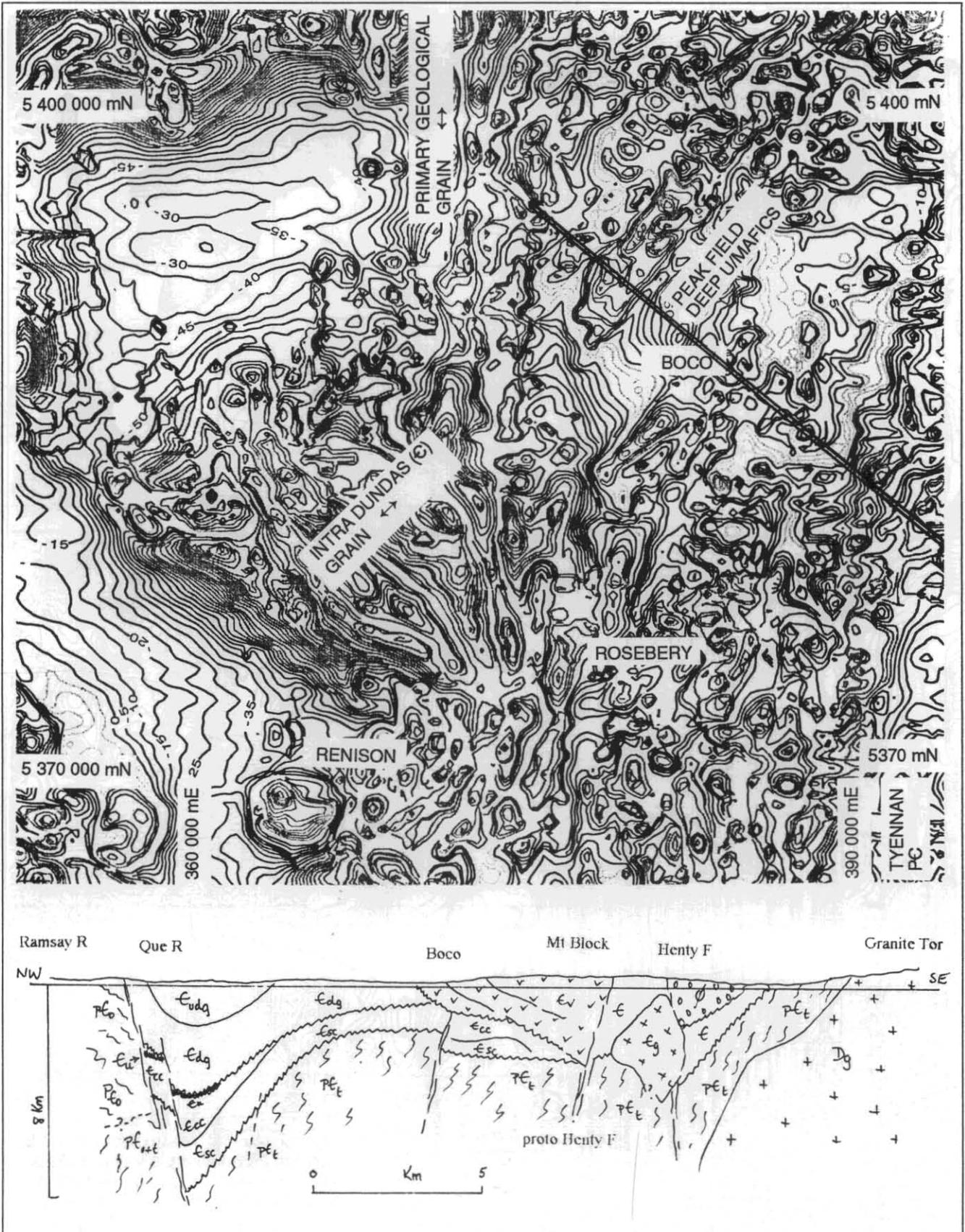


Figure 4

Part of the 1981 aeromagnetic survey of western Tasmania (Leaman, 1986) corrected for many terrain effects and converted to a residual form after removal of a regional based on continuation to 1500 m terrain clearance. The compilation reveals much fine texture and trend changes within the "trough" axis adjacent to the Mt Read Volcanics. The section suggests a possible interpretation based on a preliminary version of the processed data and residual gravity data. The interpretation can be refined but clearly implies deep narrow old troughs and overprinted half grabens prior to the Late Cambrian.

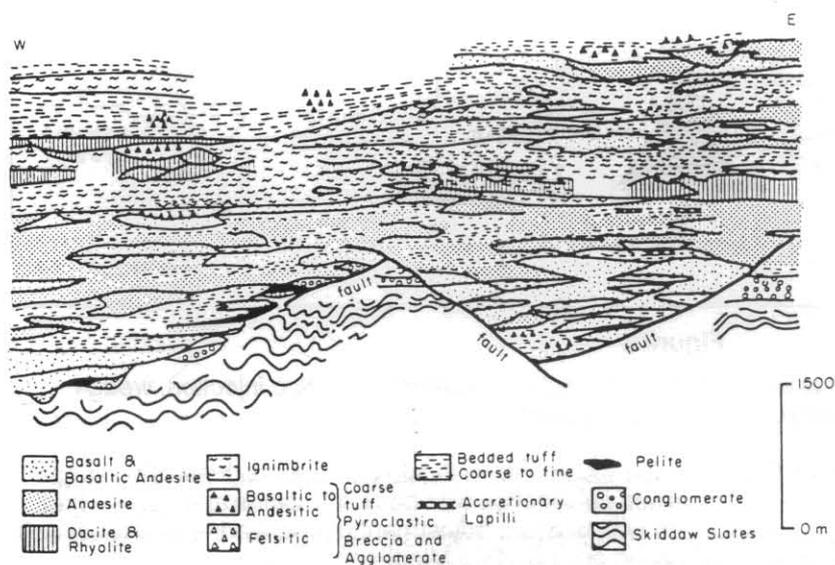
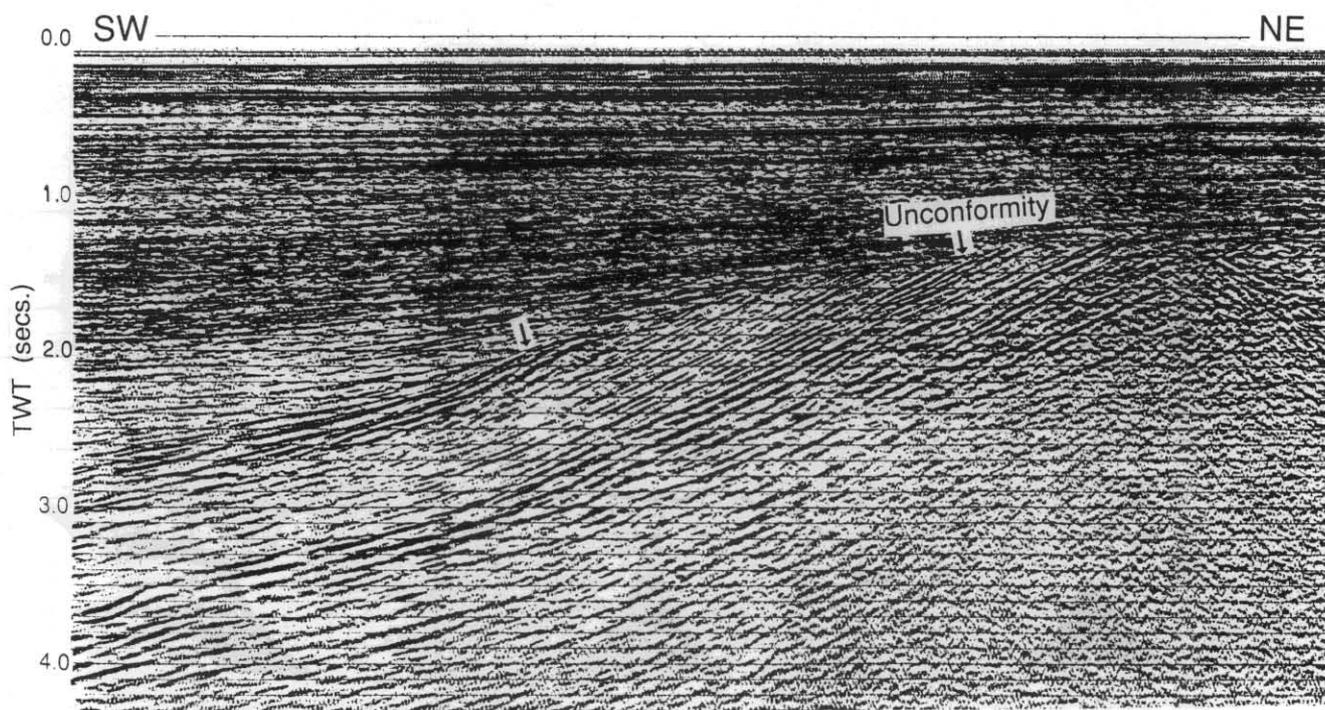
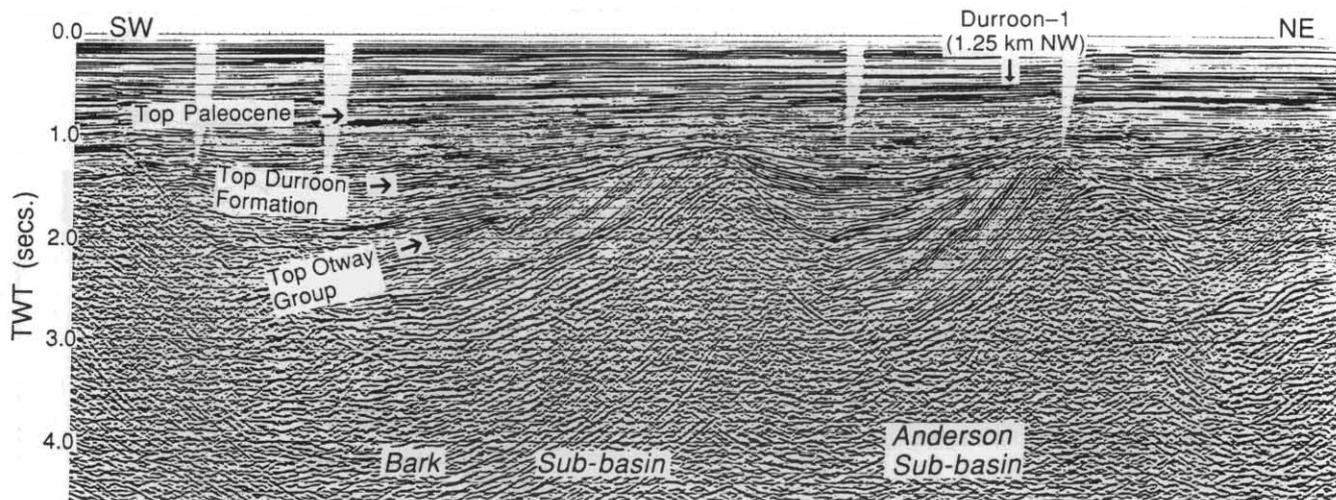
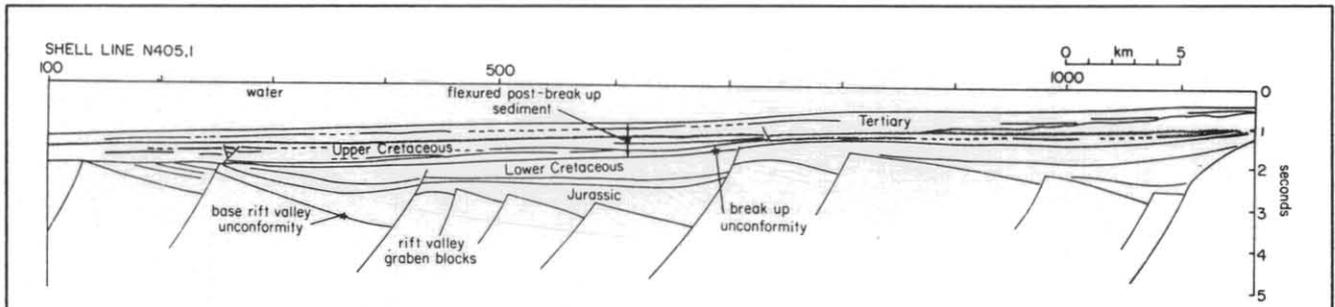


Figure 5

The reflection sections (from the Durroon Basin, Baillie and Pickering, 1991) indicate the style of relationships within basins of all ages. Note that seismic data tends to provide an unclear view of the oldest parts of the structure and that other data must also be used. The lower diagram indicates schematically the stratigraphic complexity produced by overlapping volcanic edifices within the Borrowdale volcanic succession from Buttermere to Haweswater in western England. The section is 30 km long. After Stillman (1986).

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An interpreted seismic section across the southern Australian rifted continental margin showing various morphological features.

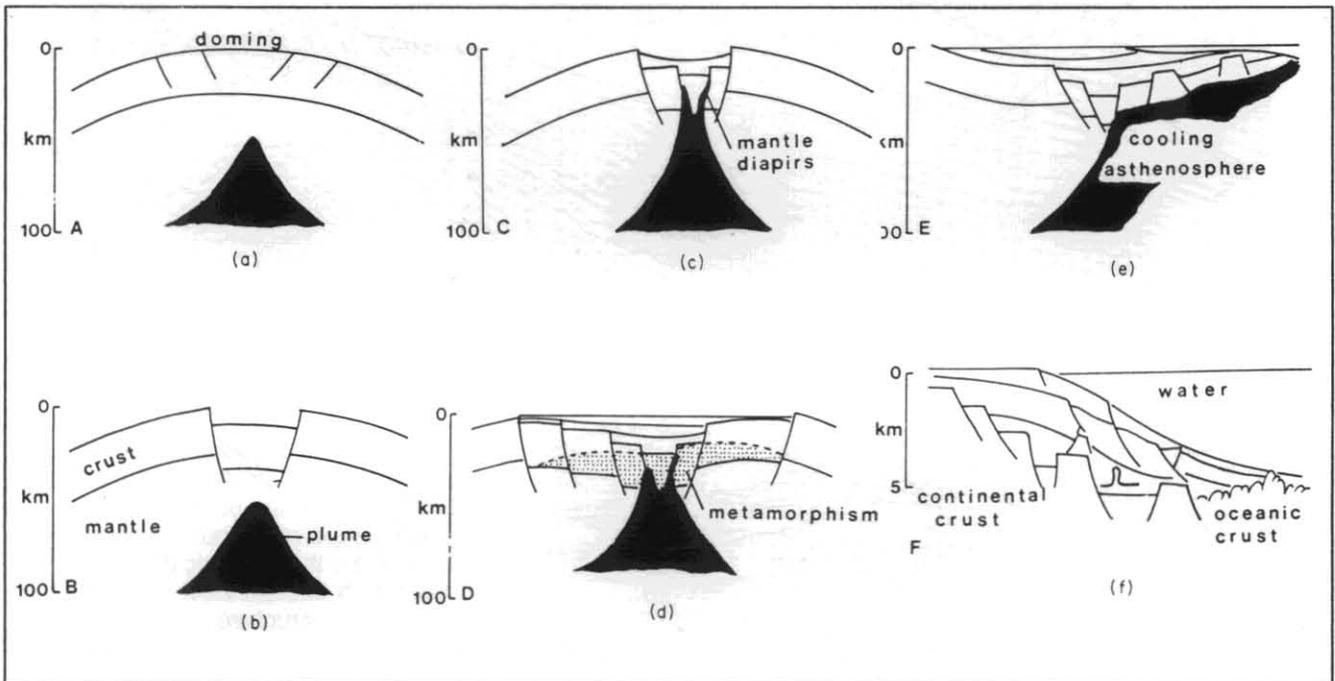
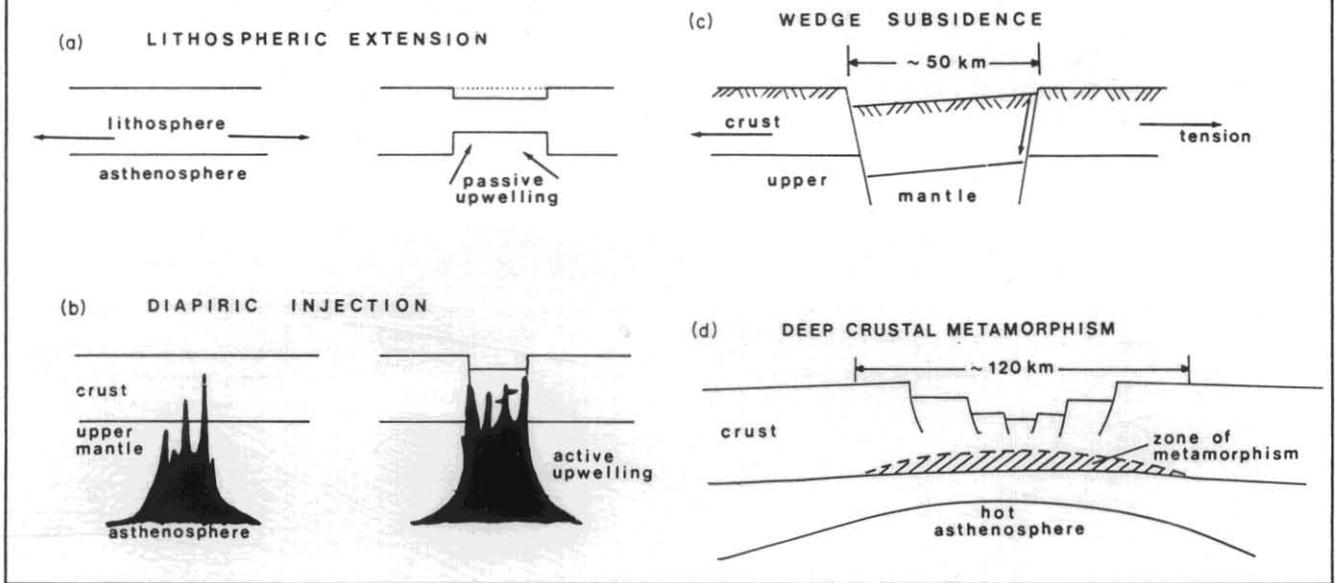


Figure 6

Top. Four possible mechanisms of rift valley formation, lithospheric extension, diapiric injection, wedge subsidence, deep crustal metamorphism.

Bottom. A possible sequence of mechanisms leading to formation of a continental margin sedimentary margin. Thermal doming with erosion, wedge subsidence, localised subsidence with basic intrusions and some filling, regional subsidence involving metamorphism, subsidence with isostatic adjustment (some marine influence) and thermal subsidence if complete disruption occurs. (See Middleton, 1984).

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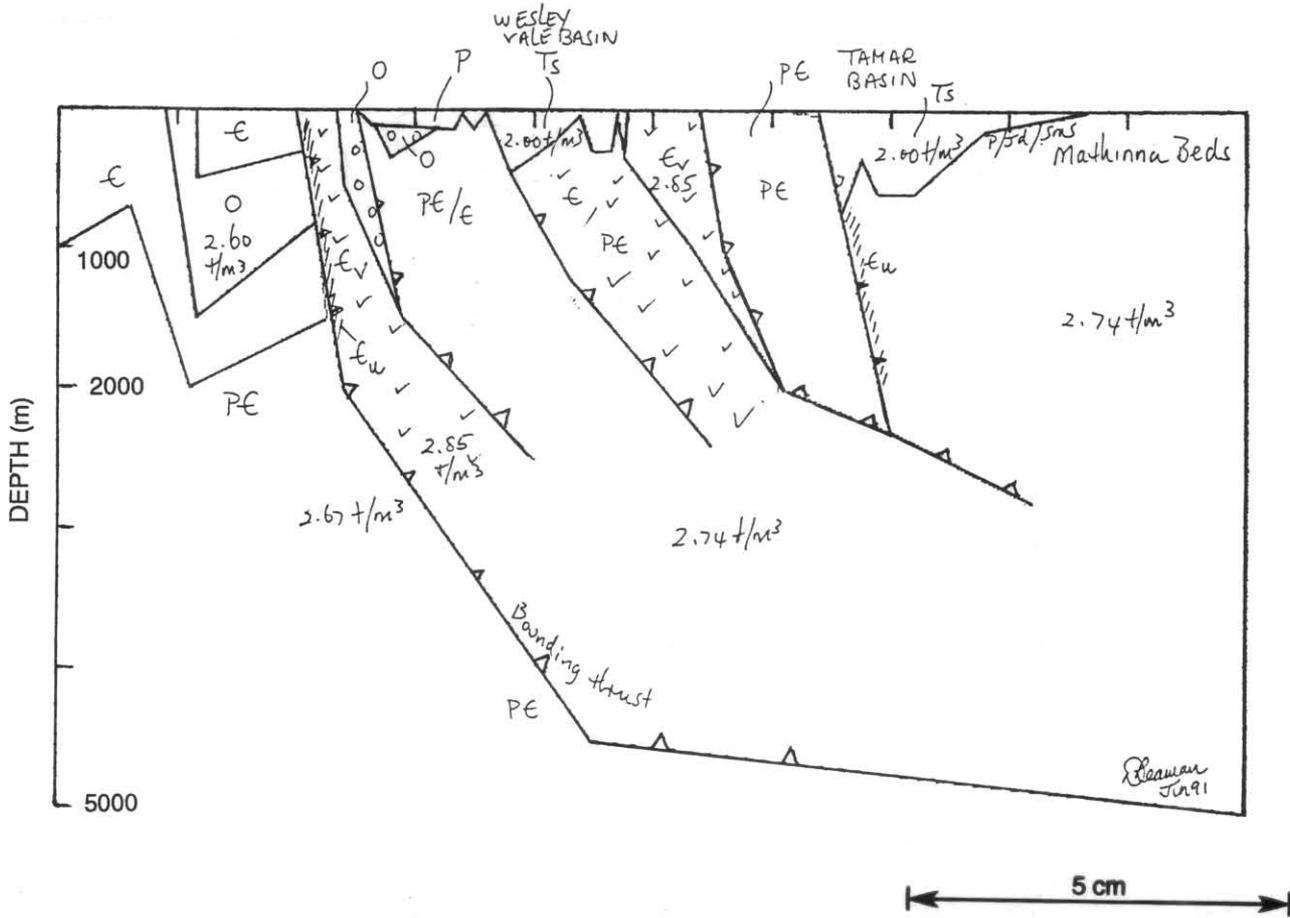
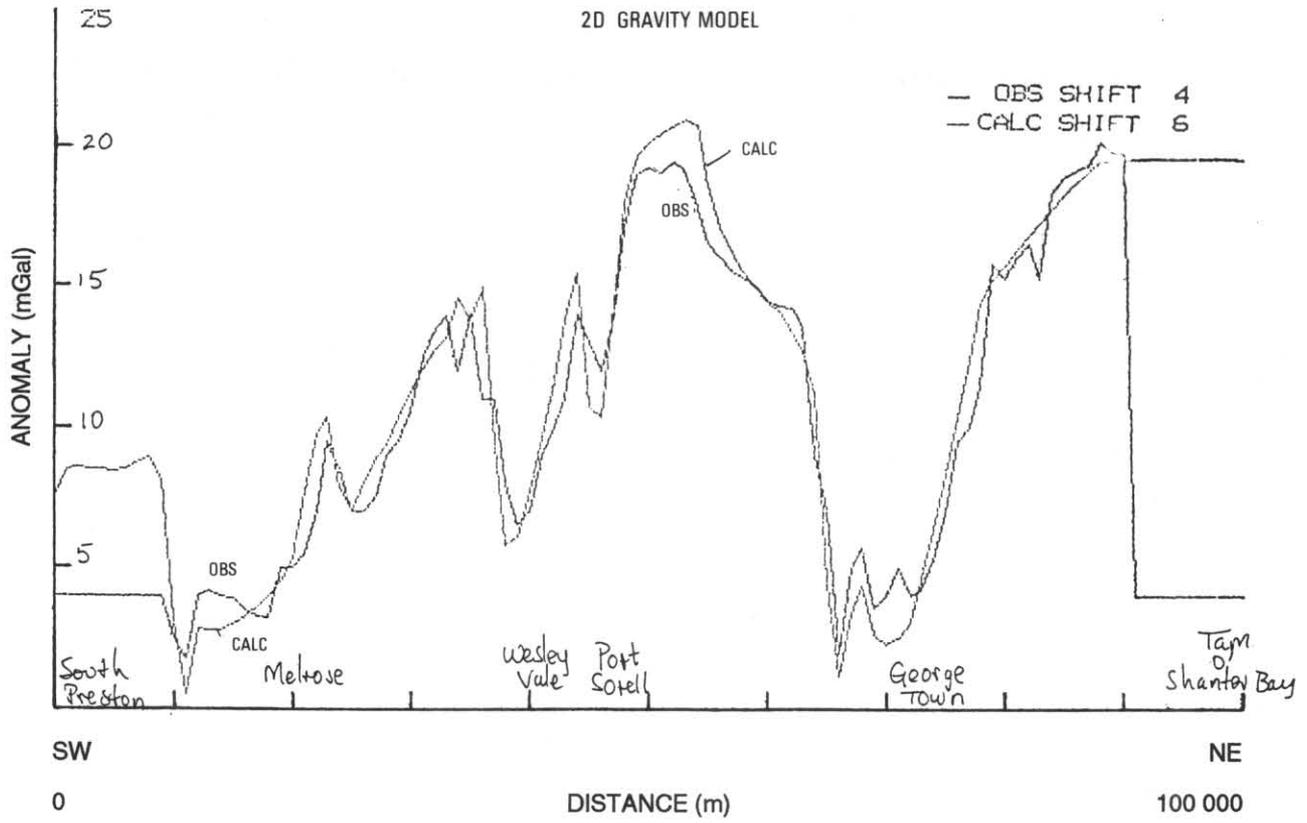
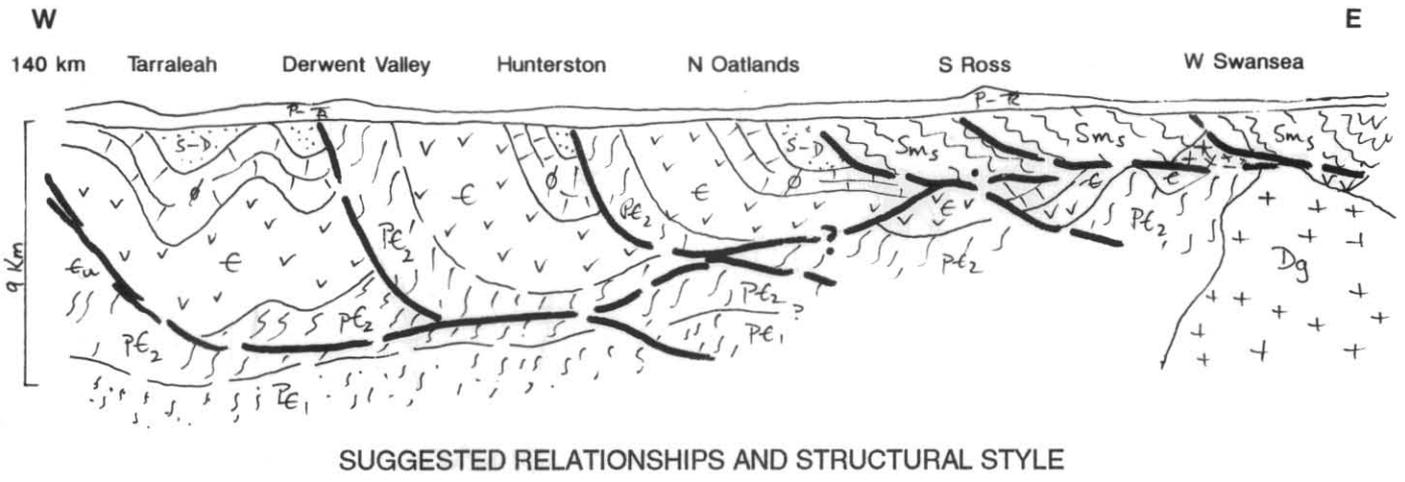


Figure 7

Section revealing inferred relationships in northern Tasmania. Note the dislocated and overthrust nature of Precambrian blocks — all from the east. Tertiary and Jurassic structures are associated with pull back of the larger detachments.

Along strike elements of the western sequence underlying the primary detachment have been incorporated within the thrust complex which includes the deep basin Mathinna facies. Figure 7 shows such pieces west of the Tamar River near Beaconsfield but similar variations occur east and south of Hobart.



SUGGESTED RELATIONSHIPS AND STRUCTURAL STYLE

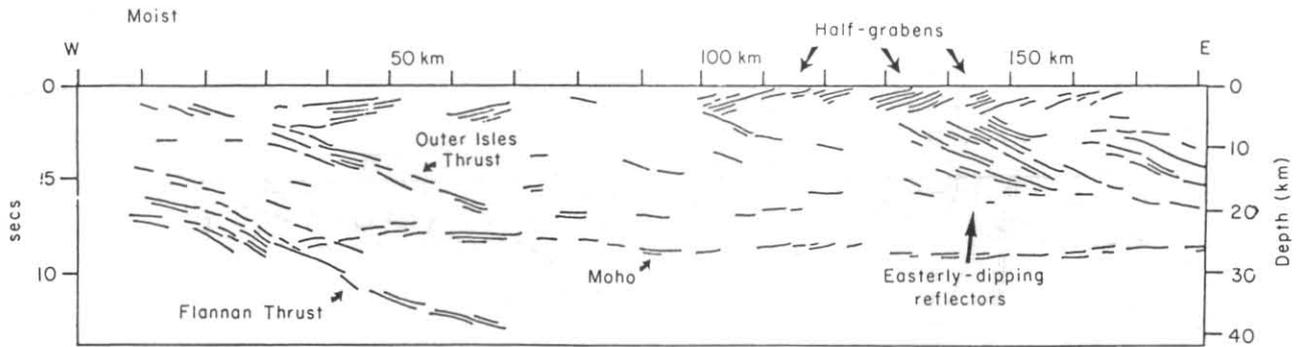


Figure 8

Regional conception of structures in eastern and central Tasmania, based on preliminary long line modelling of gravity and magnetic data. Note the continuance eastward of the western basement type and style. The major detachments incorporate slices of ultramafic rocks and can be mapped magnetically (see fig. 3). Pull back of these structures accounts for the Derwent, Cressy, Coal River and Tamar sub-basins of the post Triassic. The overall asymmetry of the section is related to the greater uplift to the east related to both the original basin axis and the batholith emplacement. The lower section shows similar relationships in northern Scotland (after Brewer, 1983), where North Sea-related tensions have pulled back the older detachments to create half grabens.

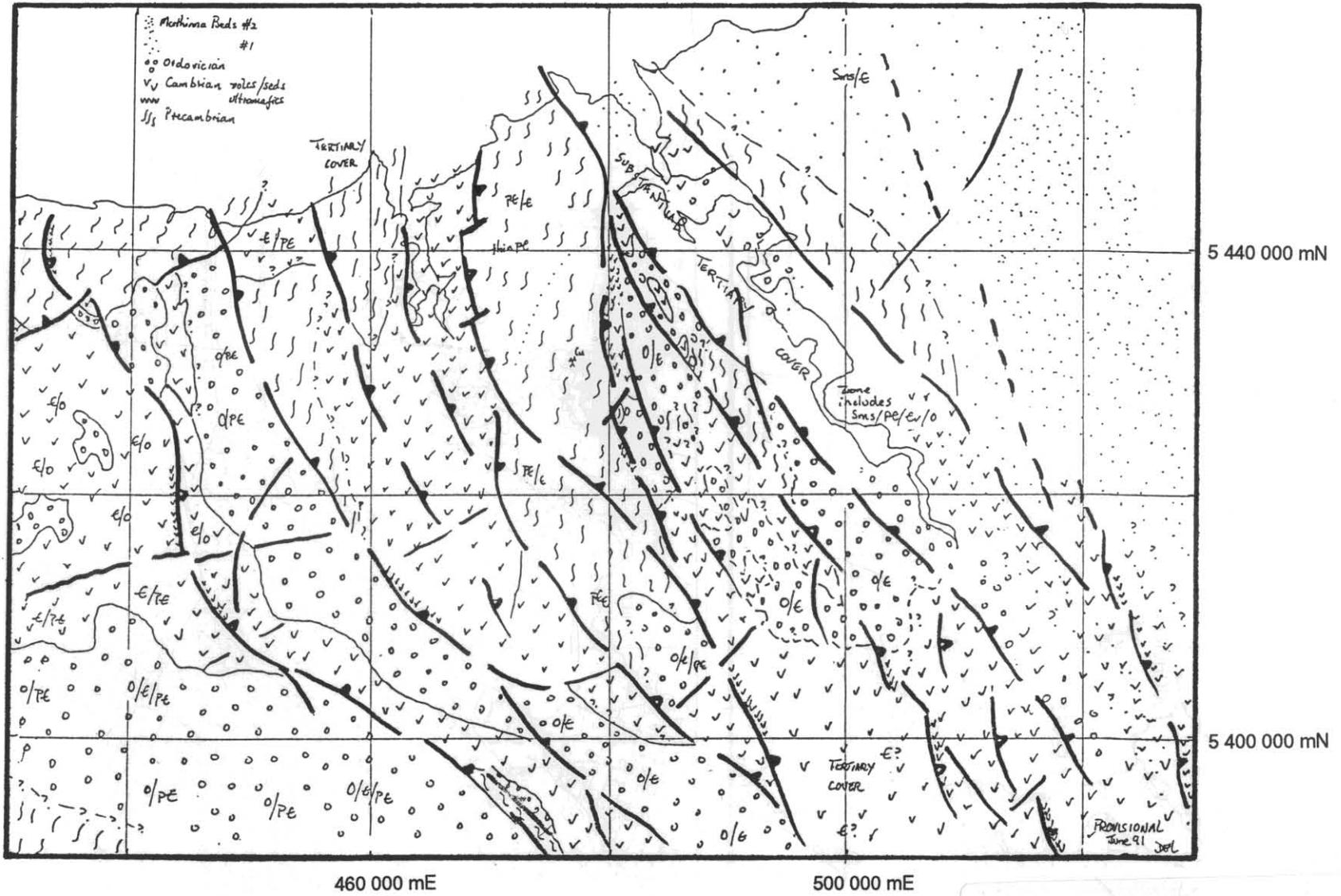


Figure 9

The inferred pattern of major pre-Carboniferous units and structures in Northern Tasmania. The distribution is as would be seen if the cover were removed. (Courtesy Conga Oil Pty Ltd).

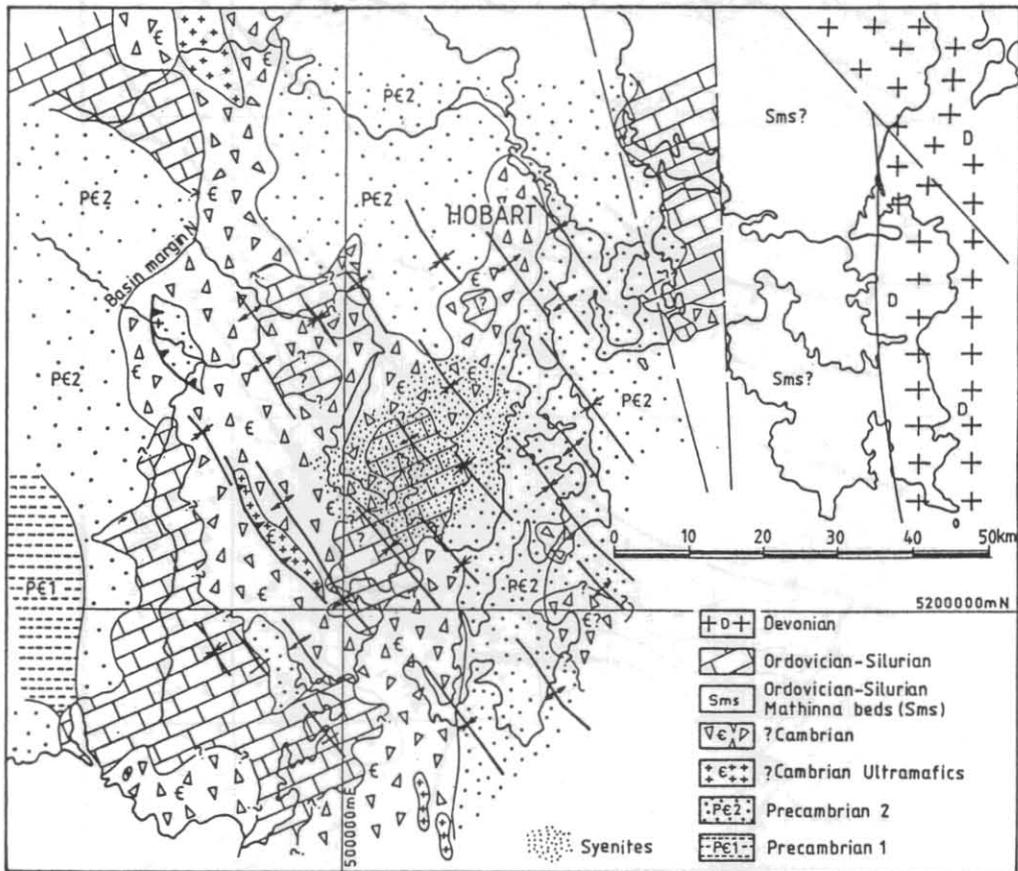
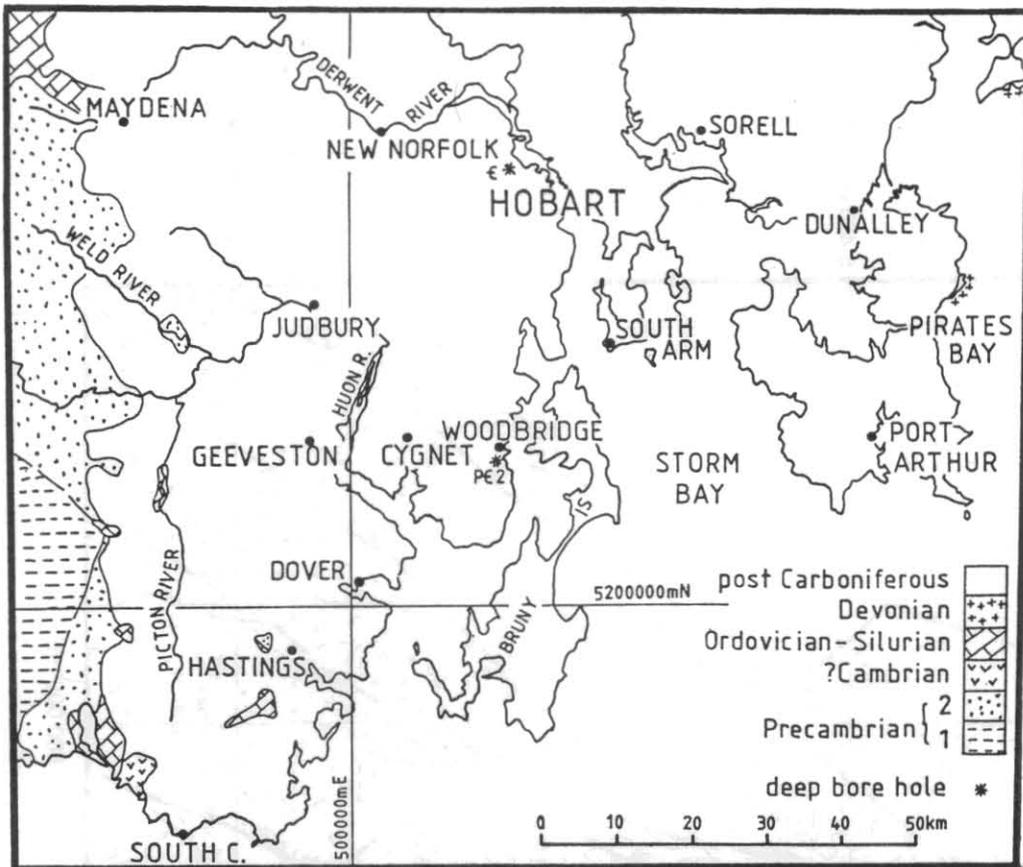


Figure 10

The upper map indicates the exposure and knowledge of the pre-Carboniferous cover in southern Tasmania. The lower map shows an interpretation of rocks at the unconformity. This is a typical west Tasmania terrane.

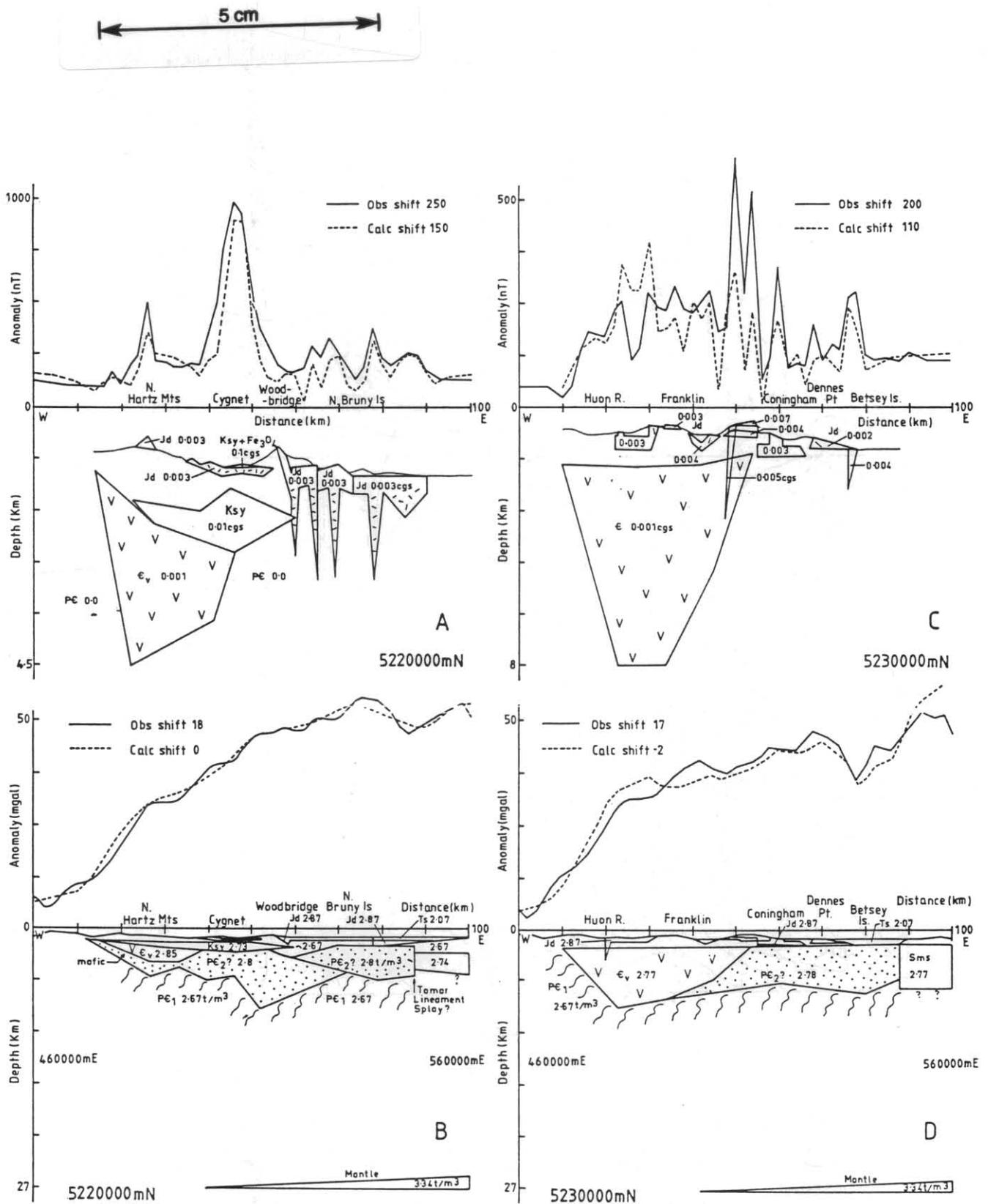


Figure 11

The models illustrate some of the basis for the interpretations offered, for the Cygnet or Huon region in particular. The style is identical to that inferred in central and northern Tasmania.

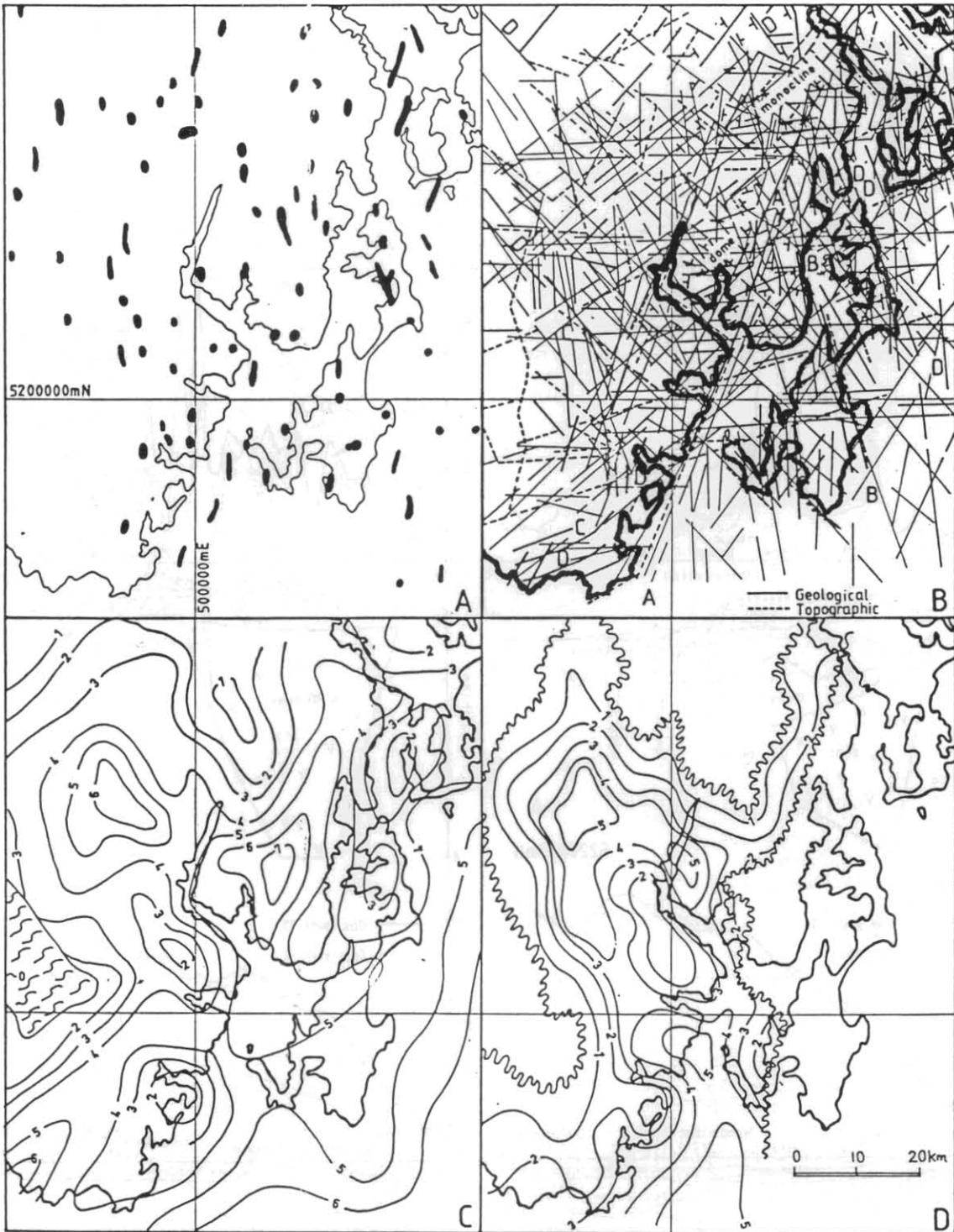


Figure 12

Summary of gravity and magnetic interpretation.

- A. Jurassic dolerite feeders, location and shapes as defined by available data.
- B. Compilation of all trend information (firm and broken lines represent post-Carboniferous or topographic features, fine lines represent features identified by geophysical data).
- C. Combined method interpretation of depth to top of Tyennan region type Precambrian basement.
- D. Interpretation of depth to base (?) Cambrian volcanic sequences (all contours in km below sea level).

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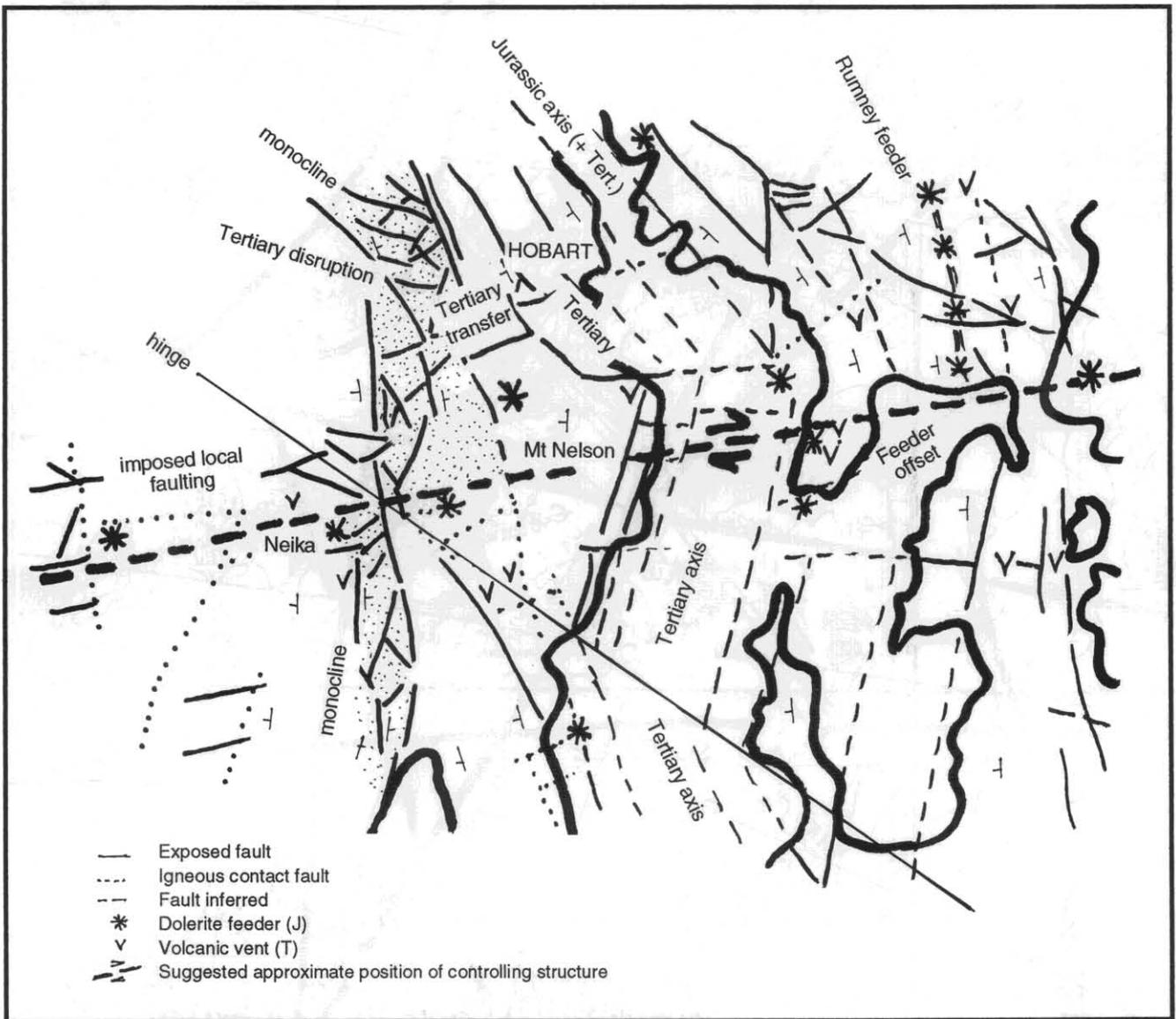


Figure 13

Possible relationships between structures observed in post-Carboniferous rocks of the Hobart area and major concealed structures. Diagram suggests one feature only. Note the trend changes, vent locations and sub-parallel sympathetic faults associated. Offset defined by monocline and eastern feeder axis (heavy dots mark matched locations). It is possible to infer both dextral and sinistral motions on different parts of the structure shown depending upon features selected. A complex history is almost certain.

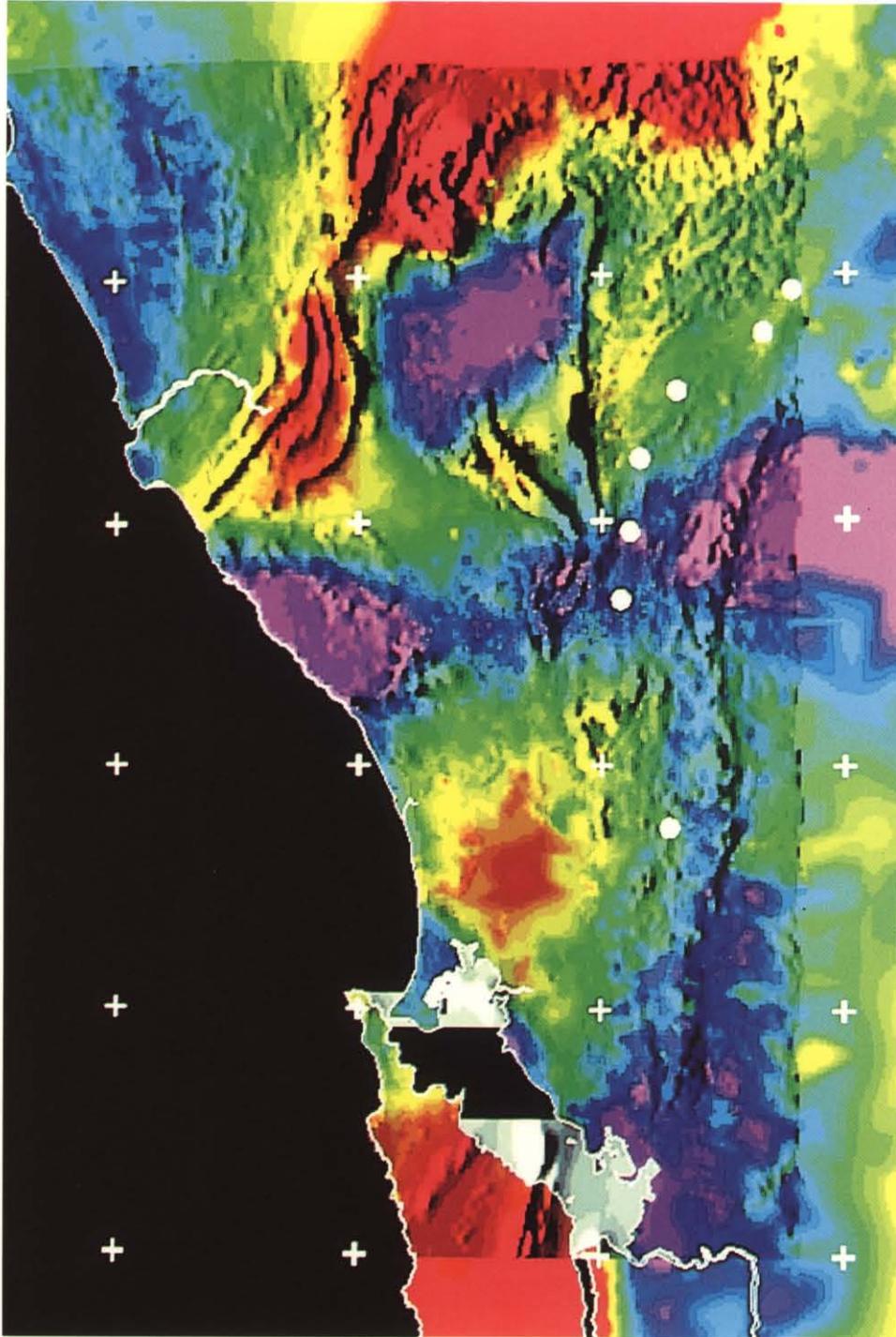
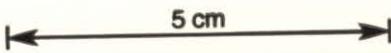


Figure 15.
(D. E. LEAMAN — *Finding Cambrian keys*)

Image showing Tasmania Department of Mines databases superimposed. Residual gravity (as in fig. 1) shown in colour (blue, low) and 1981 aeromagnetics corrected to a 250 m drape (not residuals as in fig. 4) in shadow.

Principal Cambrian mineralised sites are shown. From south to north Mt Lyell, Hercules, Rosebery, Chester, Boco, Que River and Hellyer. Note that all sites lie west of the magnetic ridge which marks the proximity of the exposed Tyennan Precambrian, but are near the main N-S gravity gradient (fig. 2). In addition, sub E-W trends can be recognised at/near each site. These trends are at about 80–85° and 280°. The first is universally observed. Small offsets (up to 4 km) of the mineralised sites, as currently known, may be due to Late Cambrian rotation and (possibly) two Devonian events which have developed flower structures and overthrust some parts of the volcanic piles. This displacement has been generally westward. Allowance for such evolution would place every site near a primary margin-transform intersection that was active during volcanism of the second rifting stage. (Image courtesy M. Roach, CODES).

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