The geological and structural controls on mineralisation at the Renison tin mine

PAUL A. KITTO

Centre for Ore Deposit and Exploration Studies, University of Tasmania

ABSTRACT

The Renison tin mine in Western Tasmania is hosted by subareal to shallow-marine, Late Precambrian to Early Cambrian Success Creek (Corbett and Lees, 1987) and shallow marine Early Cambrian Crimson Creek Formations (Kitto, 1990) within the Early Palaeozoic Dundas Trough. The deposit occurs on the northeast limb of a broad SE-plunging monocline, which in turn constitutes a major horst block bounded to the northeast by the Federal-Bassett Fault (FBF), and to the southwest by the Argent Fault. The dominant brittle deformation structures at Renison, together with the FBF, include the Blow Fault, which occurs west of and sub-parallel to the FBF, and a series of east-west interconnecting Transverse Faults. The Transverse Faults bound a complex series of minor horst and grabens.

The carbonate replacement and vein styles of cassiterite mineralisation were structurally controlled by the complex nature of brittle faulting that focused the mineralising fluids into dilatent fault zones. A detailed study of kinematic indicators on the mineralised faults has determined the stress field during mineralisation (Kitto, 1990; Kitto and Berry, 1991). Four phases of brittle deformation (Devonian to Tertiary) were determined, based on style and relative ages of fault striations. The first generation fibre growths have a mineralogy consistent with host veins suggesting contemporaneous brittle deformation and mineralisation. No striations predating the mineralisation were observed. The initial brittle deformation (BD$_1$) at Renison produced a normal-dextral orientation of striations, grooves and undulations on fault surfaces, with modelled stress tensors predicting a near-vertical maximum compressive stress and near-horizontal minimum compressive stress trending 84°. This stress regime was unique to Renison and initiated the FBF along a pre-existing monocline as a principal graben boundary fault-couple linked by minor antithetic normal faults. The Argent, Blow and Transverse Faults were also initiated by this BD$_1$ event, together with the complex system of horst and grabens bounded by the Transverse Faults.

The syn-Devonian normal faulting at Renison contrasts with the NE-SW compressional structures related to the Tabberabberan Orogeny throughout the rest of western Tasmania. The major horst structure bounded by the Federal-Bassett and Argent Faults resulted from the modification of a Devonian monocline by the forceful emplacement of an asymmetrical northwest-trending Devonian granite ridge. The FBF was propagated as a double fault structure on the easternmost margin of the granite subparallel to the -500 m , -1000 m and -1500 m granite contours. The FBF offsets the monoclinal mine sequence by upwards of 700 m in the immediate mine area. The Blow Fault Complex was initiated subparallel to the FBF over an apothysis in the -500 m granite contour, and forms the westernmost boundary to economic cassiterite mineralisation at Renison.

Local uplift in the σ$_2$ direction and a 15% N-S extension of the mine horst occurred on the eastern margin of the intruding granite, and resulted in the production of the Transverse Faults subparallel to the EW-trending section of the -500 m and -1000 m granite contours. As the granite related stress field decayed, a regional Tabberabberan dextral wrench (BD$_2$) reactivated earlier BD$_1$ fault structures and produced a dilational jog in the FBF as a consequence of differential displacements on the Transverse Faults. The stress field associated with the BD$_2$ wrench may have facilitated the formation of the largest carbonate replacement orebodies within dilational areas adjacent to the convex flexures.

The listric extensional Transverse Faults acted as basal detachments to a system of linked synthetic and antithetic displacements which formed a complex series of N-S oriented horst and graben structures in a plane perpendicular to σ$_3$. These horsts and grabens show maximum extension (>20%) to the south, directly above an apophysis in the -500 m granite contour. These fault structures controlled carbonate replacement in the up-dip dolomite horizons distal to the FBF.

The intimate association of brittle deformation structures, granite topography (Leaman, 1991), and granite geochemistry (Bajwah et al.; in prep.) suggest that the forceful intrusion of a late-stage Sn-rich granite occurred immediately beneath Renison during the Devonian. The granite intrusion not only prepared the overlying carbonate-rich sediments structurally but also supplied the source of fluids responsible for carbonate replacement and vein styles of cassiterite mineralisation.

INTRODUCTION

Australia's largest primary tin producer, Renison, is located on the West Coast of Tasmania (fig. 1) within the longitudinal Palaeozoic Dundas Trough, bounded by the Proterozoic Tyennan and Rocky Cape metasedimentary regions (Solomon, 1981). The carbonate horizons hosting replacement mineralisation lie within the subareal to shallow marine, Late Precambrian to Early Cambrian Success Creek Formation (Corbett and Lees, 1987) and shallow marine Early Cambrian Crimson Creek Formation (Kitto, 1990). Forceful emplacement of an asymmetrical granite ridge associated with the Devonian Pine Hill Granite (355 ± 4 Ma; Brooks, 1966) resulted in complex brittle deformation of the host rocks (Kitto, 1990; Kitto and Berry, 1991), providing a major focus for ascending hydrothermal fluids which resulted in carbonate replacement and vein styles of mineralisation.

An abundance of information has been documented on the Renison mine geology since the commencement of large-scale underground operations in the mid 1960s (interested readers are referred to the following authors: Patterson *et al.*, 1981; Morrison, 1982; Davies, 1985; Holyland, 1987; Kitto and Berry, 1991, 1992).

HISTORICAL PRODUCTION

The Renison orebodies were discovered in 1890 as alluvial and gossanous deposits. Hard-rock mining ceased in the 1920s when only untreatable massive iron sulphide remained. Technology in the 1930s overcame the difficulties of recovering tin from massive pyrrhotite, allowing small-scale open-cut and underground mining to resume. The large-scale underground mining operations commenced in 1967.

Renison, in 1991, had an annual production rate of approximately 550 000 tonnes at 1.2% Sn and an identified mineral resource totalling 11 million tonnes at 1.26% Sn. Since production figures have been recorded (1960), the total recovery of Sn has exceeded 115 000 tonnes.

STRATIGRAPHY*

The typical mine sequence is interpreted as two regressive and a partial transgressive cycle of subtidal-intertidal-supratidal and fluvial units (fig. 2; Morrison, 1982). The sequence is widely distributed to the north and west upon the Rocky Cape Block, but its depositional limits to the east and south are equivocal (Holyland, 1987). The stromatolitic-oolitic facies (i.e. No. 1, 2 and 3 carbonate horizons; see fig. 2 and 3) form an extensive supratidal platform continuous with the Smithton Dolomite which has undergone diagenetic or hydrothermal alteration of an originally clastic limestone (Morrison, 1982).

A summary of the major lithologies at the mine is provided in Figure 3. The basal unit to the mine sequence is the Dalcoath Member, which has identifiable upper sub-units beginning with the Dalcoath Contorted (up to 80 m). This consists of intensely contorted, laminated, black to grey shale and siltstone. Soft-sediment deformation is invoked, but Brown (1986) has also identified later tectonic overprinting. A lithologically equivalent, yet undisturbed carbonaceous

and non-carbonaceous siltstone, overlies this sub-unit. This is in turn overlain by the Dalcoath Upper (10–15 m), a laminated shale-siltstone unit containing thin, folded, boudined and nodular dolomite beds.

The No. 3 Dolomite (up to 15 m) is the lowermost of the three carbonate units which host the known stratabound mineralisation. It is a massive, light to dark grey dolostone with relatively sharp lithological contacts.

Conformably overlying this zone are the three sub-units of the Renison Bell Member (RBM). The RBM Lower comprises 20–40 m of massive white to grey, fine-grained quartz sandstone with characteristic pebble beds. The RBM Middle (10–30 m) is a laminated micaceous black shale, with local thin siltstone and sandstone laminae distinguishing it from the RBM Upper (5–10 m) with its increasing carbonate fraction. The RBM Upper has a gradational contact with the No. 2 Dolomite, and also includes a minor yet significant dolostone, the 2.2 Horizon. The No. 2 Dolomite is similar to the No. 3 Horizon except for characteristic silty interbedding and impure gradational margins.

A very distinctive marker horizon, the Red Rock Member (25–35 m), overlies the No. 2 Dolomite and marks the top of the Success Creek Group. This horizon has a highly variable lithology characteristic of a fluvial environment, and is subdivided into three units; a siltstone and fragmental-tuffaceous group; a conglomerate, grit, sandstone, carbonate group; and a chert-iron formation, carbonate group (Morrison, 1982).

The No. 1 Dolomite (8–25 m) is conformable with the underlying Red Rock and is a chemically impure equivalent of the No. 2 and No. 3 Dolomites, having well-developed silt-mudstone interbeds up to four metres in thickness.

The Upper Contorted Dreadnought Hill Member represents the basal sequence of an overlying sequence of massive to thinly-bedded siltstone, shale and mafic volcaniclastic greywackes known as the Crimson Creek Formation (>1000 m). Evaporite horizons, scattered throughout the succession, have been interpreted as shallow water sabkha representatives (Kitto, 1990). Gabbroic sills and dykes? occur within the Crimson Creek Formation at Renison, and their geochemistries would indicate that these post-orogenic collisional tholeiites have been cannibalised to source the Crimson Creek sediments.

REGIONAL STRUCTURAL SETTING

In the Renison–Zeehan region, Brown (1986) isolated an east-west compressive event (D1) which pre-dated the deposition of the early-Middle to Late Cambrian Dundas Group. D1 produced shallow east to southeast-dipping thrust sheets associated with belts of sheared and disrupted allochthonous mafic and ultramafic complexes (Berry and Crawford, 1988). A NE-SW compressive event, D2, coeval with the Tabberabberan Orogeny, was identified by Holyland (1987) to be responsible for moderately open regional northwest-trending folds. Leaman (1988) further recognised the close association regionally between the intersection of D1 sutures, D2 anticlines, granite emplacement and subsequent mineralisation. Marjoribanks (1990) postulated that the D2 event initiated the brittle

---

* Editorial footnote: Much stratigraphic and structural terminology is local mine terminology only.

deformation associated with propagation of the master faults at Renison.

OVERVIEW OF THE STRUCTURAL GEOLOGY AT RENISON

A number of the regional fault structures around Renison were correlated by Lea (1991) to the tensional regime associated with emplacement of the steep-sided northwest-trending Pine Hill Granite ridge (fig. 4). The Federal-Bassett Fault (FBF) was inferred to project steeply upward from the northeast margin of the granite ridge into the overlying Success Creek and Crimson Creek sedimentary rocks. The less-steep, westerly-dipping Argent Fault has similarly been correlated with the westerly-dipping roof of the cupola. The Argent Fault, together with the FBF, defines the Renison mine horst.

The mine horst is approximately one kilometre wide and three kilometres long (fig. 5). The Renison mine sequence associated with the mine horst clearly defines a broad monoclinal fold which steepens its dip toward the FBF (fig. 6). The monoclinal fold is thought to occur on the northeast limb of a regionally southeast-plunging anticline (Patterson, 1979). The absence of an axial-surface cleavage, however, leaves conjecture as to the presence and exact location of this anticlinal structure.

On approach to the FBF from the west, the mine sequence steepens from near-horizontal 600 m away, to almost parallel adjacent to the FBF. Rotation of the mine sequence into the plane of the FBF occurred by simple shear, and emphasised the monoclinal nature of the sediments (fig. 6). Facies variation within the mine sequence, rather than ductile thinning, is sufficient to explain the minor thickness variations observed. McQuitty (1991), however, has evoked a ductile deformation component at depth, to the North Bassett region, together with a facies variation to explain variations in the dolomite thickness.

The dominant brittle deformation structures within the immediate mine area associated with the FBF are the Blow Fault Complex (BFC), 700 m southwest of and subparallel to the FBF, and a series of east-west interconnecting Transverse Faults (fig. 5). The Transverse Faults have acted as listric basal detachment faults, upon which a set of secondary normal faults have developed and resulted in a complex series of north-south oriented horst and graben structures (fig. 6).

A detailed study of kinematic indicators on the major faults at Renison by Kitto (1990) and Kitto and Berry (1991) determined the stress field during mineralisation. Four phases of brittle deformation, from Devonian to Tertiary in age, were identified, based on the style and relative age relationships of the fault striations. The first generation of mineral fibres had a mineralogy consistent with host veins, suggesting contemporaneous brittle deformation and mineralisation. No striations predating the mineralisation were observed.

The initial brittle deformation (BD1) at Renison produced a normal-dextral orientation of striations, grooves and undulations on fault surfaces. The modelled stress tensors predicted a near-vertical maximum compressive stress (σ_1), and near-horizontal minimum compressive stress (σ_3) which trended 84° (fig. 7a, b). This stress regime was unique to Renison, and contrasts with the NE-SW compressional event

suggested by Marjoribanks (1989) related to the Tabberabberan Orogeny. Kitto and Berry (1991) concluded that the dominant brittle deformation structures were initiated by the forceful emplacement of the Pine Hill Granite, and that the early stages of cassiterite mineralisation were coeval to this BD1 event.

As the radial stress field associated with the granite intrusion decayed a regional Devonian Tabberabberan stress field remained. This caused a dextral wrench (BD2) to reactivate the earlier brittle deformation structures because of a near-horizontal maximum compressive stress, σ_1, trending 172°, and a near-vertical intermediate compressive stress, σ_2 (fig. 7c, d). The latter stages of cassiterite mineralisation continued during this BD2 event.

Two minor, post-Devonian, reactivations unrelated to mineralisation have also been recorded. The first, a reverse-sinistral displacement (BD3) with less than a few tens of metres displacement, overprints the earlier fault striations. Modelled stress tensors indicate that the maximum compressive stress (σ_1) was near-horizontal, trending 88°, and the minimum compressive stress (σ_3) was vertical (fig. 7e, f). This reactivation may be associated with a suspected regional Carboniferous thrust (Brown, pers. comm.), or due to an elastic rebound of the rocks after normal-dextral faulting. Minor Tertiary normal-sinistral reactivation (BD4) is the last recognised brittle deformation at Renison, and was formed by a near-vertical maximum compressive stress (σ_1) and a horizontal minimum compressive stress (σ_3) trending 158° (fig. 7g, h).

STRUCTURAL CONTROLS TO MINERALISATION

FIRST ORDER STRUCTURES

The primary control on mineralisation at Renison was the Federal-Bassett Fault (FBF), which provided the major focus for ascending hydrothermal fluids off the forcefully-emplaced asymmetrical Devonian granite ridge. Less important, but subparallel to the FBF, was the Blow Fault Complex (BFC), which forms the western boundary to economic tin mineralisation at Renison.

Federal-Bassett Fault (FBF)

The FBF has a strike length of several tens of kilometres (Lea, 1991) and dips to the northeast at approximately 70°, along the easternmost margin of the Renison Mine Horst. The FBF forms a double-fault structure, or fault couple, with up to 100 m of separation. In the mine area the fault couple can be divided into three distinct zones (fig. 5):

(i) Envelopes; the region south of the 'Shear L' – FBF intercept.

(ii) Federal; the region between the 'Shear L' and 'Shear P' intercepts with the FBF.

(iii) North Bassett; the region north of the 'Shear P' – FBF intercept.

NOTE: At Renison the term 'shear' is a historical term, and does not have a generic connotation.

The FBF in the North Bassett region, together with the monoclinal fold seen in the mine sequence, very closely

resemble structures described by Al Kadhi and Hancock (1980) in the Persian Gulf (fig. 8a, b). These structures show planar high-angle normal boundary faults intimately associated with subsidiary antithetic and synthetic normal faults. Such fault patterns typically characterise terrains that have experienced minor inhomogeneous extensions (Wernicke and Burchfiel, 1982). This is confirmed by cross-section reconstructions for the North Bassett region of the FBF at Renison, where extension in the vertical plane of the fault couple has varied from between 15% and 30% (fig. 9). The percentage of extension in the 'Envelope' and Federal regions is uncertain but thought to be of the same orders of magnitude.

The hangingwall to the FBF in the mine area is essentially continuous except for very minor late-stage fault offsets. The footwall structure, in comparison, is highly variable and responsible for initiating the Transverse Faults and other minor faults from flexures within the footwall structure (fig. 6).

Normal-dextral displacement of the hangingwall mine sequence relative to the footwall mine sequence by the BD_1 deformation event resulted in approximately 700 m of dip-slip movement on the FBF in the North Bassett region of the mine (McQuitty, 1991) (fig. 8b). Dip-slip movement on the FBF decreases northward to less than 400 m (Marjoribanks, 1990) but increases to the south where granite stoping of the hangingwall, at depth in the Federal area, prevents an accurate estimation of the fault offset.

Dextral-wrench displacement on the FBF during BD_2 was, at most, only a few tens of metres. It produced the dilational jog in the Federal region where right lateral reactivation of the FBF was partially transferred along the Transverse Shears, 'Shear P' and 'Shear L', resulting in a steep southeast-plunging dilational inflexion on the FBF. A similar estimate for dextral displacement on the FBF was determined by Holyland (1987) using an isodilate method for trend surface residuals on the FBF footwall and hangingwall. He suggested that an oblique normal-dextral slip movement of approximately three metres, plunging at 15° south, would explain the sulphur distribution observed within the FBF. The formation of the Melba Fracture Orebody was a probable consequence of this dextral-wrench reactivation. Previous workers have postulated several hundreds of metres of dextral wrench movement at Renison but this clearly has not occured on the FBF.

The FBF was the major focus for granite-related mineralising fluids at Renison. It provided an access for the hydrothermal fluids to adjacent dolostone horizons and to further second and third-order fault structures.

Blow Fault Complex (BFC)

The Blow Fault Complex has been interpreted as a near-continuous fault structure west of, and subparallel to, the FBF (fig. 5). Similar structures involving the Blow Fault have previously been termed the Western Boundary Fault (Davies, 1985) and the Footwall Fault (Marjoribanks, 1989). At its southern extension the BFC is interpreted to crop out approximately one kilometre west of the FBF and is terminated by the Argent Fault. The BFC strikes north-south and dips steeply east, approaching within 600 m of the FBF on the Murchison Highway in the Black Face Opencut. The BFC and FBF serve as boundary faults to the interconnecting Transverse Faults but neither is truncated by them. North of the study area the BFC is interpreted to either terminate against the FBF or change strike and parallel the FBF (Marjoribanks, 1990).

The BFC was initiated, along with the other major faults at Renison, by the BD_1 normal-dextral movements. Dip-slip displacement was of the order of a few tens of metres. Dextral wrenching (BD_2) on the BFC strongly overprints the earlier generation of normal-dextral fault striations in the Black Face Opencut and railway exposures. These features support Marjoribank's (1990) argument that some of the high strain on the FBF was transfered to the BFC during the BD_2 Tabberabberan reactivation. Only minor dextral-wrenching affected the southern extensions of the BFC as it is terminated by, but does not truncate, the Argent Fault.

The BFC was a minor conduit to mineralising fluids at Renison and did not undergo the same degrees of brittle deformation, displacement or dilation which characterise the FBF structure. The BFC was, however, important in providing access to fluids responsible for the formation of the up-dip carbonate replacement Argent and Ring orebodies (fig. 10).

SECOND-ORDER STRUCTURES

Transverse Faults

The Transverse Faults have, at Renison, been historically termed the Transverse Shears. They are a series of east-west trending, shallow to steeply northeast-dipping faults which interconnect but do not truncate the two first-order structures; the FBF and BFC. South to north in the study area, the Transverse Faults are called the Mercury Fault, 'Shear L', 'Shear P', 'Shear R', and 'Shear S' (fig. 5).

In cross-section (fig. 6), the Transverse Faults form a listric extensional fault system and act as basal detachment faults to third-order fault structures. The Transverse Faults were initiated as brittle deformation structures which splayed off convex-west flexures in the footwall of the FBF during the normal-dextral BD_1 event. Kitto (1990) has suggested that the Transverse Faults were initiated as secondary reverse faults relative to the FBF, when the FBF is oriented and viewed as a pure wrench structure during BD_1 (fig. 11). In short, normal-dextral brittle deformation on the FBF and BFC, initiated by granite emplacement, produced local uplift and north-south stretching of the uplifted block via the extensional Transverse Faults. The percentage of crustal extension experienced in the north-south direction during granite emplacement was approximately 15%, based on cross-section reconstructions.

In plan, the Transverse Faults exhibit a weak sigmoidal outline; a primary feature analogous to the helicoidal structures observed during the formation of an extensional negative flower structure commonly described in the petroleum industry (Harding, 1985; Woodcock and Fischer, 1986; Naylor et al., 1986). Surface expressions of the Transverse Faults in the study area are poor, but 'Shear L' can be observed near the Federal Opencut on Stebbins Hill and 'Shear R' in the Black Face Opencut on the Murchison Highway. 'Shear R' at this location has been interpreted by previous workers as a low-angle thrust, but first and second generation fibres on fault surfaces are consistent with BD_1 and BD_2 deformations observed elsewhere at Renison, negating any suggestion of an earlier thrust event within the study area. Shears 'R' and 'S' experienced only minor displacements relative to the other Transverse Faults.

The dolomite horizons are highly dissected and exhibit fault gaps due to second and third-order fault structures when viewed from a footwall projection (fig. 10). Sulphide replacement of the dolomite horizons was greatest in the dilational areas adjacent to the convex regions of the sigmoidal second-order Transverse Faults (e.g. the Dreadnought and North Stebbins orebodies of the Number 2 Dolomite Horizon, and the Penzance and Colebrook orebodies of the Number 3 Dolomite Horizon).

The Melba Fracture orebody, an anastomosing sheeted-vein complex hosted by the Renison Bell Formation siltstone, is anticlinal in cross-section and located between Shear 'L' and 'P'. In plan, the 'Melba' splays from 'Shear P', close to the FBF, creating an orebody which resembles a huge tensional gash opening, possibly the product of differential dextral displacement on 'Shear L' and 'Shear P' during the BD_2 reactivation.

The western margin of 'Shear P' is interpreted, in this study, to be terminated against the BFC and to occupy the same site as the 'Polaris' carbonate-magnetite orebody. Cross-sectional interpretations for this area indicate that the 'Polaris' orebody is located within a dilational zone, where 'Shear L' has ramped upward into 'Shear P' (fig. 12).

'Polaris' is a bedding-subparallel shear zone that hosts an early carbonate-magnetite and a later replacement pyrrhotite (± pyrite) mineralisation (Simonsen, 1988). These two phases of mineralisation may be associated with the two phases of brittle deformation identified as BD_1 and BD_2. Previous investigators (Barber, 1990; Marjoribanks, 1990) have proposed a pre-Devonian low angle thrust to accommodate 'Polaris'-type mineralisation, but such mechanisms are not supported by field observations.

THIRD-ORDER STRUCTURES

The second-order listric extensional Transverse Faults have acted as basal detachments to a system of linked third-order listric faults which exhibit both synthetic and antithetic displacements. These third-order structures produced a series of minor horst and grabens which strike subparallel to the FBF in a direction normal to the minimum compressive stress (σ_3) associated with normal-dextral brittle deformation (BD_1) (fig. 5 and 6). These structures controlled the carbonate-replacement mineralisation within the up-dip dolomite horizons by providing access for sulphide-rich hydrothermal fluids.

Horst and grabens within the mine area developed east of the BFC. The BFC bounds a major horst block west of the study area. Each horst and graben pair, within the mine area, have centres which diverge toward the south and reflect maximum extension in the direction of minimum thickness over basal detachments, i.e. the Transverse Faults. Regularly spaced cross-section reconstructions for the study area indicate that east-west extension, due primarily to second and third-order structures, is approximately 20% (fig. 13). Extension north of 'Shear P', however, gradually decreases to only about 5%. This area is associated with 'Shear R' and 'Shear S', and reflects the small degree of deformation that accompanied these Transverse Faults.

In plan, the dolomite horizons at Renison show extensive brittle deformation due to third-order fault structures, particularly in the up-dip areas distal to the FBF (fig. 10). In these regions the third-order structures are particularly important for carbonate replacement styles of mineralisation by providing access for the hydrothermal fluids. The formation of the Ring, Sligo and Argent orebodies in the Number 3 Dolomite Horizon appears to be strongly dependant on these third-order structures distal to the FBF.

GRANITE TOPOGRAPHY

Lea (1991), based on a gravity model for the granite profile (Leaman, 1990), has proposed that the major FBF at Renison was initiated by the tensional regime associated with granite emplacement. The gravity response of the granite (average density 2.66 t/m^3) also suggests that a lower density granite phase (average density 2.64 t/ m^3) occurs at two locations; one directly beneath the Renison Mine and the other at Pine Hill (D. E. Leaman, pers. comm., 1991). This observation strengthens the arguement proposed by Kwak (1987) that the primary source of deep magmatic solutions is related to a small granite cupola down-dip from the Federal section of the FBF, and not from the Pine Hill greisen some 400 m topographically above and three kilometres south of the Renison Mine.

Numerous researchers emphasise the effects of fluid overpressure within plutons due to crystallisation reactions in hydrous melts (Burnham, 1979; Heinrich, 1990). In such melts positive volume changes of several tens of percent cause the hydrostatic pressure to exceed the lithostatic load, and result in hydraulic fracturing. Failure of the country rocks in the direction of the minimum principal stress (σ_3) would therefore be expected at the points of highest curvature between the granite and host rock associated with the granite cupola where the stresses become concentrated. The first order FBF would therefore be expected to propagate as a normal-dextral fault along the steep asymmetrical eastern margin of the shallow northwest-plunging Pine Hill Granite ridge, subparallel to the -500 and -2000 m granite contours, in a zone of structural weakness associated with monoclinal sediments (fig. 14). During this brittle deformation event (BD_1) associated with forceful granite emplacement, the BFC and the Transverse Faults would also be initiated and developed over the eastern extension of the asymmetrical granite ridge.

In the study area, the BFC developed subparallel to the north-trending apophysis of the -500 m granite contour, confirming the close association between major faults and granite topography. This association ideally explains why the BFC may subparallel or terminate against the FBF north of the study area, and only have a few tens of metres displacement.

The second-order listric extensional Transverse Faults dissect the uplifted block bounded by the FBF and BFC and mimic the granite topography. The Transverse Faults near-parallel the east-west trend of the -500, -1000 and -1500 m granite contours and plunge to the north. The north-south extension of the uplifted block resulted from the forceful emplacement of the asymmetrical granite ridge beneath the mine area.

Third-order horst and grabens developed as a consequence of both synthetic and antithetic displacements upon the listric extensional Transverse Faults, normal to the BD_1 minimum compressive stress (σ_3). These third-order structures are the result of east-west extension along the eastern margin of the asymmetrical granite ridge where the -500 and -1000 m granite contours strike east-west. Extension in this region may have resulted from the emplacement of a late-stage granite phase directly beneath the mine area in the region of

the apophysis in the -500 m granite contour. This interpretation is somewhat supported by the geophysical data, as discussed, and the granite geochemistry of Bajwah *et al.* (in prep.). They define a hydrothermal alteration halo in the granite beneath the mine area from a tourmaline-rich inner core through a sericite zone to an outer albite halo. The Sn-rich hydrothermal fluids exolving from this late-stage granite phase would have gained access to the first-order FBF structure immediately above the granite and then focused along the second-order listric extensional Transverse Faults. These second-order structures acted as basal detachments to the third-order horst and grabens, allowing mineralising fluids access to the mine sequence dolomites distal to the FBF. In these regions carbonate replacement and vein styles of mineralisation were controlled by the third-order structures and resulted in the Updip Orebodies.

The first, second and third-order normal-dextral (BD_1) fault structures associated with forceful granite emplacement at Renison contrast with the compressional structures related to the Tabberabberan Orogeny throughout the rest of western Tasmania. The fault patterns associated with the underlying granite topography resulted from the radial stress field, related to granite emplacement, overlapping with the regional Tabberabberan stress field. The compounding effect of both stress fields was sufficient to initiate normal-dextral brittle deformation (BD_1). The early stages of cassiterite mineralisation were coeval to this BD_1 event. Ode (1957) has invoked a similar superposition of local and regional stress fields to explain the observed patterns of faults and dyke emplacements seen above a granite intrusion in the Spanish Peaks area, Colorado.

As the granite-associated stress field decayed, the earlier brittle deformation structures were overprinted by a dextral wrench, BD_2, consistent with the regional Tabberabberan pattern of faulting and reactivation. The latter stages of cassiterite mineralisation continued during this event. Dextral-wrench displacement on the FBF during BD_2 produced the dilational jog in the Federal region of the FBF, where right lateral reactivation of the FBF was partially transferred along the Transverse Shears 'P' and 'L', resulting in a steep southeast-plunging dilational inflexion on the FBF. The formation of the Melba Fracture Orebody was a possible consequence of this dextral-wrench reactivation, as was the formation of some of the largest carbonate replacement orebodies within the dilational pressure zones adjacent to the convex regions of the Transverse Faults during the associated stress field related to BD_2.

CONCLUSIONS

A detailed geological interpretation of the geology at the Renison tin mine, using cross-section interpretations and computer modelling, has demonstrated the close association between granite emplacement, brittle deformation structures, and cassiterite mineralisation.

Many of the structural complexities at Renison resulted from the forceful emplacement of an asymmetrical northwest-trending Devonian granite ridge. The brittle deformation event (BD_1) associated with emplacement initiated normal-dextral faults subparallel to the granite topography in the overlying late Precambrian Success Creek Formation and early Cambrian Crimson Creek Formation. The Federal-Bassett Fault (FBF) was propogated as a double

fault structure on the easternmost margin of the granite, and offset the monoclinal mine sequence by upwards of 700 m in the immediate mine area. The FBF was the primary focus for hydrothermal fluids that were responsible for carbonate replacement and vein styles of mineralisation. The Blow Fault Complex (BFC) was initiated subparallel to the FBF over an apophysis in the granite contours, and forms the westernmost boundary to economic cassiterite mineralisation at Renison.

The Transverse Faults interconnect the FBF and BFC, subparallel to the east-west trend of the -500 and -1000 m granite contours. These second-order listric fault structures propogated from convex-west flexures in the footwall of the FBF and dissected the mine horst, resulting in approximately 15% north-south extension. A dextral-wrench reactivation (BD_2) overprinted the earlier BD_1 fault structures and produced a dilational jog in the Federal region of the FBF as a consequence of differential displacements on the Transverse Faults. The stress field associated with BD_2 may also have played a significant role in the formation of the largest carbonate replacement styles of mineralisation at Renison, which occur within dilational zones adjacent to the sigmoidal convex flexures on the Transverse Faults. The Melba Fracture Orebody also formed in a dilational zone, between 'Shear L' and 'Shear P', possibly as a consequence of BD_2 reactivation. Carbonate-magnetite mineralisation responsible for the Polaris Orebody occurs within the Transverse Fault, 'Shear P', close to its intersection with 'Shear L'.

Third-order, north-striking horst and graben structures developed as a consequence of both synthetic and antithetic faults above the listric extensional Transverse Faults. These-third order structures resulted in a 20% extension of the mine sequence in the direction of the minimum compressive stress for the BD_1 event above an apophysis in the -500 m granite contour. These third-order fault structures controlled the carbonate replacement styles of mineralisation in the up-dip dolomite horizons distal to the FBF.

At Renison, the intimate associations between brittle deformation structures, granite topography and its alteration geochemistry strongly suggest that a late-stage tin-rich granite forcefully intruded the sediments immediately beneath the mine during the Devonian. The granite intrusion not only prepared the overlying carbonate-rich sediments structurally but also supplied the source of fluids responsible for the carbonate replacement and the vein styles of cassiterite mineralisation.

ACKNOWLEDGEMENTS

REFERENCES

AL KADHI, A.; HANCOCK, P. L. 1980. Structures of the Durma–Nisah segment of the central Arabian graben system. *Miner. Resour. Bull. Saudi Arabia* 16:1–40.

BAJWAH, Z. U.; WHITE, A. J. R.; KWAK, T. A. P.; PRICE, R. C. In prep. The Renison Granite, western Tasmania: A petrological and geochemical investigation of hydrothermal alteration.

BARBER, A. 1990. *The structure and geochemistry of the Polaris orebody Renison Bell.* B.Sc. (Hons) thesis, University of Tasmania : Hobart.

BERRY, R. F.; CRAWFORD, A. J. 1988. The tectonic significance of Cambrian allochthonous mafic-ultramafic complexes in Tasmania. *Aust. J. Earth Sci.* 35:523–533.

BROOKS, C. 1966. The Rb/Sr ages of some Tasmanian igneous rocks. *J. geol. Soc. Aust.* 13:457–469.

BROWN A. V. 1986. Geology of the Dundas–Mt Lindsay–Mt Ramsay area. *Bull. geol. Surv. Tasm.* 62.

BURNHAM, C. W. 1979. Magmas and hydrothermal fluids, *In:* BARNES, H. L. (ed.). *Geochemistry of Hydrothermal Ore Deposits. 2nd Edition.* 71–136. John Wiley & Sons.

CANNARD, C. 1989. *Renison Bell Tin Mine ore reserves report.* (unpublished).

CANNARD, C. 1991. *Renison Bell Tin Mine ore reserves report.* (unpublished).

CORBETT, K. D.; LEES, T. C. 1987. Stratigraphic and structural relationships and evidence for Cambrian deformation at the western margin of the Mount Read Volcanics, Tasmania. *Aust. J. Earth Sci.* 34:45–68.

CRERAR, D. A.; SUSAK, H. J.; BORESIK, M.; SCHWARTZ, S. 1978. Solubility of the buffer assemblage pyrite + pyrrhotite + magnetite in NaCl solutions from 200° to 350°. *Geochim. Cosmochim. Acta.* 42:1427–1439.

DAVIES, B. M. 1985. *The nature and mechanism of stratabound mineralisation in the Renison Mine.* Ph.D. thesis, James Cook University : Queensland.

HARDING, T. P. 1985. Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion. *Bull. Amer. Assoc. Petrol. Geol.* 69:582–600.

HEINRICH, C. A. 1990. The chemistry of hydrothermal tin (-tungsten) ore deposits. *Econ. Geol.* 85:457–481.

HOLYLAND, P. 1987. *Structure and hydrodynamics of the Renison Tin Mine.* Ph.D. thesis, University of Queensland.

KITTO, P. A. 1990. *The history of brittle deformation and reactivation at Renison tin mine, Tasmania.* Mine report, Renison Limited (unpublished).

KITTO, P. A.; BERRY, R. F. 1991. A history of brittle deformation and related mineralisation at Renison tin mine, Western Tasmania. *Rec. Bur. Miner. Res. Geol. Geophys. Aust.* 1990/95. (SGEG Ore Fluids Conference, Canberra).

KITTO, P. A.; BERRY, R. F. 1992. The structural controls on mineralisation at the Renison tin mine, western Tasmania. *Abstr. geol. Soc. Aust.* 32:70–71.

KWAK, T. A. P. 1987. W-Sn skarn deposits and related metamorphic skarns and granitoids. *Developments in Economic Geology* 24.

LEA, J. R. 1986. *Study of Shear P.* Mine report, Renison Limited (unpublished).

LEA, J. R. 1991. *Renison mine lease exploration: Models, concepts, interpretation and future directions.* Mine report, Renison Limited (unpublished).

LEAMAN, D. E. 1988. *Granites of west and north-west Tasmania. Provisional interpretations for the Heemskirk Granite.* Geophys. Rep. Mt Read Volc. Proj. Dep. Mines Tasm.

LEAMAN, D. E. 1990. *Renison mine lease gravity survey.* Consultants report, Leaman Geophysics.

MARJORIBANKS, R. W. 1989. *A structural study of the Renison Mine area with recommendations for further exploration.* Mine report, Renison Limited (unpublished).

MARJORIBANKS, R. W. 1990. *Structural observations of the Renison Mine area with some exploration implications.* Mine report, Renison Limited (unpublished).

MCQUITTY, B. M. 1991. *Report on phase 1 of the Rendeep Project; Lower North Bassett resource.* Mine report, Renison Limited (unpublished).

MORELAND, R. 1988. *The Renison Bell Tin Mine, technical review.* Mine report, Renison Limited (unpublished).

MORRISON, G. W. 1982. *Stratigraphy and sedimentology of the Renison mine sequence.* Mine report, Renison Limited (unpublished).

NAYLOR, M. A.; MANDL, G.; SIJPESTEIJN, C. H. K. 1986. Fault geometries in basement-induced wrench faulting under different initial stress states. *J. Struct. Geol.* 8:737–752.

ODE, H. 1957. Mechanical analysis of the dyke pattern of the Spanish Peaks area, Colarado. *Bull. geol. Soc. Am.* 68:567–576.

PATTERSON, D. J. 1979. *The geology and mineralisation at Renison Bell, western Tasmania.* Ph. D. thesis, University of Tasmania : Hobart.

PATTERSON, D. J.; OHMOTO, H. H.; SOLOMON, M. 1981. Geologic setting and genisis of cassiterite-sulfide mineralisation at Renison Bell, western Tasmania. *Econ. Geol.* 76:393–438.

SIMONSEN, M. 1988. *An interpretation of the carbonate-magnetite fault.* Mine report, Renison Limited (unpublished).

SOLOMON, M. 1981. An introduction to the geology and metallic ore deposits of Tasmania. *Econ. Geol.* 76:194–206.

WERNICKE, B.; BURCHFIEL, B. C. 1982. Modes of extensional tectonics. *J. Struct Geol.* 4:105–115.

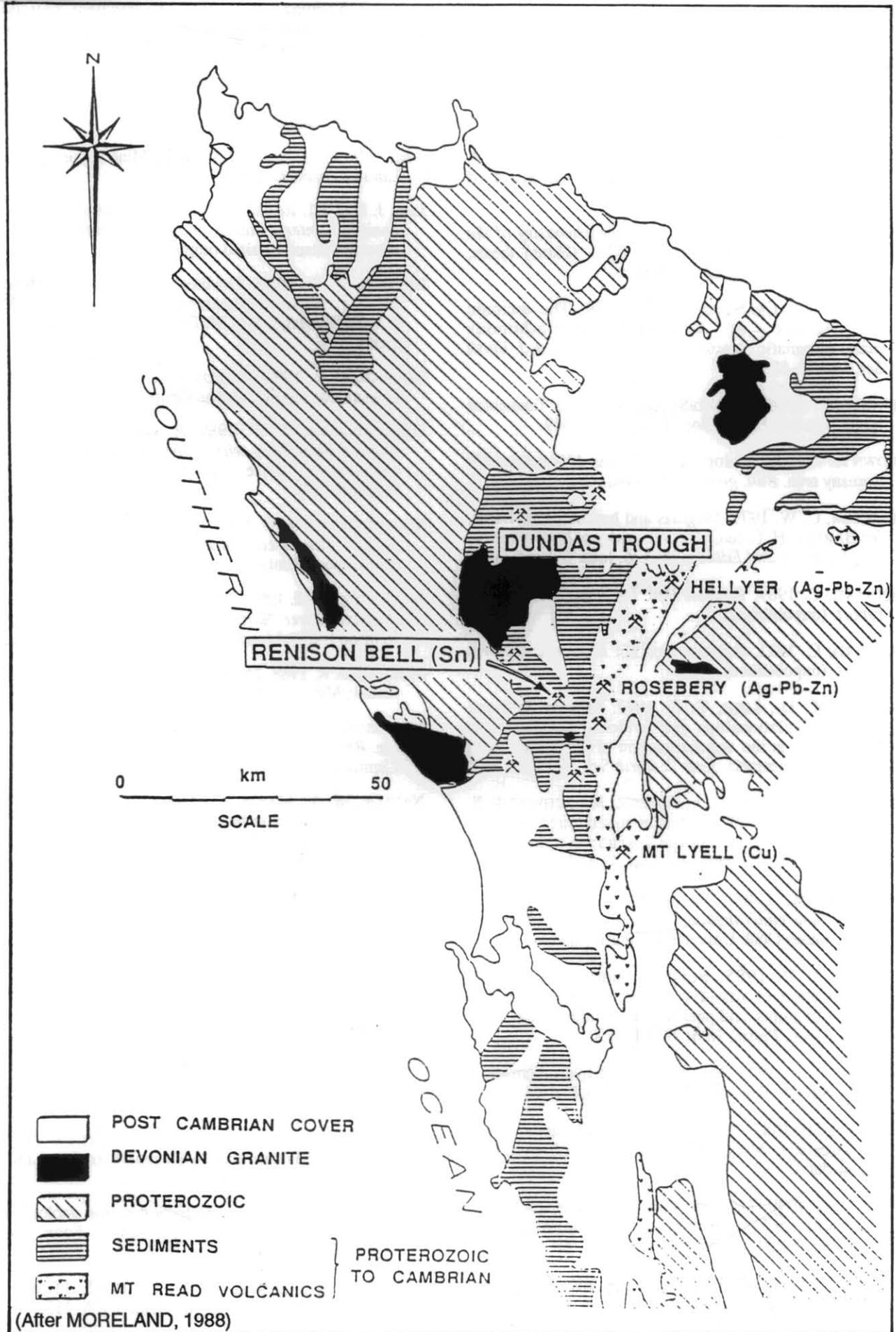WOODCOCK, N. H.; FISCHER, M. 1986. Strike-slip duplexes. *J. Struct. Geol.* 8:725–735.

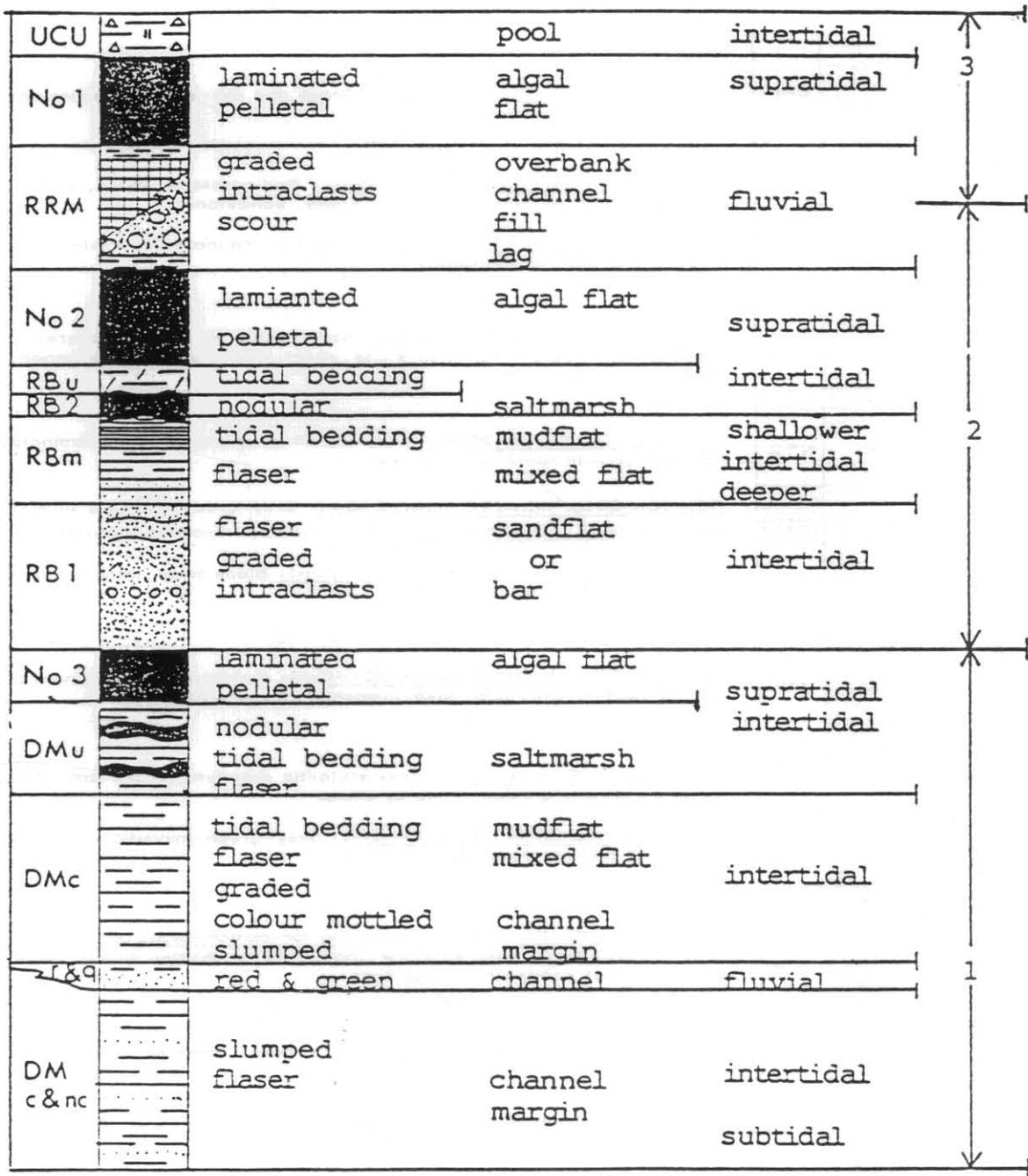**Figure 1**. Regional geology, western Tasmania.

Unit		Features	Environment	Interpretation	Cycle
UCU		pool		intertidal	
No 1		laminated pelletal	algal flat	supratidal	3
RRM		graded intraclasts scour	overbank channel fill lag	fluvial	
No 2		lamianted pelletal	algal flat	supratidal	
RBu		tidal bedding		intertidal	2
RB2		nodular	saltmarsh		
RBm		tidal bedding flaser	mudflat mixed flat	shallower intertidal deeper	
RB1		flaser graded intraclasts	sandflat or bar	intertidal	
No 3		laminated pelletal	algal flat	supratidal intertidal	
DMu		nodular tidal bedding flaser	saltmarsh		
DMc		tidal bedding flaser graded colour mottled slumped	mudflat mixed flat channel margin	intertidal	1
		red & green	channel	fluvial	
DM c & nc		slumped flaser	channel margin	intertidal subtidal	

Figure 2

Sedimentary cycles in the Renison mine sequence, based on interpreted depositional environments. The lower two cycles are retrogressive, and the third cycle is partial but transgressive (from Morrison, 1992).

5 cm
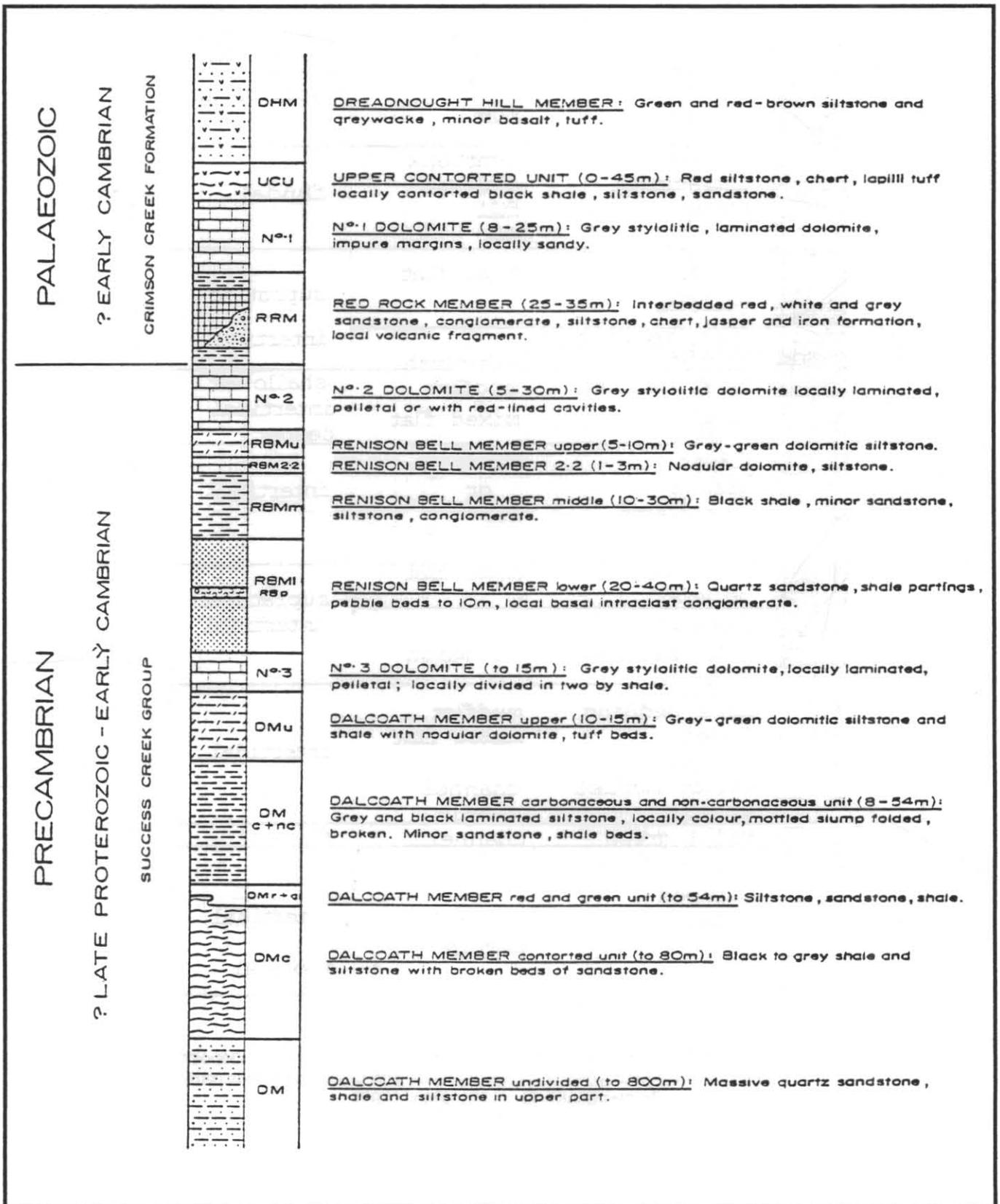
Figure 3

Stratigraphy of the Renison mine sequence (from Moreland, 1988).

5 cm

Figure 4

W

CRIMSON CREEK FORMATION

MINE SEQUENCE

SUCCESS CREEK FORMATION

1500RL

ARGENT FAULT

FEDERAL-BASSETT FAULT

1500RL

PINE HILL GRANITE RIDGE

E

38000E

40000E

42000E

44000E

MINE CROSS SECTION

65800 NORTH

0   1000m

(After LEA, 1991)

-500RL

-500RL

TASMANIA — AN ISLAND OF POTENTIAL

5 cm

12/21

RENISON TIN MINE – SURFACE GEOLOGY

Scale |⎯⎯ 200 m ⎯⎯|

Legend

CCF	Crimson Creek Formation
DHM	Dreadnaught Hill Member
	No.1 Dolomite Horizon
RRM	Red Rock Member
	No.2 Dolomite Horizon
RBM	Renison Bell Member
	No.3 Dolomite Horizon
DM	Dalcoath Member

Geology interpreted from drill hole data by P.Kitto – April 1991
Centre for Ore Deposit and Exploration Studies – The University of Tasmania

Figure 5

5 cm

FIGURE 6

MINE CROSS SECTION

65820 NORTH.

W · E

ARGENT FAULT

BLOW FAULT

MERCURY FAULT

N°1 DOLOMITE

N°2 DOLOMITE

N°3 DOLOMITE

'SHEAR P'

'SHEAR L'

MELBA ORE

FEDERAL-BASSETT FAULT

5 cm

13/21
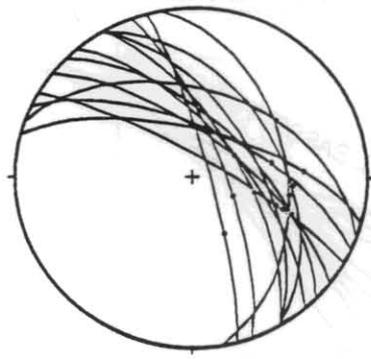
(a) BD1 - normal-dextral fault striatins for FBF.
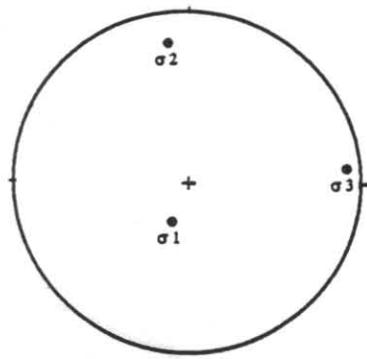
(b) Principal compressive stress directions for BD1.
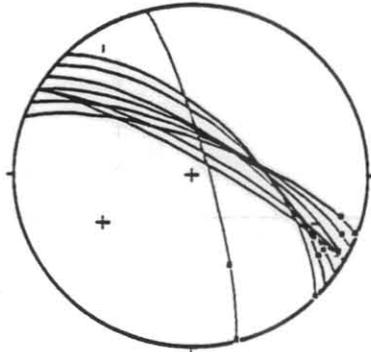
(c) BD2 - dextral wrench fault striations for FBF.
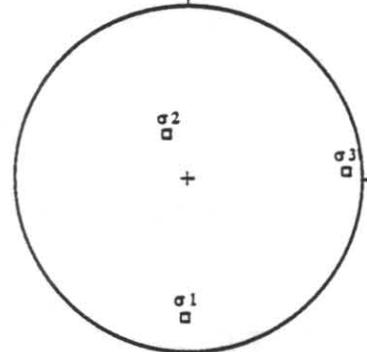
(d) Principal compressive stress directions for BD2.
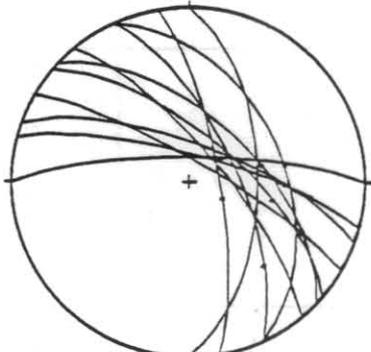
(e) BD3 - reverse sinistral fault striations for FBF.
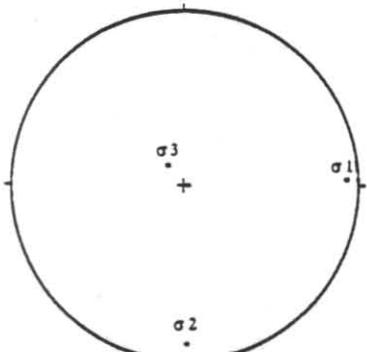
(f) Principal compressive stress directions for BD3.
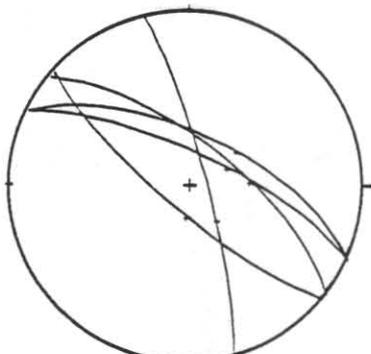
(g) BD4 - normal sinistral fault striations for FBF.
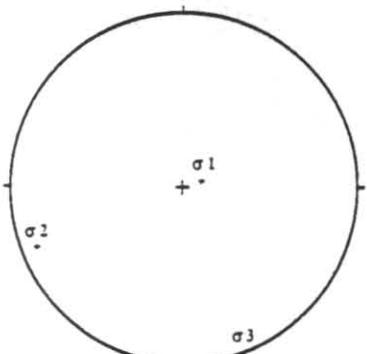
(h) Principal compressive stress directions for BD4.

Figure 7

Lower hemisphere equal area projections illustrating the brittle deformation history for
the Renison tin mine, western Tasmania (from Kitto and Berry, 1991).

5 cm
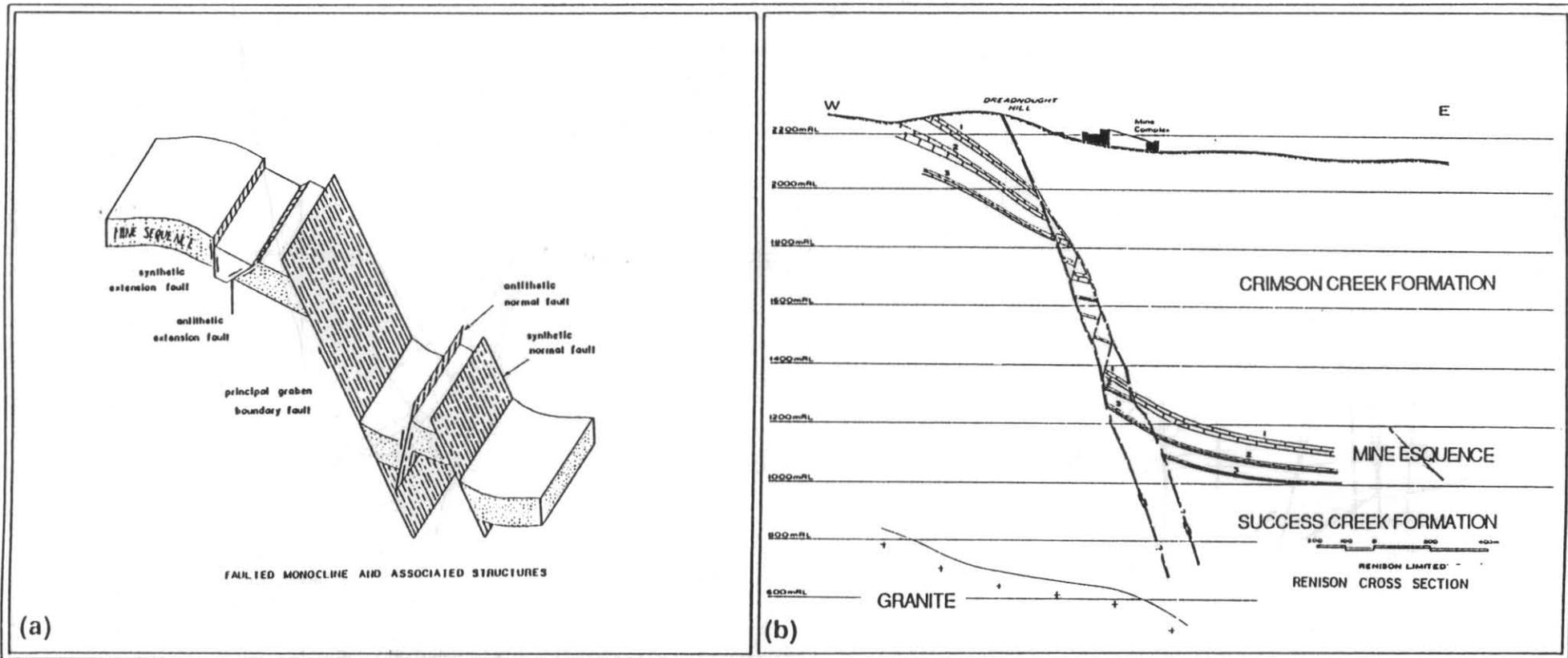
Figure 8a

Faulted monocline and associated structures (after Al Kadhi and Hancock, 1980).

Figure 8b

North Bassett cross-section, 67000 North (after McQuilty, 1991).
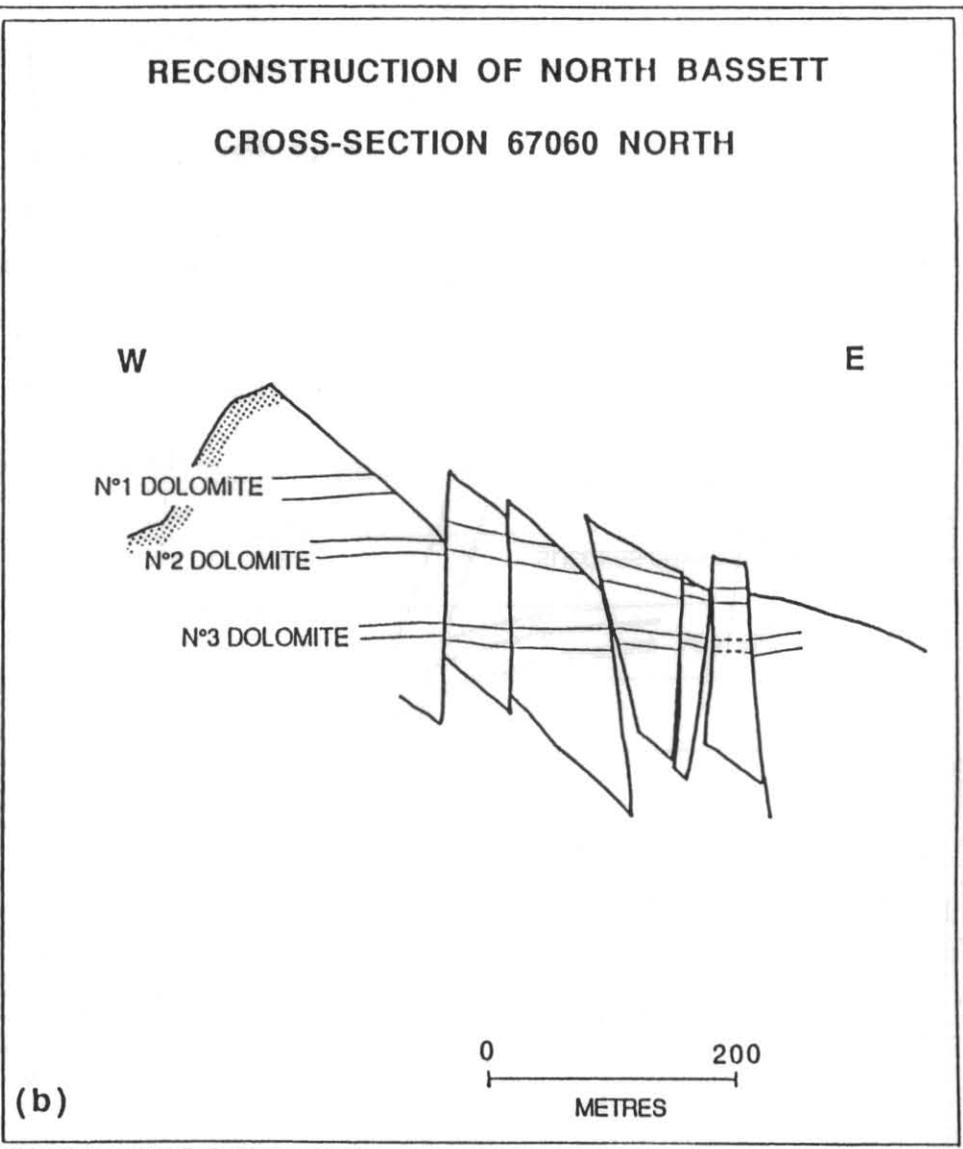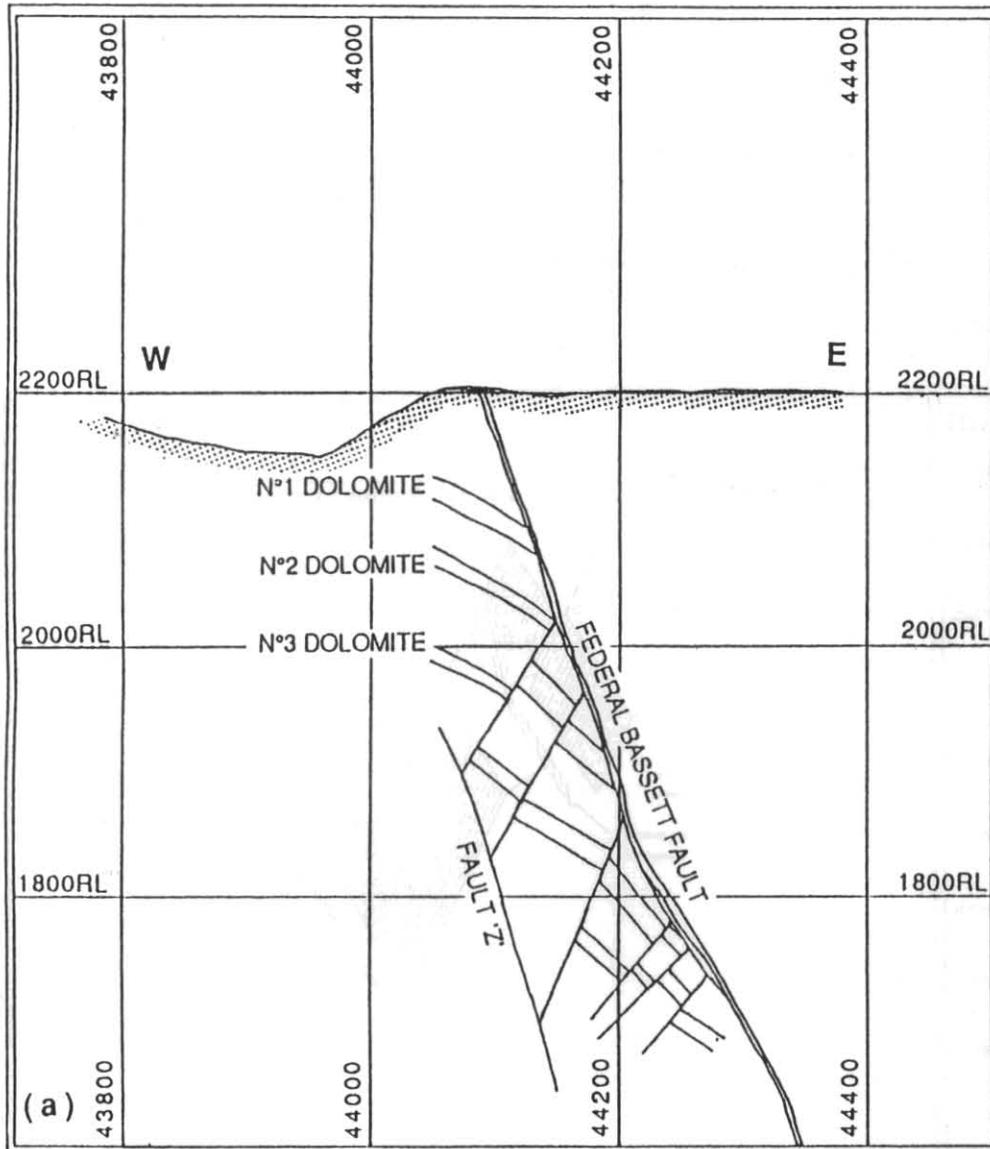
Figure 9a

North Bassett cross-section, 67060 North.

Figure 9b

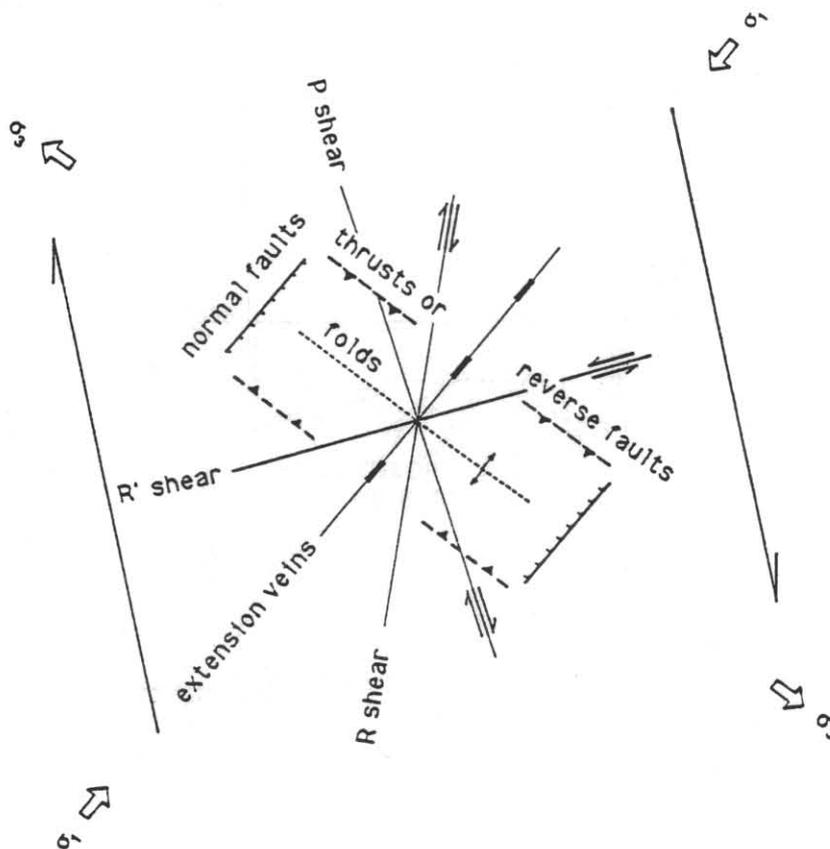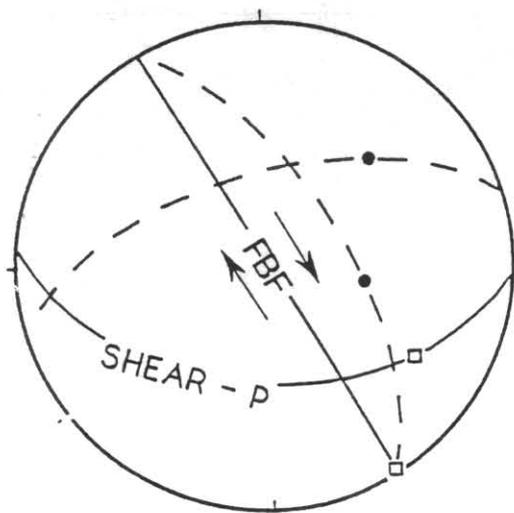Reconstruction of North Bassett cross-section, 67060 North.

SULFIDE REPLACEMENT OF No.3 DOLOMITE
(FOOTWALL PROJECTION)
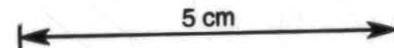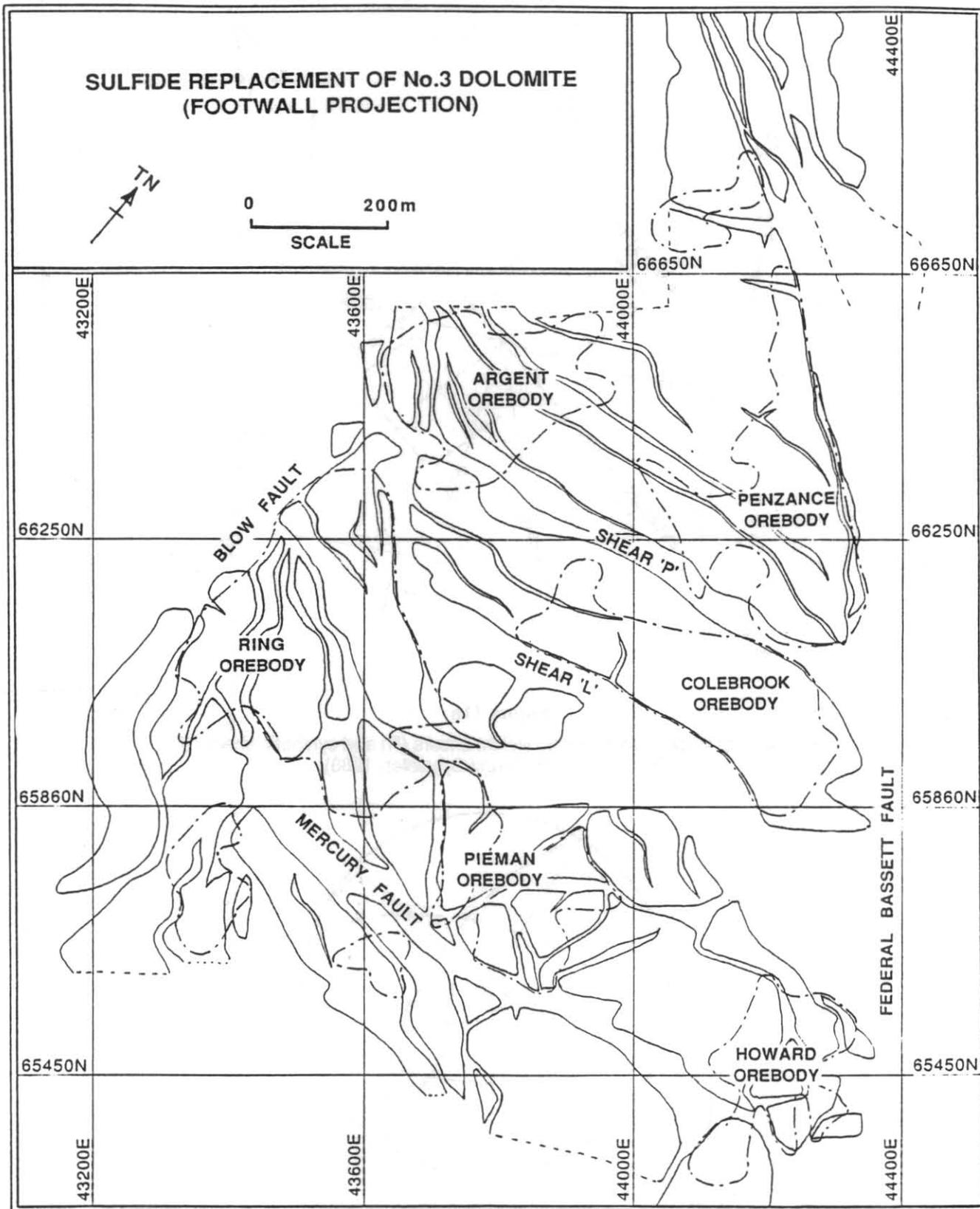
Figure 10

Figure 11a

Orientation of folds, reverse faults, Reidel shears (R) and synthetic shears (P)
(after Harding, 1974 and Sylvester, 1988).

_ _ NORMAL−DEXTRAL MOTION

—— ROTATION TO DEXTRAL WRENCH

5 cm

Figure 11b

Lower hemisphere equal area projection of the Federal-Bassett Fault and the secondary reverse fault 'Shear P'.

POLARIS CROSS SECTION
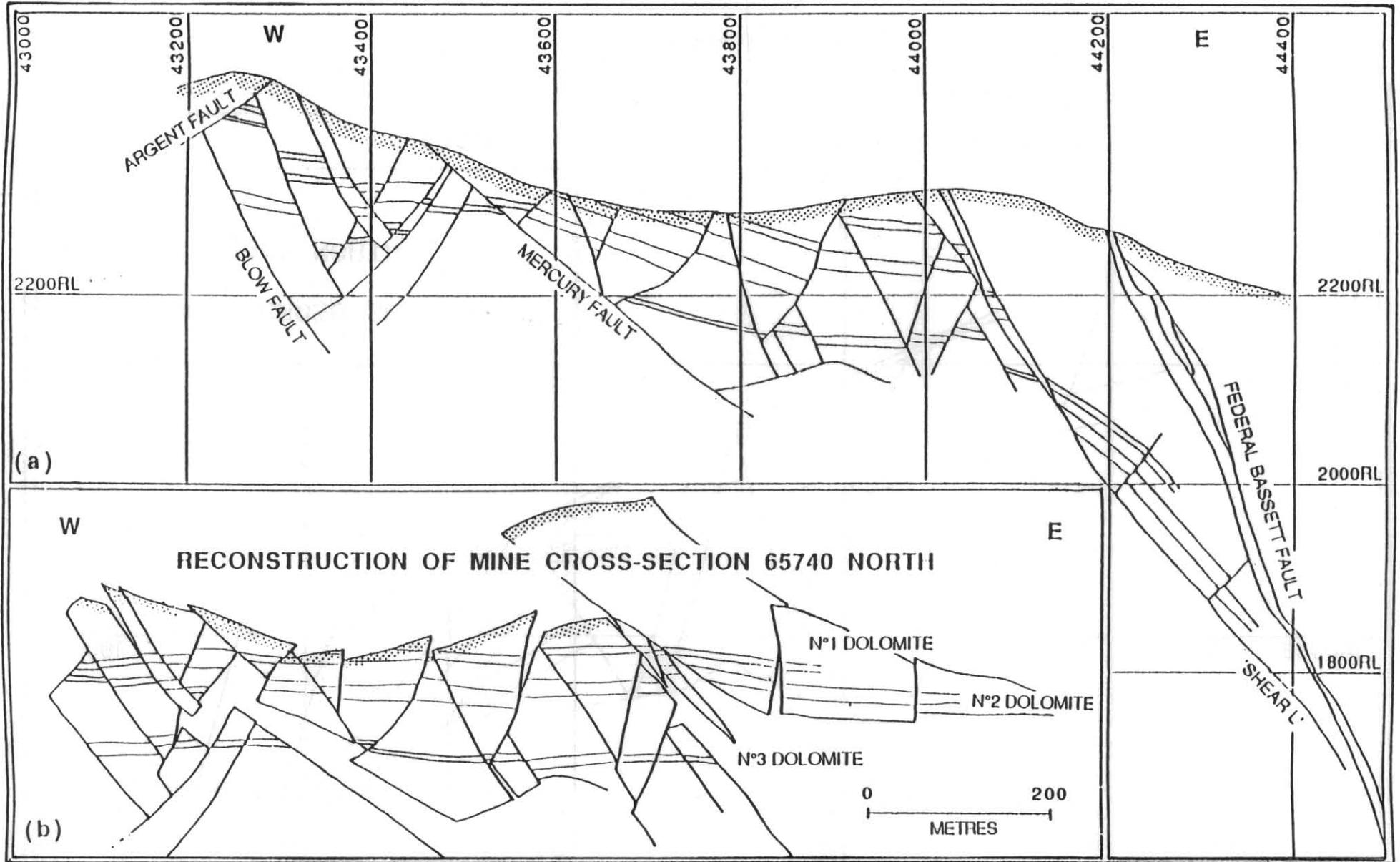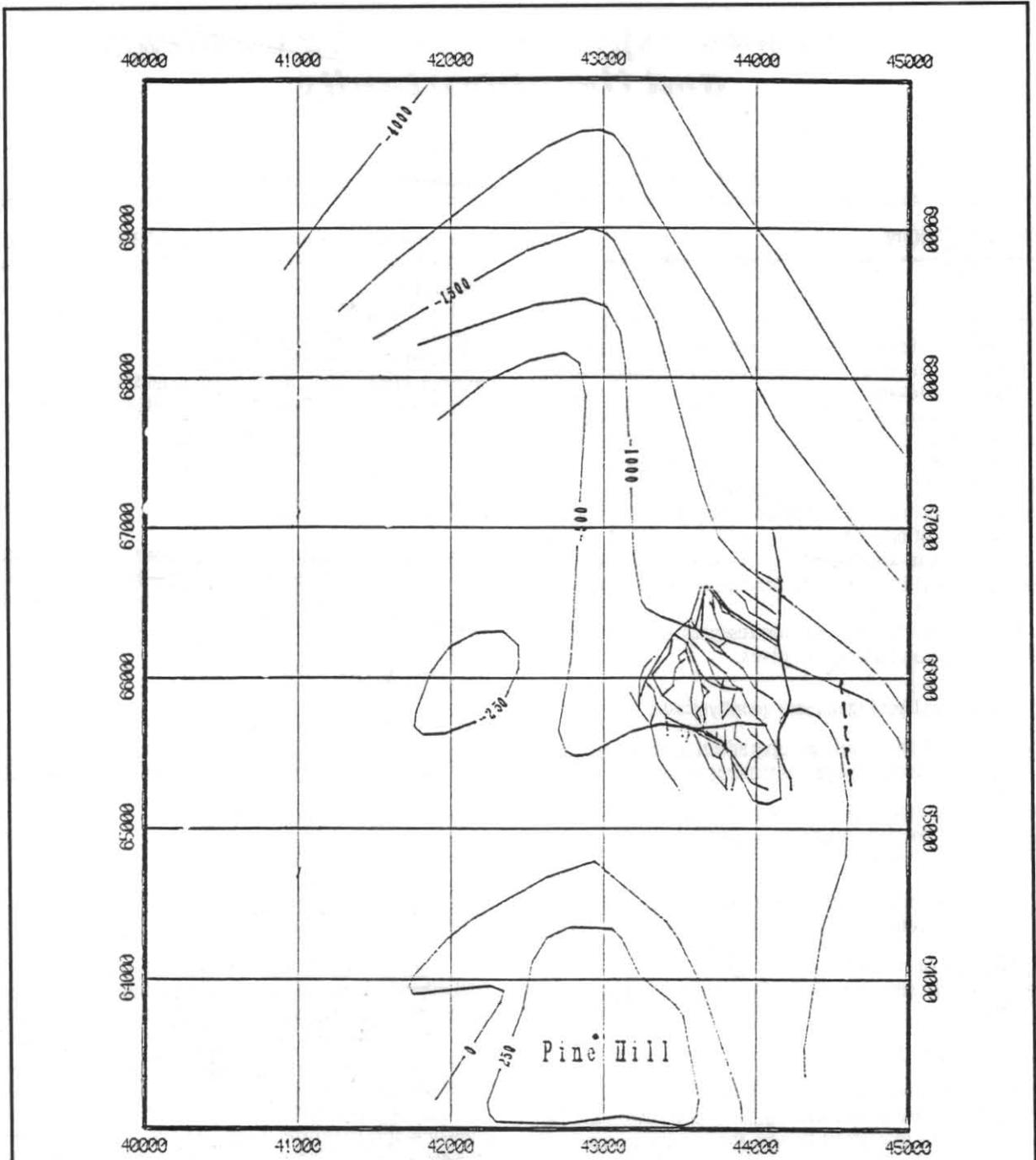
66440 NORTH

0   100 m

Figure 12

5 cm
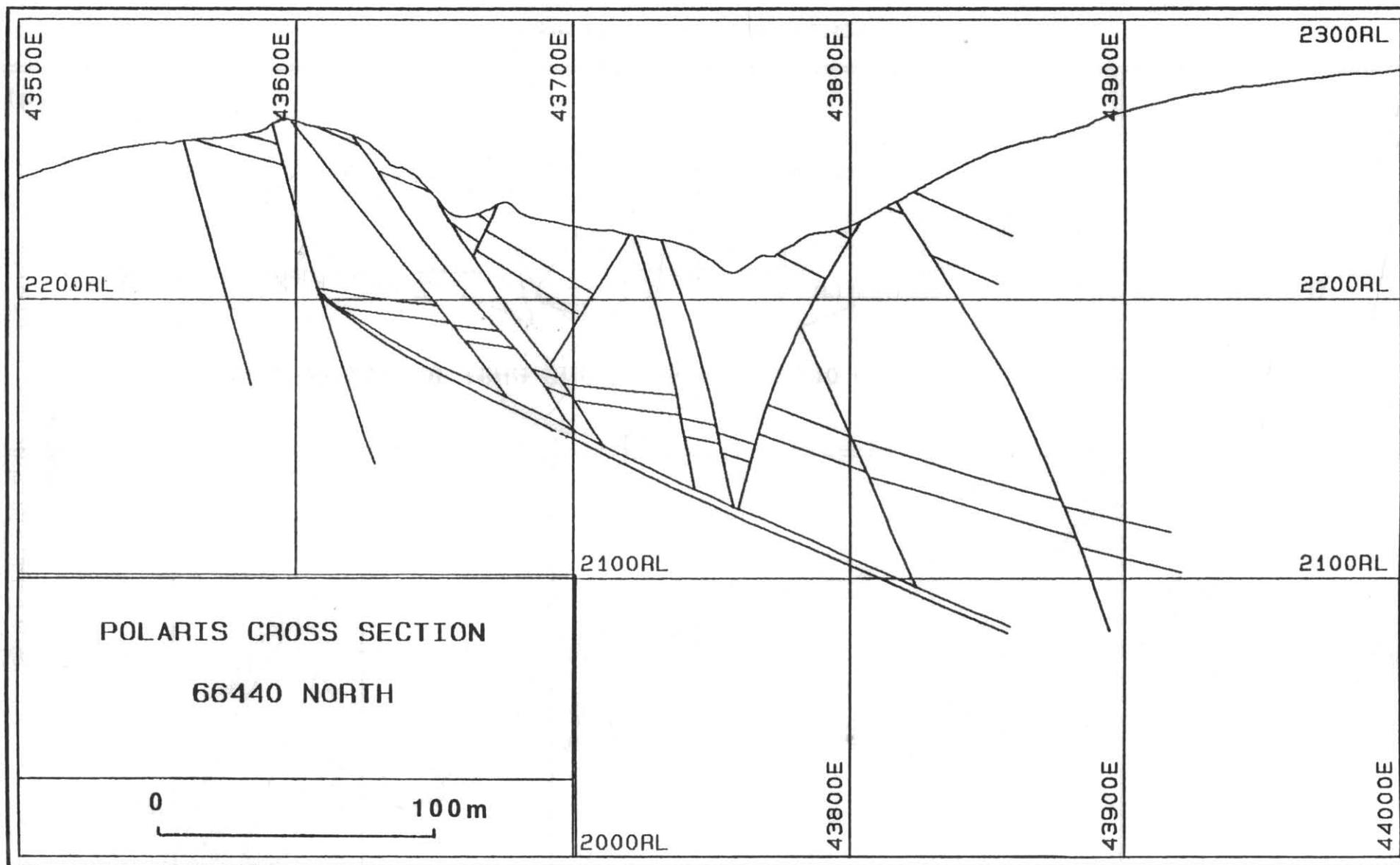
Figure 13a. Mine cross-section, 65740 North.

Figure 13b. Reconstruction of Mine cross-section, 65740 North.
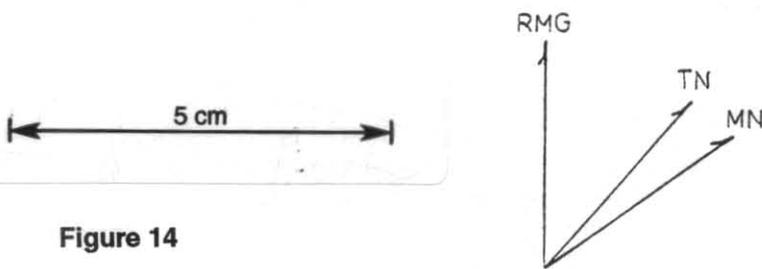
Location Diagram

FAULTS AND GRANITE CONTOURS

5 cm

Figure 14