007603 PROPERTY FILE

Report on activities June 1995

Structure of the Westmin Mine at Myra Falls

Ron Berry
CODES Key Centre, University of Tasmania

Introduction

The project was aimed at defining the structural style of the presently active part of the Westmin mine at Myra Falls. The study was carried out over 8 days in June 1995. Most of the time was spent looking at drill core with an evening spent looking at the Price Hillside outcrops and one morning underground in the Gopher zone. All structures in the following discussion are referred to by regional orientation (azimuth relative to the mine grid is given in brackets. Mine North is equivalent to regional NE).

Regional structure

The regional structure of Vancouver Island has been discussed in a number of papers. Nixon et al (1994) includes a coherent statement of the Mesozoic and Tertiary structural history of northern Vancouver Island. They proposed the following history

Phase 1. Mid to Late Jurassic
- NE compression with NW striking thrusts.
- NW trending folds (including the Buttle Lake uplift)

Phase 2 Late Cretaceous
- N direct compression
- NW striking oblique dextral faults

Phase 3 Tertiary
- NW-NNW extension
- NE-ENE striking normal faults
- weak reactivation of wrench faults

Unfortunately the nature of the pre-Jurassic deformation is less clear. The Sicker Group is generally thought to be unconformably overlain by Karmutsen Formation (e.g. Brown & Yorath 1985) but the nature of this unconformity is poorly constrained. In many locations it is a disconformity.

At the Westmin mine, a pre-Jurassic deformation is recognized as subvertical NW striking faults which pre-date Island intrusives (Juras 1987)

Mine scale structure

Reid (unpublished report to Westmin) identified a number of structural elements in the mine. A summary of Reid's structural history is listed below:

1. Horizontal upright open NW (W) trending folds
2. Anastomosing subvertical zones of strong cleavage with stretching lineation (referred to as L1 in this report) trending NW to NNW (W to WNW) these zones were at least partly dextral
3. NW (W) striking faults partly related to cleavage have early sinistral and late dextral movement

4. N (NW) striking dextral and W (SW) striking sinistral faults
5. High angle reverse faults with NW (W) strike
6. Normal movement on NW (W) striking, NE (N) dipping, faults which contain clay gouge

This structural history correlates well with the regional structure. The normal faults (6) correlate with Tertiary extension. Events 4 and 5 as described by Reid are consistent with the late Jurassic event. The major difference seen at the mine is that the Cretaceous dextral movement on NW striking faults recognized in northern Vancouver Island are only recognized as reactivation of earlier faults in the mine area (late stage of part 3 and possibly 2). Reid identified the open upright NW trending folds at the mine as early whereas folds of this trend have been recognized regionally (e.g. Buttle Lake uplift) as folding the Karmutsen Formation. They have been correlated with SW directed thrusting and interpreted to be of Jurassic age. The lack of a significant unconformity under the Karmutsen Formation around the Buttle Lake uplift limits this folding to local zones (or pre Permian Buttle Lake Formation). This conflict is discussed further below.

The major mine structures which have no known analogues in the Mesozoic stratigraphy are:

2. Anastomosing subvertical zones of strong cleavage with stretching lineation trending NW to NNW (W to WNW)
3. NW (W) striking faults partly related to cleavage with early sinistral movement

These are the structures which Juras (1987) observed are intruded by the Island granitoids of mid-Jurassic age and which best interpreted as late Paleozoic (pre-Karmutsen Formation) on the existing data.

General Results

From my observations of the style and orientation of faults in core it seems reasonable to simplify the multi-stage structural history to a three stage evolution. The stages are summarized in Fig. 1. They are:

1. Pre-Jurassic

1. Early wrench movement dominated by entirely ductile shear zones. These include subvertical cleavage zones (2 above) and early parts of 3. The sense of shear on these zones is still in doubt. The work of Reid was inconclusive as to which movement sense dominated the early steep faults. The structural style of the flat zones suggest that these are also active during this generation of fault movement. My impression from hand specimen work was that the flat faults produce a top to the NW (W) movement sense, consistent with the early sinistral movement reported by Reid. In contrast, hand specimen textures of many of the steeper shear zones indicate a dextral movement.

Oriented samples of steep shear zones, two from the Price hillside and four from the Gopher zone, were examine in thin section. All of these samples were dominated by dextral sense of shear. In three samples there was evidence for an earlier fabric. In two cases this could be reasonably interpreted as a sinistral sense of shear. A sample from the Price hillside with a flat lying shear zone indicated top to NW (W) sense of shear. The extent of the dextral fabric on steep shear zones suggests this movement sense totally dominates this system and an overall dextral displacement is predicted for these zones, albeit with low reliability. The top to NW (W) sense on flat faults suggests that these structures were not substantially reactivated during dextral phases of movement. The textures within shear zones intruded by Island plutonic suite needs more detailed investigation to unravel the history of movement on these zones.

The only veining associated with these structures is very fine quartz veins within the black slates in the flat fault zones. There may be some epidote veining associated with cleavage formation in the upper Myra Formation.

The structures described here are anomalous. They lack any brittle features. In core it is often difficult to recognized the associated cleavage. (In outcrop the cleavage is more obvious.) The lack of any brittle features and weak cleavage compared to the strain, as defined by deformed clasts, is interpreted as limiting this structure to a pre- to early syn-peak metamorphic age. The weak cleavage may be partly the result of contact metamorphism related to the Jurassic Island intrusives. If a two stage activation is proved on these structures the foliation may be suppressed by the action of two different strain fields which both enhance the lineation.

2. Late Mesozoic

Both stages 4 and 5 of Reid are associated with quartz carbonate veins. Both show typical brittle ductile textures (discrete faults surrounded by narrow zones of cleavage development c.f. Ramsay 1980). In core these structures have a discrete fault surface surrounded by a zone of enhanced cleavage development. The cleavage development zone is stronger on the thrust faults. The orientations of both stages 4 and 5 require maximum compression to be NE-SW (N-S).

Late stage dextral movement on NW striking subvertical faults may correlate with the regional Cretaceous deformation but I was unable to distinguish this event in core.

3. Tertiary

Finally the normal fault movement appears to be largely associated with gouge (6. of Reid above). I did not find any veins, spatially associated with gouge, which definitely indicated a normal movement. My only worry about this interpretation is that my study did not include core from the North Fault which is interpreted to be the major normal fault in the immediate area. On a mine visit in May, I briefly visited the North Fault underground and there was not a obvious large gouge zone on this structure. My recollection of the North Fault was that it does have a cleavage compatible with normal movement and this is overprinted by a wrench lineation. Some further work is required to characterize the nature of movement on the North Fault and its relationship to gouge.

This stage requires extension towards the NE (N). It may correlate with the formation of the Queen Charlotte basin (Miocene).

Folding

A major anomaly in the structural history is the age and significance of NW trending folds. Regionally there can be little doubt that a NW trending gentle to open fold phase is associated with Mesozoic thrusting. The critical point is whether this is the only fold phase in the mine stratigraphy. Regional maps show no stratigraphic cutoffs in the

Buttle Lake uplift (Muller 1980) suggesting that any pre-Karmutsen Formation folding was very restricted or that folds pre-date the Permian Buttle Lake Formation. The Mesozoic folding is related to SW directed thrusting (Nixon et al 1994) with overturning of folds to the SW. This style of folding is consistent with the sections drawn for the Lynx mine; e.g. Fig. 8 of Walker (1985) shows a open to tight fold above a thrust surface consistent with the regional observations of thrust related folding.

Other structures such as the more upright fold style in the Price Hillside mapped by Juras (1987) are less like the expected geometry of hangingwall anticlines. In the Price Hillside there is a strong spatial association with intense NW striking shear zones with strong subhorizontal stretching lineation. This lineation parallels the fold axis direction (Walker 1985). Reid considered the folds were early and possible related to this stretching lineation. The correlation of the folds with wrench faults suggests they may be positive flower structures which are typical of transpressional settings (Fig. 2). This model would explain why the stretching lineation throughout the deposit (including the high strain zones of the Price and Myra lenses is parallel to the fold axis. It would produce local folding. At the present level of regional data this interpretation cannot be excluded. The significant feature of this model is that is predicts very large displacements on the early wrench faults which may substantially disrupt the ore lenses (especially those in and near the anticlinal structure.

While the three stage structural history suggested here glosses over some of the details in the original study by Reid, it includes most of the structures and has the advantage that these structures are recognizable from textures and orientation in core (fig 3). The major omission is the Cretaceous dextral reactivation of the Paleozoic wrench structures. The aim of this simplified system is to provide a usable set of criteria to aid fault recognition in sections and include kinematic aspects of faulting which can support a more predictive model for ore lens geometry.

Specific Projects

The flat fault above HW Main.

The flat fault above HW main is a anomalous structure. It is consistently recognized over 100's of metres. The recognized structural elements all contain gouge which is related to normal movement. The movement is in the plane of the sections and yet the fault has no recognizable displacement.

I looked at a number of holes which cut through the flat fault above HW Main. The holes considered were W100, W130, W131, W132, W138, W139, 24-066, 24-069, P13-309, P13-313, 20-423 and 20-424. In each case the gouge and broken core that was mapped as the flat fault lies within a zone of relatively flat lying cleavage (cleavage at more than 60° to core axis. In contrast away from the flat faults cleavage is either weak or lies at a low angle to core axis (steep cleavage zones as identified by Reid).

A classic flat fault zone is a zone of 10 m of strongly cleaved rocks with the cleavage dipping less than 40°. In this zone there is 1-3 sections of gouge which vary from 5 cm to 50 cm long and are also bounded by surfaces with shallow dips. In half the flat faults viewed there was also a zone of strong brittle ductile deformation (usually less than 1 m wide).

The brittle ductile shear zones have a more prominent cleavage that is folded incoherently, in kink style or into a shear band geometry as shown on figure 3 (Second generation). These zones were usually recognizable thrust faults based on the shear band geometry and quartz fibre veins. The movement direction was at a high angle to the stretching direction (L1). The faults are spatially associated with quartz carbonate veins. These thrust style faults were not restricted to flat faults but were more common in these zones. None of the thrusts seen in the flat fault above HW had the appearance of a major fault. (See Gopher zone below). The quartz carbonate veins were also found in brittle ductile faults which are steep and have wrench movement (mainly dextral in the HW main zone considered in this study)

The consistent recognition of a flat fault from gouge reflects a reactivation of an older structure. The older structure has a NW trending stretching direction which correlates with the pre-Jurassic wrench faulting. This structure will have an out of section movement which is very difficult to recognized on the existing sections. Very little reactivation has occurred during Tertiary extension but it has been enough to mark this fault position by zones of gouge.

Faulting in the Ridge Zone East section

The rationale for this study was the proposal that the strong E-W stretching lineation was consistent with breaks in the ore formed by extensional faults. The study failed to find any flat structures which were consistent with this interpretation. It is unlikely that extensional low angle structures have caused the breaks in mineralization in the Ridge Zone East. It did emphasize the fact that there are a number of flat faults lying both above and below the ore position.

I looked in detail at the structure within two holes on the 8+23E section and one hole on the 9+94E section. On the 8+23 E section, hole 15-425 was very informative. While there were many minor faults of a variety of types in this core (and especially many brittle ductile style subvertical wrench faults) there was only one zone that was similar to the flat faults in HW main. This was the section from 788-833'. This had a strong cleavage and gouge zones at 788' and 793'. The cleavage was at a high angle to core axis. On the geology section in the Mine records this structure was shown as part of a fault zone dipping moderately N. In holes 15-427, 15-428 and 15-431 there was a similar structure visible and the results were consistent with the interpretation shown on the geology section. The fault shown on this section cut across the stratigraphy at 30° and could not be responsible for omitting the ore position in this section.

On section 9+94E I concentrated on hole 15-340. In this core there are three zones which look like the flat fault: 312-332', 830-849' and 1108-1167'. The last of these is truncated by a steep brittle ductile wrench fault at 1167'. Each of these zones has a strong first generation cleavage, at a high angle to core, overprinted by at least one substantial gouge zone. The first of these structures has been drawn on the section but the other two have not. Again they do not appear to be in a position or orientation suitable to omit the ore position without this being recognizable from the stratigraphy.

Marshall Zone structure

I looked in some detail at 15-502. The mineralization is hosted in a broad zone of sericite silica alteration which has a strong cleavage throughout. The cleavage is subparallel to the core axis. The highest strain is near the contact with the footwall andesite (543-560 m) and below the ore position. The strong cleavage continues for 5 m into the footwall andesite. In contrast in 15-503 the cleavage is not as strong through the ore position. There is a strong cleavage zone in the footwall andesite which continues for 25 m from the top contact. Again the cleavage is subparallel to the core axis Since these holes are drilled at about 45 to the north the inference is that there is a moderate north dip to these shear zones. The high strain zones remain below the ore position in these two holes. High strain zones like this have also been recognized in the footwall of HW main (W131). The dip to the north is similar to the structures recognized in the Ridge Zone East. At this stage there is no reason to expect the structural style to be different in the Marshall Zone than that found further E.

The Myra/Thelwood contact.

Stephen Juras gave me a list of 30 holes which passed through this contact. In particular I was look for a stretching lineation similar to that found in the ore, as this would emphasize the existence of flat ductile structure in contrast to the report by Reid which emphasized steep shear surfaces. I looked at seven holes. In six of them there is a zone of more intense flat lying cleavage below the contact and for the other one the contact is missing because of a high angle fault. Below the contact is a pebbly unit which might have been a fault breccia but this is completely overprinted by the cleavage.

The Price hillside is very instructive as it shows the effect of intense subvertical wrench faults which are aligned along the Price-Myra-Lynx ore zone. On the Price hillside near the Price adit, The wrench faults are less than 5 m apart. Each zone consists of a strong subvertical cleavage and intense subhorizontal stretching lineation. On each of these structures the bedding is offset by a few metres. This observation combined with the known structure from Juras (1987) suggests a direct correlation with positive flower structures which are typical of wrench environments where there is some component of compression, such as at a restraining bend. A page from Sylvester 1988 is attached (Fig. 2) showing classic flower structures which are possible analogues for the Price hillside.

Between these faults, a few narrow horizontal cleavage zones with the same lineation were visible. These zones were often on bedding planes. They were very much sub-ordinate to the wrench structures and might best be considered as transfer zones between the large steep faults. The upper contact of the Myra Formation was coherent and was only sheared in some parts. The unit below the contact had the appearance of a conglomerate and this explains the fact that the "breccia" seen in the drill core was always uniformly overprinted by cleavage. My observations support an erosional origin for the low angle cutoffs at the upper contact of the Myra Formation.

Structure in the vicinity of the Gopher Zone

I was given a short tour of the Gopher zone on Friday 22nd of June. The two important results of this were the observation that the top 5 m of the flat fault that underlies the Gopher zone was dominated by second generation reverse faulting unlike the flat fault above HW Main, and that the steep faults within the Gopher zone that bound the ore have strong first generation wrench features that are identical to those on the Price hillside. The foliation and lineation also effect the ore and there are shreds of deformed dykes on and near this contacts (Fig. 4). Samples taken from these contacts are dominated by dextral sense of shear. This includes the dismembered dykes in the ore and surrounding pyrite sericite schistose zones.

The existence of this steep wrench structure bounding the Gopher zone emphasizes the difficulty in recognizing growth faults which may have been controlling the mineralization. The steep ductile shear zones are largely parallel to the long axis of the ore lenses. They have very little evidence of brittle deformation. The stratigraphy cannot be matched across these structures because of the out of section movement. Thus they often mimic the criteria which are used to recognize growth faults. The features which separate them from earlier structures is the intense lineation (and less visible steep cleavage) in these zones. They are very straight and often truncate the alteration on a very sharp boundary. The ones in the Gopher zone have shreds of dykes parallel to the fault demonstrating the high strain involved. In contrast, more convincing growth faults are likely to be very subtle features with diffuse boundaries overprinted by alteration, there should be no ductile deformation unless it is due to strong reactivation. A good example is the northern margin of HW main as shown on many sections including the one shown by Sherlock & Barrett (in prep). This study supports the existence of NW striking growth faults as suggested by the mine geologists (S Juras pers. comm.) but suggests that they are probably less numerous (or less easy to demonstrate in large numbers) than has been proposed.

References

Brown AS & Yorath CJ 1985. Lithoprobe profile across southern Vancouver Island: geology and tectonics; trip 8. In Tempelman-Kluit, D. Field guides to geology and mineral deposits in the southern Canadian cordillera. p8.1-8.23.

Juras S. 1987. Geology of the polymetallic volcanogenic Buttle Lake Camp, with emphasis on the Price Hillside, central Vancouver Island, British Columbia, Canada. Ph.D. thesis unpubl. Univ. British Columbia.

Muller JE 1980. The Paleozoic Sicker Group of Vancouver Island British Columbia. Geol. Survey Canada, Paper 79-30, 23p.

Nixon GT, Hammack JL, Koyanagi VM, Payie GJ, Panteleyev A, Massey NWD, Hamilton JV & Haggart JW 1994. Preliminary geology of the Quatsino- Port McNeill map areas, Northern Vancouver Island (92L/12, 11). BC Geological Survey Branch Paper 1994-1, 63-85.

Ramsay JG 1980 Shear zone geometry: a review. J Structural Geology 2, 83-99.

Sherlock RL & Barrett TJ in prep. Geology and geochemistry of the HW deposit, central Vancouver Island.

Sylvester A.G. 1988. Strike-slip faults. Geol. Soc Am. Bull. 100, 1666-1703.

Walker RR 1985. Westmin resources' massive sulphide deposits, Vancouver Island; trip 1. In Tempelman-Kluit, D.(ed.) Field guides to geology and mineral deposits in the southern Canadian cordillera. p1.1-1-13.

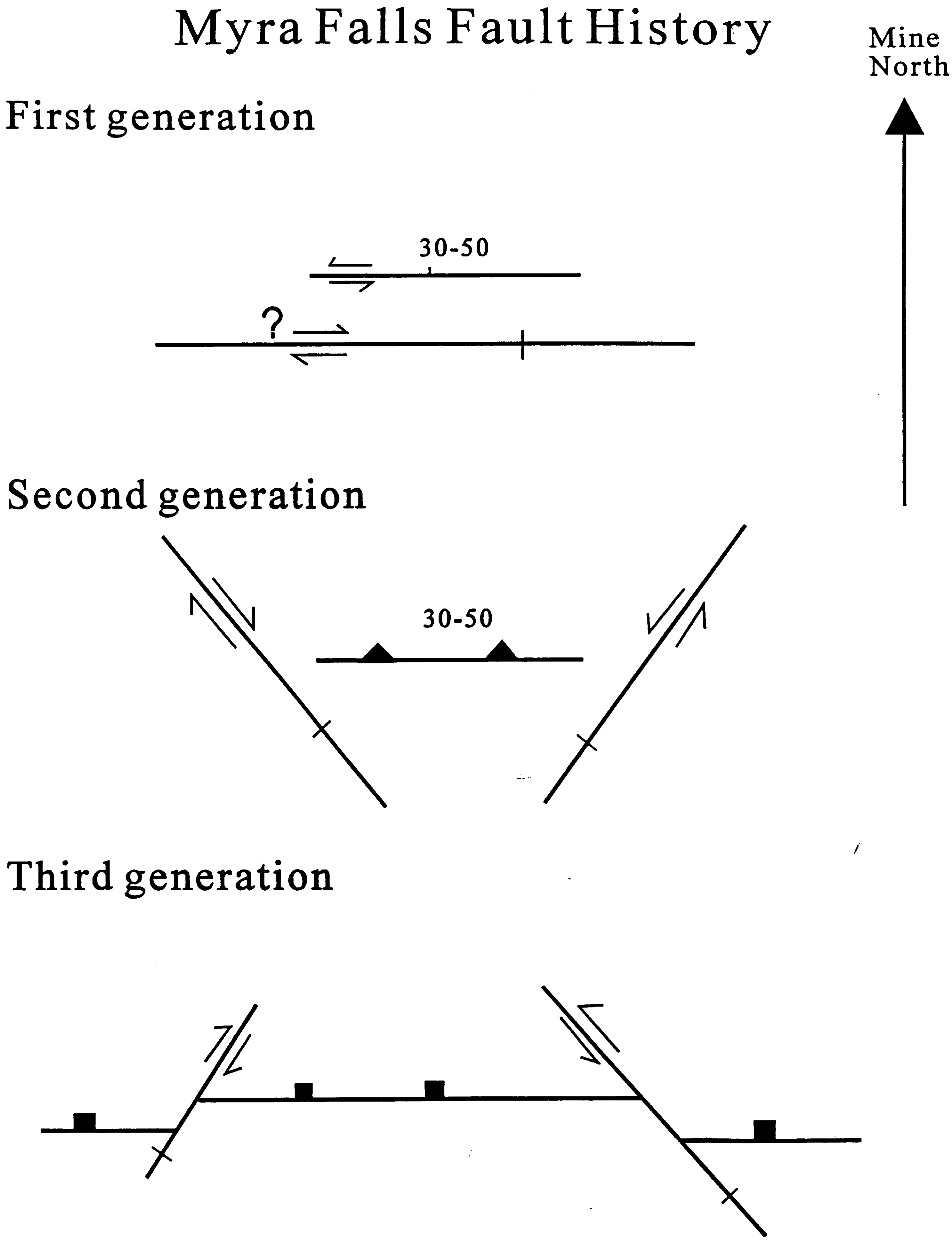


Figure 1. Summary diagram of structures recognized in the Myra Falls area (partly modified from Reid unpubl. Rep.). All orientations refer to the mine grid azimuth.

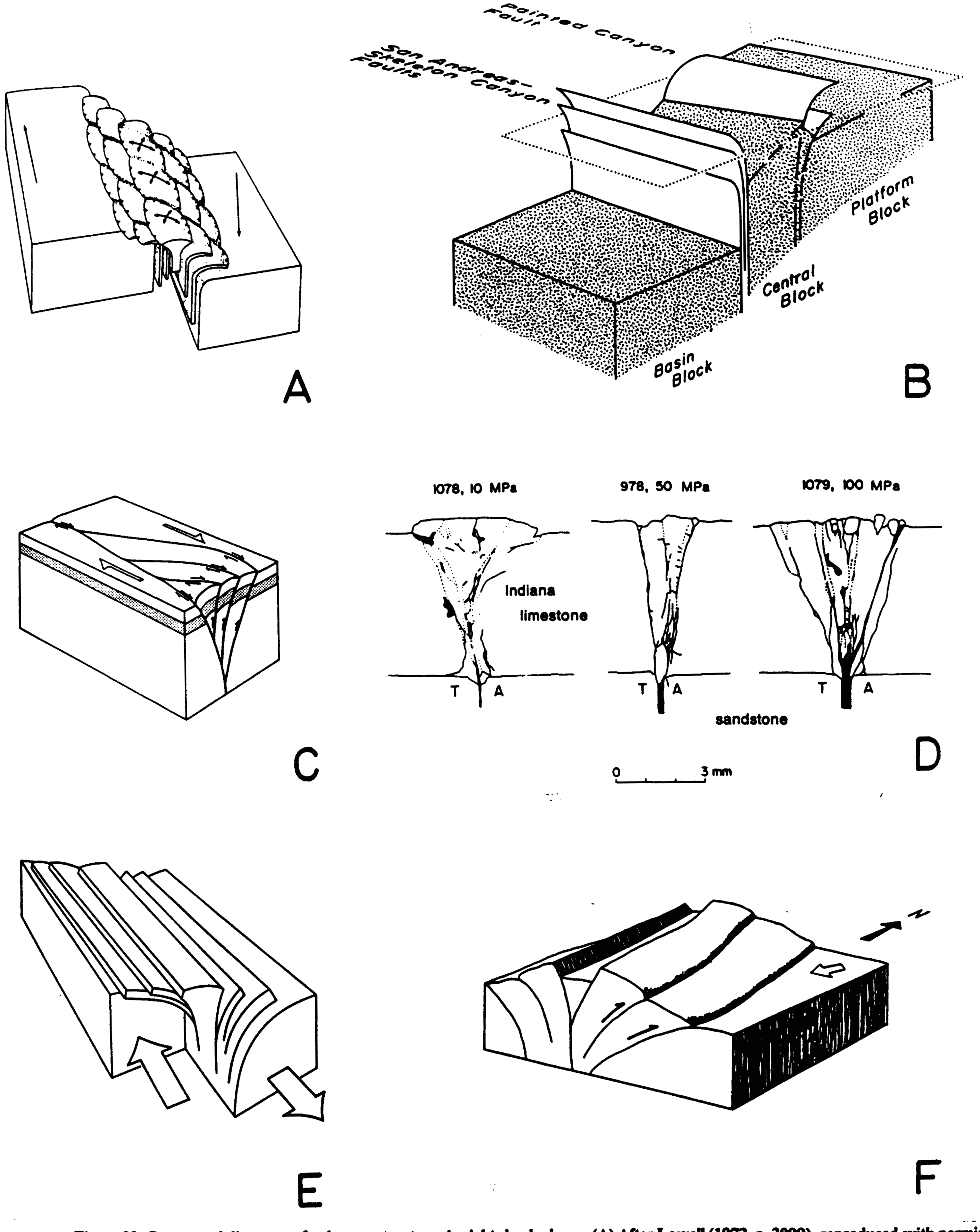


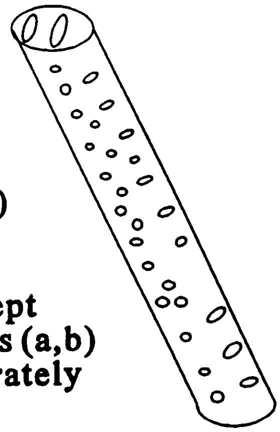
Figure 22. Conceptual diagrams of palm tree structures in right simple shear. (A) After Lowell (1972, p. 3099), reproduced with permission o Geological Society of America and of Lowell, 1988; (B) after Sylvester and Smith (1976), reproduced with permission of American Associatior of Petroleum Geologists and of Sylvester, 1988; (C) after Woodcock and Fisher (1986), reproduced with permission of Journal of Structura Geology; (D) after Bartlett and others (1981), reproduced with permission of Elsevier Science Publishers and of Bartlett, 1988; (E) adaptec with modifications from Ramsay and Huber (1987, p. 529); (F) with axial graben after Steel and others (1985), reproduced with permission o Society of Economic Paleontologists and Mineralogists.

Figure 2. Figure 22 of Sylvester (1988)

Myra Falls Fault History

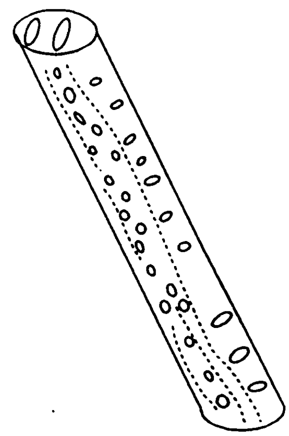
First generation

a



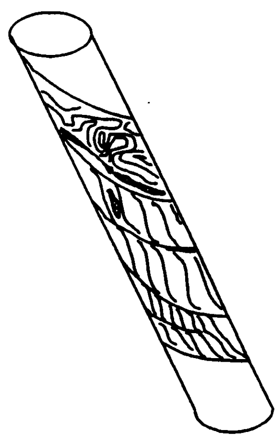
b

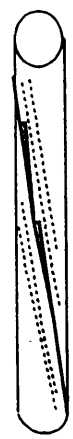
c



Early lineation (L1) subhorizontal and cleavage usually subvertical (c) except in discrete flatfaults (a,b) where it dips moderately north

Second generation



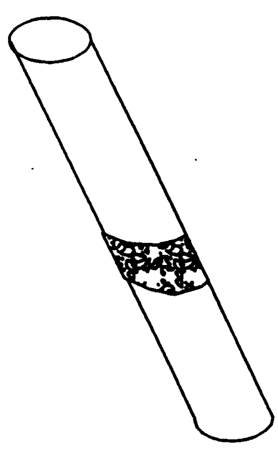


Mainly subvertical wrench faults associated with quartz carbonate veins and weak local cleavage development

Grooves or quartz fibres on faults are subhorizontal.

Less common brittle ductile style thrust faults with quartz carbonate veins, strong local cleavage showing drag into small faults surfaces and all steeper than the fault surfaces indicating reverse movement. Grooves or quartz fibres on fault surface are 90 to L1

Third generation



Normal faults dominated by unstructured gouge. May be some very weak cleavage development. Grooves on faults are 90 to stretching lineation L1

Very minor reactivation of early wrench faults

Figure 3. Structures in the Myra Falls area, showing their typical appearance in core. All orientations refer to the mine grid azimuth.

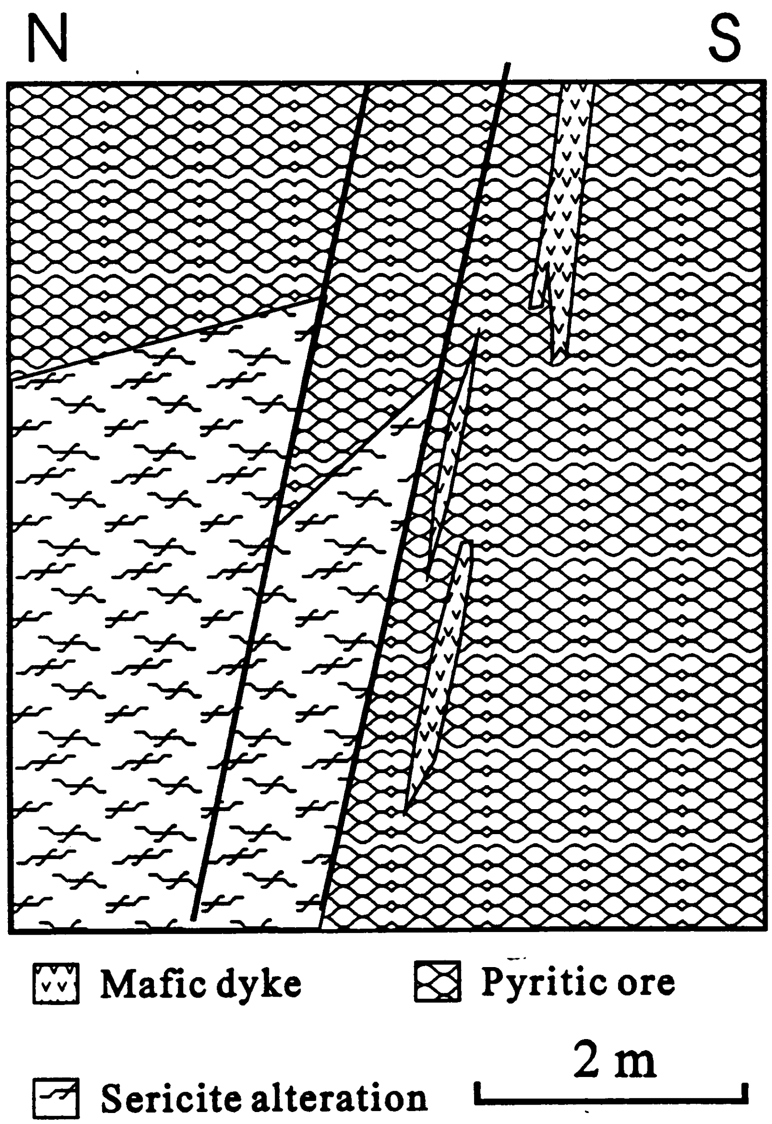


Figure 4. A sketch of a steep fault in the Gopher zone, looking SE. Note the multiple slices of mafic dyke. Each slice has a strong cleavage and stretching direction. All the units in this zone have a steep cleavage parallel to the fault and an E-W stretching lineation. These fabric element require a high strain in this zone after dyke intrusion. The zone is dominated by dextral sense of shear.