# Mt Isa - Reconstruction of a Faulted Ore Body [and Discussion]

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# Mt Isa – reconstruction of a faulted ore body

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A major geological problem in the Mount Isa District is the significance of the flat greenstone contact which underlies the copper ore bodies at the Isa Mine. Recent structural studies have shown this surface to be one of a set of curved normal faults which flatten in depth and are termed spoon faults.

Displacement on the spoon faults ranges upward of 2 km and total extension for the spoon fault domain exceeds 80 km. The domain is bounded by tear faults of which the Mount Isa fault is an example.

Reconstruction of the spoon fault domain gives insight to the sedimentary basin which originally included the Mount Isa ore bodies. The reconstruction indicates Isa and Hilton to be two faulted parts of the same ore basin and probably of the same ore body. It also strongly suggests a central concealed part to occur between Isa and Hilton.

The extreme extension of the spoon fault domain coupled with the thick basic volcanic section suggests that the domain represents an ancient zone of crustal tension initiated by shear along a curved cratonic boundary.

## Introduction

One of the major problems confronting Australian mine and exploration geologists and those interested in base metal sulphide genesis is the significance of the greenstone 'basement' which underlies the Mt Isa ore bodies. The stratiform lead-zinc and copper lodes of the Isa mine dip steeply westwards terminating abruptly against basic volcanics and arenites on an irregular, low angle surface (figure 1). This plane has been variously referred to as an unconformity, an intrusive contact or a fault. The most reasonable interpretation is a low angle fault which displaces the down dip extensions of the ore bodies. With such a large, faulted and concealed target as incentive, Anaconda Australia personnel have directed their attention to a structural synthesis of the Mt Isa area in recent years.

This paper is a synthesis of results from considerable regional and detailed field work undertaken by staff geologists between 1969 and 1973. The author devoted over twelve months to mapping and analysis of information specifically to determine the geometry of faulting and to test if a concealed, faulted segment of the Isa ore body did exist.

## Stratigraphic setting

The regional geology of the Mt Isa District has been described by Carter *et al.* (1961) and more detailed descriptions have been given by Carter (1953), Murray (1961), Bennett (1965, 1970), Smith (1969) and others.

The Middle Proterozoic (Carpentarian) sequence which includes Mt Isa rests uncomfortably on Lower Proterozoic crystalline rocks. The Carpentarian rocks are essentially unmetamorphosed and consist of four major units. A basal arenite sequence, the Mt Guide quartzite, is overlain conformably by a sequence of interbedded arenites and tholeiitic basic volcanics termed the Eastern Creek Volcanics. A third sequence of quartz sandstone, siltstone and conglomerate termed the Myally Beds, locally and unconformably overlie the volcanics.

The upper unit consists of siltstone shale and thinly bedded, fine-grained dolomitic sediments which unconformably rest on either the Eastern Creek Volcanics or Myally Beds. In the vicinity of Mt Isa, this sequence is termed the Mt Isa Group where it locally contains a formation of carbonaceous shale, potassic tuffite, dolomitic siltstone, framboidal pyrite and the base metal sulphides of the Urquhart Shale. The Mt Isa Group ranges in thickness from some 3600 m at Mt Isa to less than 2000 m at the Hilton Mine, 20 km north of Mt Isa. Rocks of the Mt Isa Group form the top of the preserved Carpentarian sequence in the area. They are believed to occupy an isolated basin, but are loosely correlated with the Gunpowder and Paradise Creek formations to the northwest (DeKeyser 1958) and the Surprise Creek beds and Corella Formation to the northeast and east.

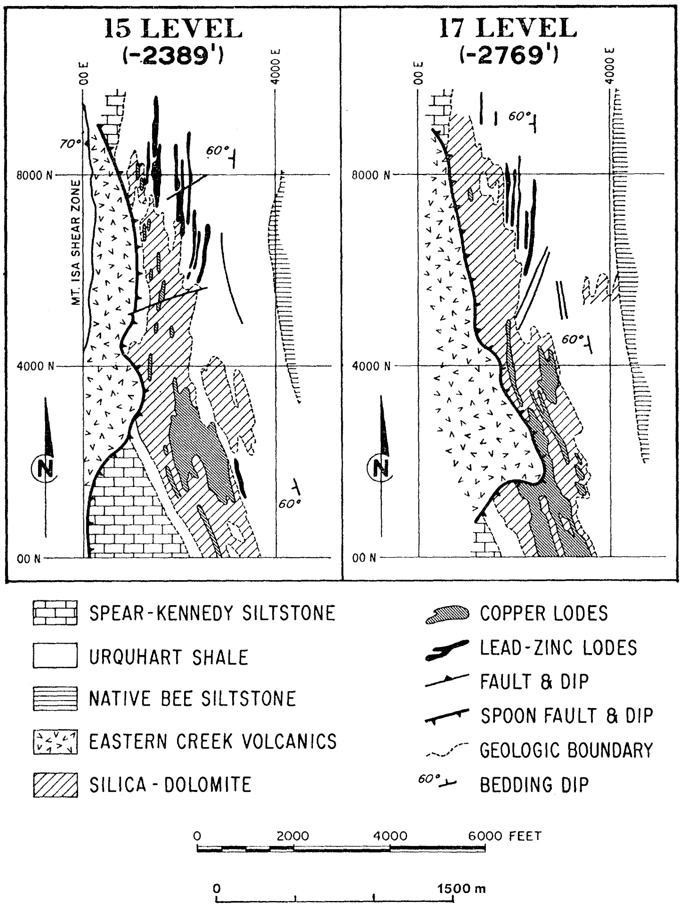

Figure 1. Relation of the basal fault to the ore sequence at Mt Isa. Compiled from information released by Mt Isa Mines Ltd.

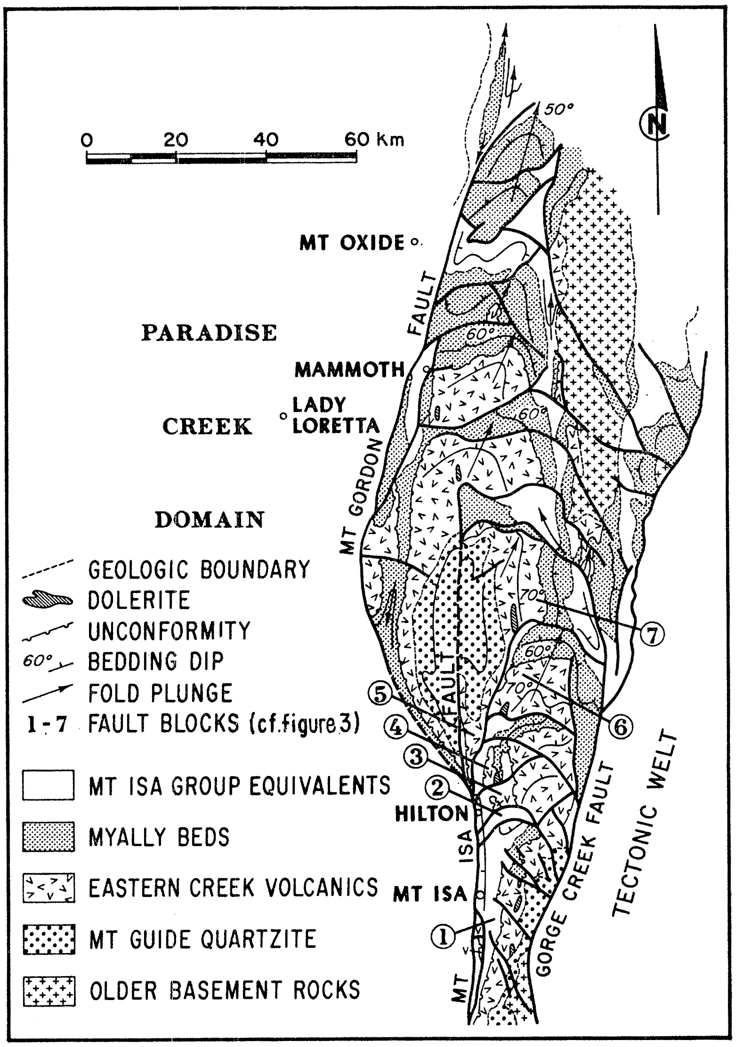

Figure 2. General geological map of the Mt Isa spoon fault domain. Data derived from Carter *et al.* (1961) and additional field mapping by the author.

## Base metal deposits

The Isa Mine has proven reserves of 57 million tonnes of lead-zinc ore in laminate beds which form a number of discrete stratiform lenses interbedded with low grade pyritic shale. The lenses are separated spatially from the huge copper lodes, with reserves in excess of 142 million tonnes of 3 % copper ore which occur down dip from, and are both laterally equivalent to and immediately above the lead-zinc lodes (figure 1). The copper lodes occur within a sheath of 'silica-dolomite' – a crystalline dolomite with associated fractured and siliceous shale.

Two other major lead-zinc deposits are known in the region. The Hilton Mine about 20 km north of Mt Isa occurs in the Urquhart Shale, and Lady Loretta, situated some 100 km to the northwest of Mt Isa (figure 2), which lies within the Paradise Creek Formation.

A major copper deposit is being mined at Mammoth and copper occurs near Lady Loretta and Mt Oxide. No significant copper is known at Hilton. Recent information released by Mt Isa Mines indicates significant deep extensions to the copper at Mt Isa. These extensions, termed the 3000 ore body by Mt Isa Mines Ltd, will be shown to equate with the faulted central portion of the ore basin, termed Isacon in this paper.

Most workers now concede that the lead-zinc deposits are exhalative-sedimentary, but the origin of the copper remains enigmatic. Some authors believe the copper is also syngenetic, though modified by local tectonics (Solomon 1965; Bennett 1970). Bennett (1970) considers the silica-dolomite to be a shallow water facies of the lead-zinc bearing shales which includes recrystallized algal mats or reefs forming against an active pene-contemporaneous fault line. The algal activity would have controlled the Eh-pH environment to cause exclusive precipitation of copper as distinct from lead-zinc in the deeper water shale environment.

Others, notably Murray (1961) and Cordwell *et al.* (1963), support a separate, epigenetic origin. Conclusions from recently published geochemical investigations by Smith & Walker (1971) suggest copper may be derived, together with other elements, from the deeply leached greenstones beneath the ore bodies.

The following analysis suggests a primary exhalative-sedimentary origin for all the base metals in a symmetrically zoned Py–(Pb–Zn–Ag)–Cu ore basin. Pore fluids associated with the movement on the fault separating Hilton and Mt Isa are believed to extensively recrystallize and locally redistribute the copper ore and associated silica-dolomite.

## STRUCTURAL ANALYSIS

The Mt Isa region has undergone a long and complex structural history. The density of faulting is clearly shown on published maps and, in particular, on the excellent set of 1:100000 maps recently available from the Bureau of Mineral Resources.

Analysis of such a complex, heterogeneous fault pattern can be attempted by grouping relative ages, orientations, style, sense and magnitude of movement. This has been attempted previously by Cordwell *et al.* (1963) with limited success. Smith (1969) demonstrated normal and rift faulting contemporaneous with sedimentation. Neither author undertook analysis of faults on the basis of style and magnitude.

Where all minor faults are ignored and faults with displacement in excess of 1000 m only are considered, a relatively simple picture emerges (figure 2). A regional anticline, plunging 60° north is repeated in a number of fault blocks for over 160 km north of Mt Isa.

The Isa and Hilton ore bodies occur within separate fault blocks, but in similar positions on the 60° west dipping limb of the regional anticline.

Each fault block is bounded by a curved fault plane which cannot be followed clearly to the east, but progressively merges westwards with one of two major bounding faults. The Mt Gordon fault is a complex zone of brittle failure, whereas, the Mt Isa fault is a ductile shear zone. Both structures are tear faults with displacement on the Mt Isa fault ranging from zero to over 4000 m down throw on the eastern side. The Mt Gordon fault separates the relatively undeformed Paradise Creek domain from the Mt Isa domain. In the east, the Gorge Creek fault similarly separates the basement 'tectonic welt' from the Mt Isa domain.

The curved cross faults are commonly quartz-filled and brecciated with marginal quartz-fibre filled extension gashes, which would suggest tensional structures. Fault plane dips are difficult to determine, but generally are moderate to steep southerly. Locally (in the Paroo Range area), the fault bounding block 4 (figure 2) dips shallowly (15–40°) south. Stratigraphy indicates normal fault displacement.

The faults have a strong curved trace in plan. It will be shown that despite their steep surface dips, they must be curved in section to flatten with depth and, thus, can be termed spoon faults. The spoon shape is the general form of failure in land slides and is common in the basin-range normal faulting of Nevada (Proffett 1971).

Sediments between the spoon faults are weakly to moderately cleaved except adjacent to the bounding faults. The relative lack of cleavage indicates an absence of strong compressive strain across the spoon fault domain (Dunnet 1969). The open folds with consistently steep north plunges (60°), despite weak internal deformation, suggest substantial rotation of the fault blocks. These observations are important in defining a mechanism of faulting.

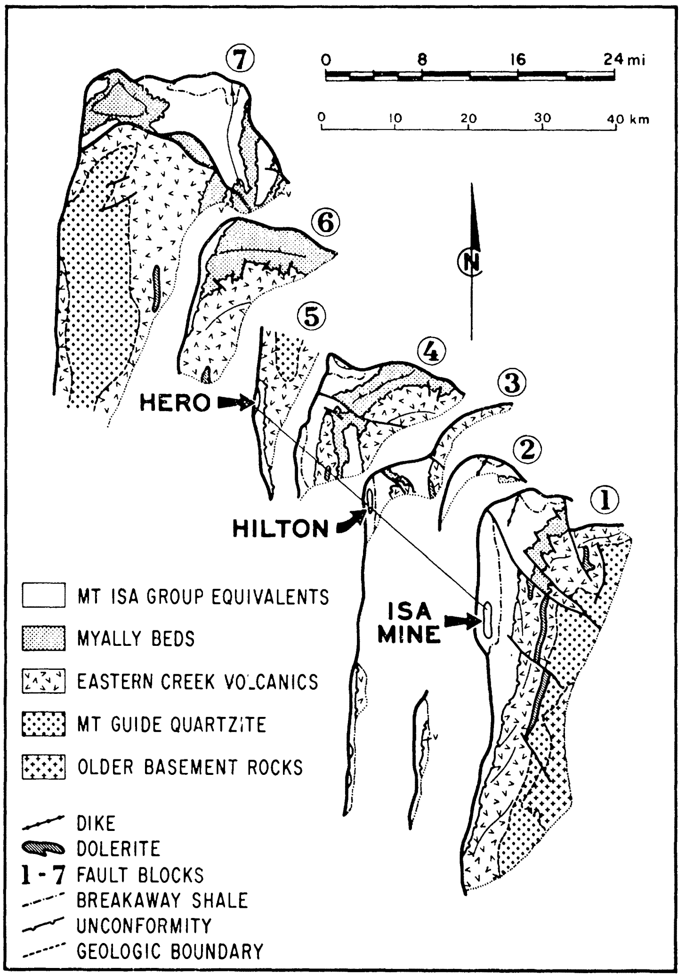

Figure 3. Southern part of the map area of figure 2 showing major fault blocks expanded to produce a tectonic profile of the regional anticline. Distance between fault blocks greatly exaggerated.

## Structural reconstruction

Any attempt at reconstruction of the unfaulted sedimentary sequence and calculation of displacement on the spoon faults requires establishment of points common to adjacent fault blocks.

The surface plans of the southern seven fault blocks (1–7, figure 2) are shown in figure 3, where each block has been relocated in space to produce a tectonic profile viewed along the major anticline. Each block has the form of a serial section through the relatively unfaulted, but internally deformed sedimentary pile.

The continuity of features from one block to the next is strikingly apparent in this diagram and supports the hypothesis that the spoon faults bound narrow fault slices which dip shallowly to the south.

The pinch-out of Myally beds on the unconformity at the base of the Mt Isa Group is a line recurrent in blocks 1, 3, 4 and 6. This pinch-out lineation plunges approximately 60° NW in each fault block. The lineation is known to be formed by a pene-contemporaneous fault bound margin to Myally sedimentation in macrolithon 1 (Smith 1969) and, thus, prior to spoon faulting, it can be assumed a continuous, approximately straight linear element through the sedimentary pile (1–7).

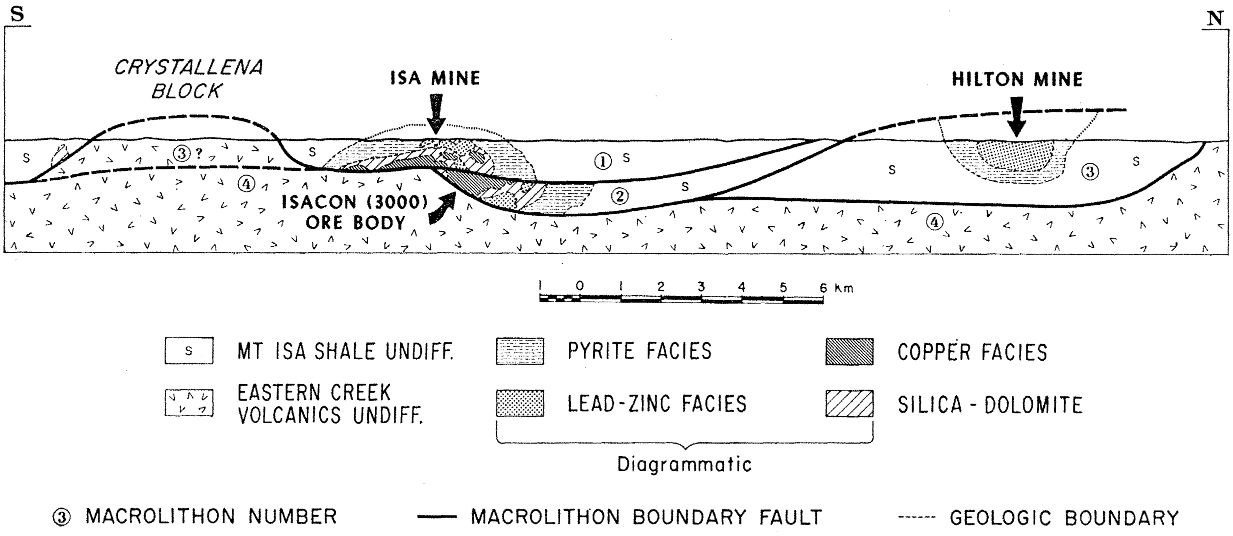

FIGURE 4. Geological long section between Mt Isa and Hilton showing the three slices of the ore body.

Reconstruction of the lineation to a continuous line element necessitates a north–south displacement direction. The observed horizontal offsets of such a steep plunging lineation requires displacement on shallowly south-dipping fault planes.

This general reconstruction shows that the dolorite bodies in blocks 1, 3, 4, 6 and 7 are probably not separate sills, but faulted slices of the same sill.

The most striking deduction from the reconstruction is that the Isa ore body in block 1 is a faulted part of the Hilton ore body in block 3 or at least that they are two ore bodies originally in very close proximity to one another. It must be concluded also that if Isa and Hilton were continuous, a totally concealed ore body slice, termed Isacon, exists beneath block 1 in block 2 between Isa and Hilton.

The striking similarity between lead-zinc ore stratigraphy at Hilton and at Isa, described by Bennett (1970) and Mathias *et al.* (1971), strongly supports not two separate ore bodies, but two faulted slices through the same huge base metal deposit.

A unique solution for the position of the concealed Isacon ore body can be obtained with reasonable accuracy. A dyke common to blocks 1 and 2 is shown on Bennett's (1965) map in the area south of Lake Moondara (figure 3). The triple plane intersection of this dyke with the basal Breakaway Shales and the spoon fault plane is a unique point in each fault block. Horizontal displacement of this point in block 1 relative to 2 is approximately 2000 m in a north–south direction. Because of the steep plunge of the dyke-bedding intersection, this solution is relatively independent of the dip of the spoon fault plane. The displacement sense and direction is consistent with that deduced from the pinch-out lineation solution.

Thus, Isacon should be some 2000 m north of and beneath Isa. A deep intersection of the no. 14 lead-zinc ore body at 12000 N on the Isa Mine grid, some 2000 m north of the last known no. 14 lode position, is believed to be part of the Isacon slice. Current deep diamond drill intersections of copper ore in the 3000 ore body beneath and north of the Isa Mine are also believed to be faulted extensions of the 1100 ore body in block 2.

## The shape and orientation of the basin

The argument presented below suggests that the ore in the three fault slices of Isa/Isacon/Hilton represents the major portions of an original continuous ore body. The present position and geometry of the ore is shown diagrammatically in figure 4, a long section between Isa and Hilton.

Reconstruction of this configuration to the original deposition orientation requires three discrete translations.

1. Reconstruction of the fault slices to obtain a subcircular ore body.
2. Rotation of the regional anticline plunge to a subhorizontal attitude.
3. Rotation of the anticlinal limbs to a subhorizontal position to 'unroll' the regional anticline.

This procedure is an approximation of a probably continuous deformation event and does not account for internal strain during deformation. It indicates, however, that the current surface of Isa was originally the southern or southeastern margin of the ore body.

In the upper levels of Isa, individual lead-zinc ore lenses tend to culminate, which suggests the present ground surface is close to the original southeastern margin of the ore basin.

The Isacon slice has not been eroded and probably represents the rich, thick core to the basin. The thickness of block 2 is some 1000 m at ground level, and assuming this thickness continues at depth, the possible volume of ore in Isacon can be very substantial indeed.

Very little information has been published on the shape of the Hilton ore body. Bennett (1970) implies a gradation from silica-dolomite marginal lithologies at Hilton into lead-zinc lodes and probably into pyrite facies with depth. Mathias *et al.* (1971) refers to the strong similarity between ore lenses 1 to 3 at Hilton and the Black Star lodes (1–5) at Isa as distinct from lenses 4 through 7 at Hilton which resemble the Racecourse (6–14) lodes at Isa. The thin enclosing sedimentary sequence at Hilton relative to Isa (Mathias 1972) and lack of known ore in block 4 suggest that, at depth, Hilton will merge into pyrite facies of the nothwestern basin margin.

Low grade disseminated copper mineralization occurs at the Hero prospect in block 5 (figure 3). The copper occupies a fault breccia and the matrix of a fault scarp conglomerate in a sequence which apparently represents the thin marginal sandy facies to the Mt Isa ore basin. The mineralization is associated with alkali-rich hydrothermal alteration and may be a vent for hot springs feeding brine to the ore basin. No other ore source has been recognized to date.

Thus, the total reconstructed Isa/Isacon/Hilton ore basin is believed sub-circular and some 4000 m in diameter. Copper lodes and copper beds tend to occupy the centre and top of the ore basin, with surrounding and lower silver-lead, zinc and marginal pyrite beds. This reconstruction of Isa/Isacon/Hilton conforms to the general basinal geometry of Sullivan (Freeze 1966) Meggan (Ehrenberg *et al.* 1954) and Rammelsburg (Kraume 1960).

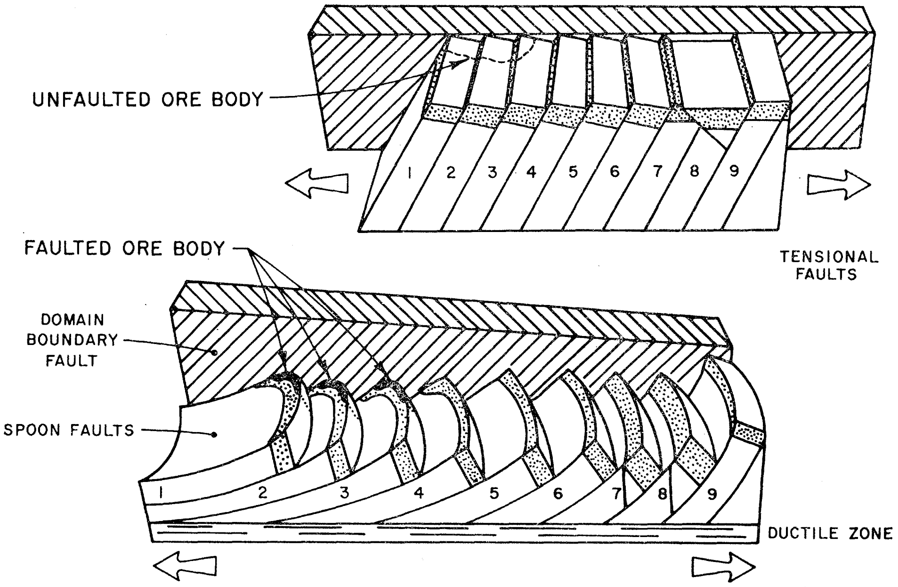

FIGURE 5. Representation of faults in the spoon fault domain initiated as tensional normal faults which progressively rotate due to extension at depth.

## MECHANISM OF FAULTING

The consistent 60–70° north dips and plunges on bedding and folds in each fault block gives insight to the mechanism of spoon faulting. Bedding can be assumed sub-horizontal before faulting and is thus rotated during faulting. The consistent curved nature of the spoon faults in plan is probably reflected in section so that faults flatten with depth and merge with a decollement where deformation is more ductile (figure 5). A number of deformation mechanisms could fit this picture and could be analysed as shown by Ramsay & Graham (1971). However, the generally small magnitude of compressive strain within fault slices indicates a discontinuous simple shear model is applicable as a first approximation. The fault planes are initiated steeply in tension, but as extension proceeds, they become shear planes such that the blocks passively rotate and bedding becomes progressively steeper. This model requires considerable reduction in crustal thickness between the tear-type domain boundary faults analogous to the Mt Isa and Mt Gordon faults.

## DISCUSSION

A mechanism involving large extensions in the crust has been shown to markedly effect the Carpentarian rocks at Mt Isa. The extension domain is separated by sigmoidal faults from a domain of minor deformation to the west and one of major ductile deformation to the east. The deep seated nature of the extension domain structure is indicated by the localization of a thick sequence of basic volcanics within the extension zone. The occurrence of a major base metal deposit in this domain cannot be considered fortuitous and both the plumbing for ore solutions and the establishment of euxinic deposition sites is a direct consequence of the movements.

The sygmoidal nature of domain boundary faults is indicative of a faulting mechanism. A shear couple acting along these faults will produce tension in the crust in the region of boundary fault curvature. There is evidence of markedly different physical properties in the two bounding domains, in their regional gravity patterns, structural and metamorphic styles and degree of igneous intrusion. The western Paradise Creek domain is part of the North Australian Proterozoic platform, whereas, the Tectonic Welt and Cloncurry Belt to the east have characteristics of a mobile belt. The shear and separation is thus believed to have localized along a primitive plate boundary and at a triple junction site. This is discussed more fully in a companion publication (Dunnet 1975).

The tectonic process outlined above gives a ready mechanism for remobilization of copper adjacent to the spoon faults. Movement can only be maintained on such flat faults where the pore fluid pressure is high. In this environment suitable for pressure solution, moderately elevated $P/T$ conditions will permit carbonates, silica and copper sylphides to be readily soluble and be redistributed along the fault plane.

Such a mechanism does not uniquely define the origin of the copper. The 1100 ore body of Isa has moved over at least 2 km of greenstone and probably much more. The movement would allow a progressive solution and recrystallization of primary copper bearing 'silica-dolomite'. It would, equally, permit progressive replacement of primary pyrite by more chalcophile copper leached from the greenstones. Either mechanism could account for the greenstone leaching observed by Smith & Walker (1971).

In a recent paper, Jolly (1974) presented a model for leaching of copper from Keewanawan volcanics during low grade metamorphic dehydration reactions and migration of copper rich fluids to lower temperature environments. Such reactions in the Eastern Creek volcanics would make copper bearing fluids available along fault planes to the sedimentary environment during deposition or during faulting of the Mt Isa ore basin. The thermal gradient around the late tectonic granites (Sybella granite) may localize dehydration reactions and fluid migration.

Future work must show whether greenstones along the displacement path of the Isa and Hilton ore bodies show higher grade, dehydrated mineral assemblage and metal leaching not observed elsewhere in the region.

In view of the presence of copper in similar stratigraphic positions at Isa and Hilton and the hydrothermal mineralization at Hero, the author tends to favour a synchronous exhalative sedimentary origin for the copper and lead-zinc mineralization from fluids of metamorphic dehydration origin.

Considerable credit must go to the Anaconda Company former chief geologist, John Hunt, who initiated the search for a concealed Mt Isa and my associate, Gorol Dimo, whose enthusiasm assisted in the solution.

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## *Discussion*

P. F. WILLIAMS (*Geology Department, University of Lieden, Holland*). I accept Dr Dunnet's interpretation of the geometry of the faults of the Mt Isa region and in fact proposed the same geometrical interpretation in a report to Mt Isa Mines Ltd in 1971. However, I cannot accept the remainder of Dr Dunnet's structural interpretation.

Within his central domain there are folds with an axial plane cleavage that are locally tight to isoclinal. These folds vary in orientation and are refolded by a second generation of northerly plunging folds. This history is best demonstrated in the field but can also be seen on the 'Geological map of Mt Isa district' (Battey 1962).

East of the Mt Isa Fault the map shows two large folds; a synform, with its axial plane trace passing through Mt Isa, and an antiform which exposes basement rocks along the eastern side of the map. These two large folds have approximately north–south striking axial planes and plunge northerly. They are second generation folds ($B_2$). In the hinge of the antiform, near

Transport Bay, the map shows a fold (37000 E, 51000 N) with an east–west trending axial plane that is obviously being refolded by the antiform. In the field this first generation fold ($B_1$) is seen to be tight to isoclinal and to have an axial plane cleavage. The cleavage is best seen in the Moondarra siltstone and is parallel to layering, except in the $B_1$ hinge. It is folded by the $B_2$ antiform.

Such $B_1$ folds are not common in the Mt Isa group but other examples can be seen on the map and more can be found in the field. Furthermore, the very common parallelism of cleavage and bedding in rocks that are known to contain isoclinal folds is strongly indicative of widespread isoclinal folding.

The faults described by Dr Dunnet appear to be folded by the $B_2$ folds and have therefore been interpreted as pre-$B_2$ by the writer. The possibility that they developed as curved 'spoon faults' cannot be eliminated but if so they developed with an axis of curvature that lies in the $B_2$ axial surface. However, these faults certainly post-date $B_1$; they are unaffected by $B_1$ folding and they cut the $B_1$ folds and axial plane cleavage.

Thus the structure and history are more complicated than proposed by Dr Dunnet. The possibility of the faults being penecontemporaneous with sedimentation is not eliminated since the folds may also be penecontemporaneous but the arguments presented by Dr Dunnet are invalid and any such interpretation is therefore pure speculation.

This of course does not detract from Dr Dunnet's important economic argument that the mineralization may be repeated in every fault slice. His recognition of the existing repetition, is, in my opinion, an important contribution to the search for new ore-bodies in the Mount Isa district.

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D. Dunnet. The local, early ($B_1$) folds were first brought to my attention by Dr B. P. Walpole in 1962 and subsequently discussed with Dr Williams in 1969. I fail to see how they invalidate the observations and interpretation summarized in this paper. The folds are non-penetrative features and as Dr Williams states are 'not common'. There is certainly no evidence for widespread megascopic isoclinal folding of this period. I believe these folds result from soft sediment slumping. The presence of associated cleavage does not invalidate their early genesis.

Unfortunately Dr Williams has not considered the compelling evidence for penecontemporaneous faulting in the Mt Isa region. He also makes the common error of assuming superimposed structural criteria to represent separate and unrelated deformation events rather than sequences in a rotational developing tectonic cycle. The sequence of events proposed by Dr Williams is essentially similar to my own and I believe is the response to right lateral wrench faulting on the Mt Isa fault system.

I proposed four recognizable events:

1. Early normal faulting which strikes west-northwest and is penecontemporaneous with Myally Beds through at least Urquhart Shale deposition time. Locally the faults control Myally Beds conglomerate and sand filled troughs as in the Gum Creek area (Smith 1969). At Hero Bore, 40 km north of Mt Isa, a rapid facies change of Breakaway Shale and Native Bee Siltstone equivalent to conglomerate marks the edge of the Mt Isa Shale basin and is coincident with

their overlap across a growth fault directly onto Eastern Creek Volcanics. Similar compelling evidence for fault controlled sedimentation can be seen in the Crystal Creek and Mammoth areas further north.

2. Local slumping and soft sediment deformation shows as response to the early faults. The fold at 37 000 E, 51 000 N (Mt Isa Mine grid) and a nappe structure with similar vergence at 32 000 E, 48 000 N are believed to represent slumps of the basal Mt Isa Group sediments into the still active Gum Creek trough.

3. Continuation of movement leads early normal faults to progressively merge into spoon faults. Late flat normal faults locally cut and rotate early normal faults. The gross effect is a north–south extension and major translation to the south.

4. Compression across the spoon fault domain during later stages of faulting accentuates the initial spoon fault curvature. It produces $B_2$ folds of Williams in quite penetrative deformation adjacent to the Mt Isa fault. Deformation is less intense towards the centre of the spoon fault domain as expected in compression resulting from inhomogeneous shear tectonics.

The sequence of events proposed by Dr Williams correspond to 2, 3 and 4 above. His suggestion that $B_1$ folds are a separate and unrelevant event, and thus early normal faults are unrelated to spoon faults, is possible but unlikely considering the parallelism and similarity of fault style. Undoubtedly the tectonic picture is more complex than that proposed but I believe it will fit the broad framework outlined above.