BMR Journal of Australian Geology & Geophysics, 7, 119-124.

THE ROLE OF PRE-EXISTING SULPHIDES IN COPPER-ORE FORMATION AT MOUNT ISA, QUEENSLAND

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The sulphide deposit at Mount Isa, northwest Queensland, is a siltstone-shale sequence that has been metamorphosed to lower greenschist facies and variously altered by hydrothermal events. Galena and sphalerite, forming the lead-zinc-silver orebodies, and fine-grained pyrite are interbedded with the sediments, but chalcopyrite mineralisation appears to have overprinted these. In the largest copper orebody, the 1100 Orebody, a massive high-grade core of chalcopyrite is developed at the same stratigraphic level as rich pyrite mineralisation; with a reduction in the concentration of pyrite in this core. Cobalt is strongly associated with the copper ores and shows this same relationship. Sulphur isotope values for the chalcopyrite and pyrite are in the same range, indicating a common sulphur source. Sulphur abundances in the pyritic horizons do not increase with increasing copper grade. These factors support the view that sulphur needed for the formation of chalcopyrite and cobalt-rich sulphides was derived from the pre-existing sequence. Those sulphur sources controlled the copper, silica, and cobalt deposition from the mineralising solutions, and provide the link in explaining the spatial relationship of the copper to the lead-zinc-silver ores.

Introduction

The Isa Mine base-metal deposit at Mount Isa, Queensland, is contained in the Urquhart Shales, a sequence of dolomitic shales and siltstones of Middle Proterozoic (Carpentarian) age that has undergone structural deformation and metamorphism to lower greenschist facies. Major folding, with axial plane trends varying from northwest-southeast to north-south, has rotated the whole sequence into a westerly dipping attitude.

Neudert & Russell (1981) have described the depositional environment of the sediments as being shallow water, with intermittent hypersaline and emergent conditions, and they suggested a modern analogue in the lake complex of the Dead Sea graben, including the associated continental sabkhas. McClay & Carlile (1978) found pseudomorphed sulphate evaporites in the dolomite and laminated cherts, and interpreted them as being originally gypsum and anhydrite that crystallised in the sediments prior to compaction.

The basin in which the carbonate-rich sediments were deposited periodically became anoxic, when syngenetic or very early diagenetic fine-grained framboidal pyrite was formed. This fine-grained pyrite is now finely interbedded with the carbonate-rich sediments and faithfully follows the bedding.

The galena and sphalerite-rich beds forming the lead-zinc-silver orebodies are interbedded with the siltstones, shales, and pyritic shales, and are conformable except in those areas where folding has caused redistribution. The relation of the lead-zinc ores to the enclosing and conformable sediments has been well documented by various workers, (Bennett, 1965; Mathias & Clark, 1976), and a syngenetic or very early diagenetic deposition is well established.

A 'silica-dolomite' (Fig. 1) sequence and associated chalcopyrite forming the copper orebodies overprints this sequence and, therefore, pyritic shales, siltstones, and shales are included in the 'silica-dolomite' (Fig. 2). The occurrence of galena and sphalerite in the zone is rare, and would indicate that there was none present originally or that it has been remobilised in the alteration process. The significant features of the 'silica-dolomite' are: a coarsening of the dolomite grain size forming recrystallised dolomitic shale, production of

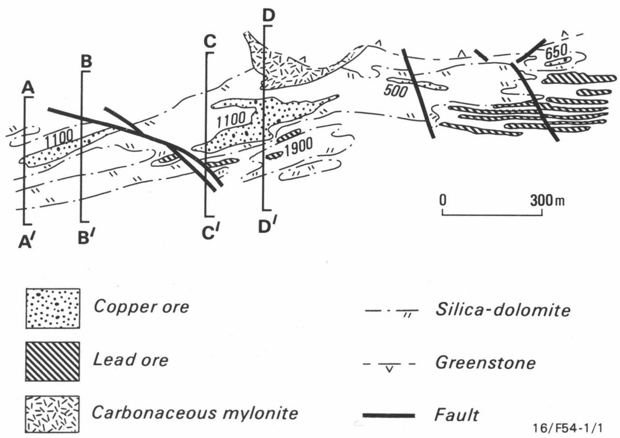

Figure 1. Geological plan of No. 15 Level, Isa Mine.

Figure 2. 'Silica-dolomite' distribution in relation to the host sequence.

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dolomite masses with enclosed shale fragments, and, in parts, silicification and brecciation of the shales and siltstones. Full descriptions of the 'silica-dolomite' rock types are presented by Mathias & Clark (1976).

The whole of the Urquhart Shale is truncated at depth by major faulting, which has caused juxtaposition of a greenschist complex, locally termed greenstone, and the Urquhart Shales. The greenstone has been correlated with the Pickwick Metabasalt Member of the Eastern Creek Volcanics by Gulson & others (1981a). The 'silica-dolomite' is widest at the junction of the shales and the greenstone (Fig. 2), interdigitating up dip and along strike with the normal sequence. This geometry indicates that the formation of the 'silica-dolomite' was intimately associated with the fault as the feeder source. The relation of the greenstone to the ore has been complicated by later movements along the fault zone.

A major fine-grained pyrite zone occurs stratigraphically below the lead-zinc sequence (Fig. 3), interdigitating southwards with the 'silica-dolomite' and the cupriferous sequence, and a further fine-grained pyrite zone is intimately associated with the upper lead-zinc-silver orebodies, but is not present southwards.

Thus at Mount Isa, at least three stages of mineralisation occurred: the fine-grained pyrite, the conformable galena and sphalerite, and the overprinting chalcopyrite mineralisation. The timing of the total mineralisation has been variously described. Mathias & Clark (1976) proposed a totally syngenetic origin for all the ores, with a physico-chemical separation of the metals in the basin. Finlow-Bates & Stumpfl (1979) argued for sub-surface deposition of chalcopyrite in a pre-ore breccia, with syngenetic deposition of galena, sphalerite, and pyrite, all from the same ore solution. Gulson & others (1981b) have taken the opposing stance of no relation between the galena-sphalerite and the chalcopyrite.

Trace lead isotope investigations conducted by Gulson & others (1981b) revealed that the isotopic arrays for copper mineralisation intersect the average lead-zinc

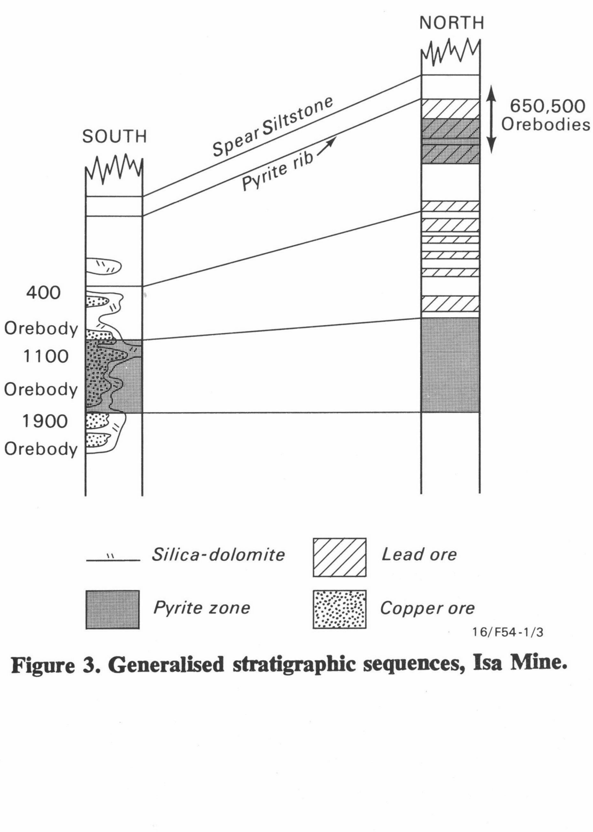

Figure 3. Generalised stratigraphic sequences, Isa Mine.

ore value, and probably represent a variable component inherited from the originally pyritic host shales. The genetic model they presented involved a structural, hydraulic fracturing process or a ductility contrast between the invaded host and the underlying greenstone to develop a fracture zone into which the chalcopyrite was deposited. They concurred with the syngenetic model for the lead-zine-silver ores, but they concluded the copper ore was introduced from brine solutions generated during major regional deformation and metamorphism.

Any genetic model for the Mount Isa deposit has to explain the occurrence of two discrete but spatially close ore types. The geometric arrangement suggests a common bond between the copper and the lead-zinc-silver ores. In consideration of the structural model, the greenstone basement extends well beyond the pre-existing deposit, structural conditions seem similar, and yet, to date, known major copper mineralisation is confined to the same stratigraphic sequence as the lead, zinc, and silver. Lambert (1976) suggested there has to be a reason for the restriction, and he suggested the presence of pyrite would probably be essential for 'fixing' the copper ores.

Investigations into gangue/chalcopyrite relations in the southern 1100 Orebody illustrated the significant influence fine-grained bedded pyrite had on the distribution of copper ore in that area (Robertson, 1975). To establish the significance of this factor in regard to the total copper mineralisation, the gross characteristics of the major copper orebodies have been reviewed and the most significant orebody selected and analysed with respect to copper ore and fine-grained pyrite relationships.

The copper ores

The major copper orebodies described by Mathias & Clark (1976) can be classified simply by dominant host rock lithology, ore disposition, and significant ore mineral associates (Fig. 4). Their sizes may be represented by their percentages of the total known copper reserves. These characteristics show that the orebodies can readily be divided into two types:

Dolomitic disseminated ores

The dolomitic disseminated ores are associated with recrystallised dolomitic shales and dolomitic breccia. The chalcopyrite is generally disseminated amongst the dolomite grains or present as small discontinuous veins. The 650 and 500 Orebodies are included in this type, but being confined by sheared hangingwall and footwall limits, they cannot be related to their adjacent environments.

Pyritic and siliceous massive veined ores

These ores are associated with the original fine-grained pyrite-rich shales and barren shales that have been silicified and brecciated. The chalcopyrite is present in irregular veins grading upwards into massive chalcopyrite. Significantly, this group has a cobalt-copper ore association not seen elsewhere in the sequence, the major cobalt mineral now being cobaltite. This is the most important type of copper ore in the Mount Isa deposit, but the dolomitic type ores have a greater areal distribution.

Number	% known copper resource	HOST SHALE				ORE		Ore associates
		Recrys-tallised	Pyritic	Dolomite breccia	Siliceous breccia	Massive vein	Dissemin-ated	
650, 500		▲		▲		▲	▲	
400		▲		△			▲	
1100 H/W		▲		▲			▲	
1100 F/W		△	▲	△	▲	▲		Cobalt
1900		△	▲	△	▲	▲		Cobalt
3000		△			▲	▲		Cobalt
3500		△	▲		▲	▲		Cobalt

▲ *Major component* △ *Minor component* 16/F54-1/4

Figure 4. Characterisation of the major copper orebodies.

1100 Orebody

The major ore zone, the 1100 Orebody comprises both types of ore, and is well documented from drill holes and underground excavations. Therefore, it should provide representative information on the copper ore/pyrite relations, and constitute a model for the other copper orebodies.

Four cross-sections have been studied through this ore zone, its attendant 'silica-dolomite' halo and the unaltered sequence (Fig. 1). The copper grade distribution within the 'silica-dolomite' has been established by using variograms to estimate the copper continuity, and from the geostatistically derived grade estimates, a grade mesh was calculated and contoured (Fig. 5). In the shales, sulphur-rich areas in the form of lead-zinc orebodies and zones of fine-grained pyrite have been plotted (Fig. 5). The value of 20% by volume was used to delineate the fine-grained pyrite, as zones containing this amount of pyrite are recorded in normal mining operations. The tuff beds described by Croxford (1964) have been used as marker beds to compare the position of the copper accumulation with the sulphides in the pre-existing sequence (Fig. 5, 6, 7, 8).

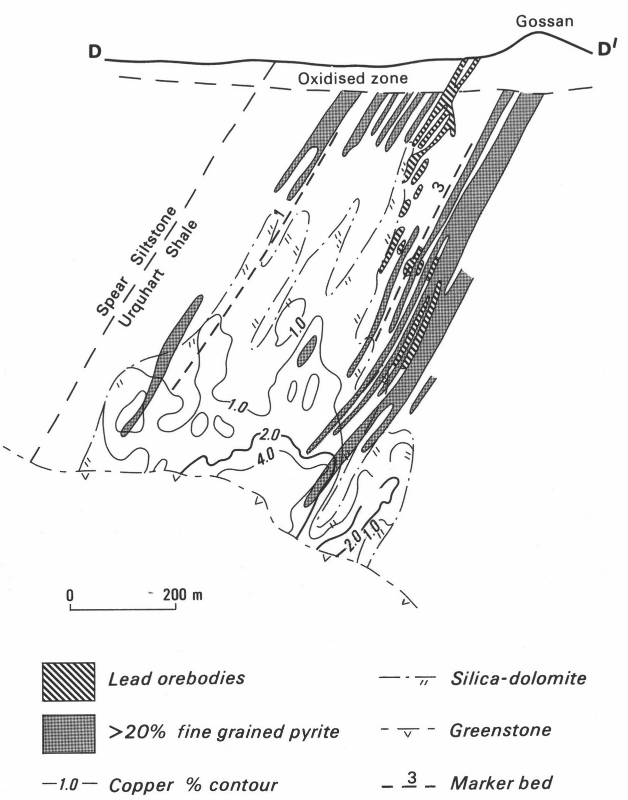

Figure 5. 'Silica-dolomite' and copper distribution in relation to the host sequence, section D-D′.

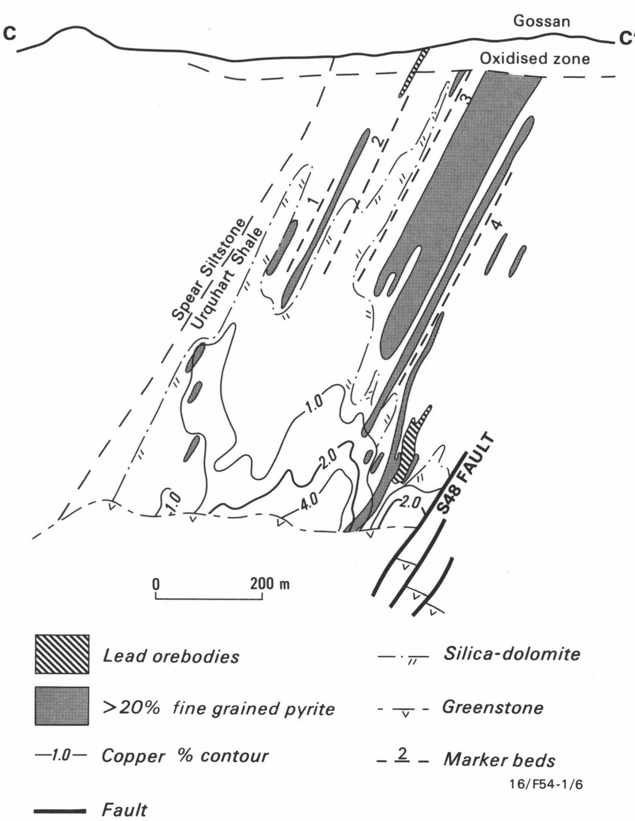

Figure 6. 'Silica-dolomite' and copper distribution in relation to the host sequence, section C-C′.

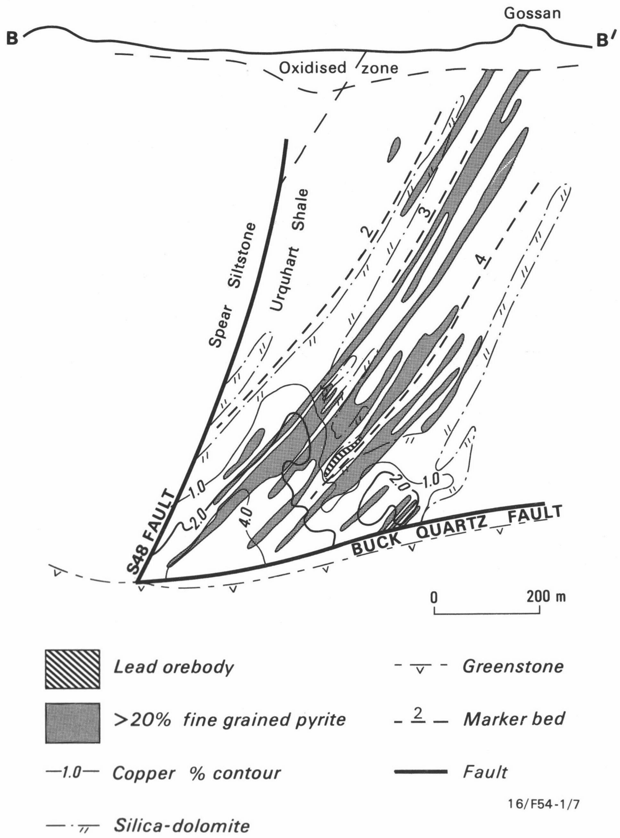

Figure 7. 'Silica-dolomite' and copper distribution in relation to the host sequence, section B-B′.

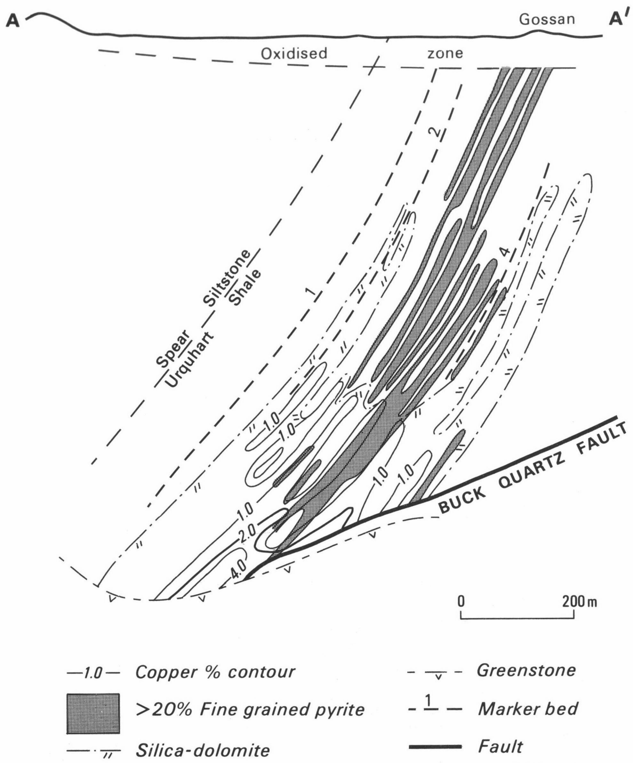

Figure 8. 'Silica-dolomite' and copper distribution in relation to the host sequence, section A-A′.

From the study of the cross-sections a number of conclusions can be drawn:

- The reduction in the abundance of fine-grained pyrite in the high-grade core areas (Robertson, 1975) is common throughout the 1100 Orebody. In the areas equivalent to the 1900 Orebody (Fig. 1, Sections C-C′ and D-D′) there are insufficient data in the up-dip sequence for any similar conclusion or otherwise to be made.

- The highest-grade copper zones are stratigraphically equivalent to the zones of abundant, fine-grained pyrite.

- Over the 1.3 km represented by the cross-sections, the fine-grained pyrite and the copper concentrations maintain a similar stratigraphic relation to the marker horizons. This is particularly illustrated by horizon 3, which sits above the pyrite zone, and horizon 4, which sits below the pyrite zone and the projection of that zone down dip into the cupriferous body. A number of attempts to trace the tuff beds into the 'silica-dolomite' have met with little success and, therefore, perfect correlation can not be made.

- The lower-grade ores are more irregularly distributed and in some sections (Fig. 5 and 6) have different trends to the core zone. The core zone is conformable with the orientation of the host sequence. The lower-grade zones have a more steeply dipping trend and their distribution is asymmetric to the core zone. The trend of these lower grade zones could be a result of redistribution by later structural events.

In the original characterisation (Fig. 4), it was noted that the pyritic ores are also siliceous, and, from the rock-type distributions presented in Mathias & Clark (1976) and the grade distribution (Fig. 9), it can be seen that the high-grade core is contained in the siliceous rock types, and the lower-grade, more irregularly distributed ores are in the coarsely crystalline dolomitic zones.

Within the high-grade copper zone, fragments of fine-grained pyritic shales are common, and in the more 'bedded' ores of the 1900 Orebody fine-grained pyrite is in places interlayered with chalcopyrite. Replacement textures with chalcopyrite replacing fine-grained pyrite are rare, but have been seen in all the orebodies containing the pyritic siliceous ores. Knights (1981) illustrated such textures occurring in the 3500 Orebody.

Sulphur isotopes

The hypothesis that can be put forward is a chemical reaction between the pre-existing sulphur-rich horizons, particularly where massive accumulations are present, and the invading cupriferous solution, resulting in deposition of copper and silica. The dissolution and replacement of the fine-grained pyrite would release sulphur, which could be used in the chalcopyrite formation.

The limited isotope data (Fig. 10) derived from Solomon (1965), Solomon & Jensen (1965), and Smith & others (1978) show a spread of $\delta^{34}S$ values for the fine-grained pyrite of between +5‰ and +29‰. The very limited chalcopyrite data show a narrower spread within the fine-grained pyrite range. In comparison, the

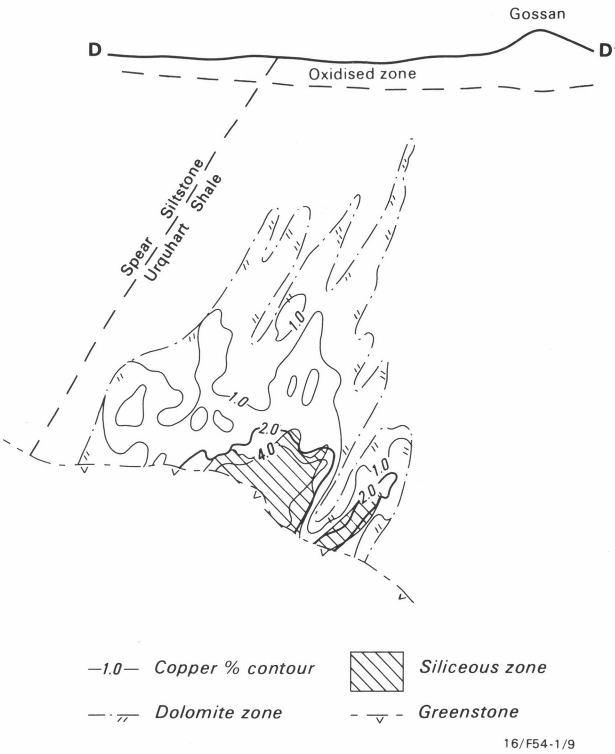

Figure 9. Dolomite and silica distribution in relation to the copper contours, section D-D′.

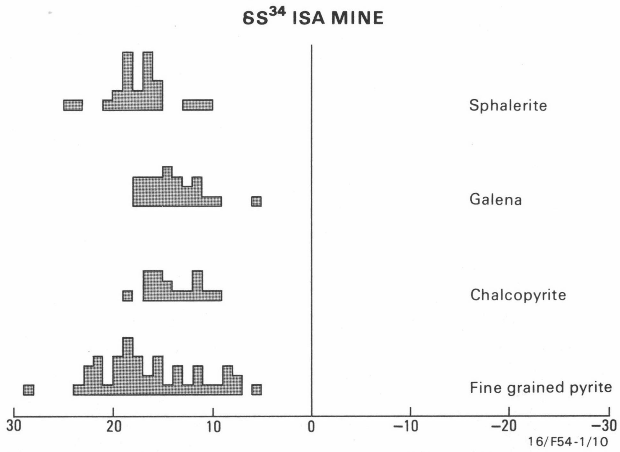

Figure 10. Sulphur isotope histograms—Mount Isa.
Values of $\delta^{34}S$ in parts per thousand.

more comprehensive galena data show a range similar to the chalcopyrite, whereas the sphalerite data show a wider range, comparable with the fine-grained pyrite. These data lead to two possible conclusions:

- The chalcopyrite could have used sulphur and iron from the pyrite in the sediments in its formation. A decrease in the range of the sulphur isotope values could be due to homogenisation during the dissolution and replacement process.

- The chalcopyrite could have a sulphur source similar to that of the other sulphides in the deposit.

If sulphur accompanied the copper in solution, this would be in addition to the sulphur already in the sequence, and if a reasonable continuity of the fine-grained pyrite horizon is assumed, this should result in an increase of sulphur with copper grade. The 80 m wide zone of fine-grained pyritic shale below No. 3 tuff marker horizon (Fig. 7), outside the 'silica-dolomite' halo, contains by volume 0.01% Cu, 22.7% S. The same horizon within the 2% Cu contour contains 2.3% Cu, and 17.8% S, and within the 4% Cu contour it contains 5.1% Cu, 17.3% S. These figures imply, in fact, that sulphur has been reduced in this horizon during the copper mineralisation phase, and most probably redistributed to the adjacent 'silica-dolomite'.

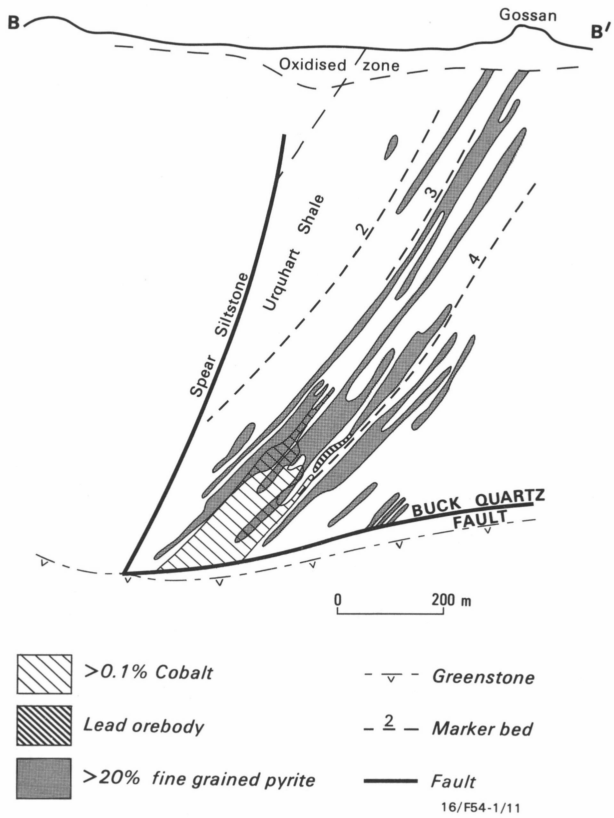

Figure 11. Cobalt distribution in relation to the host sequence, section B-B′.

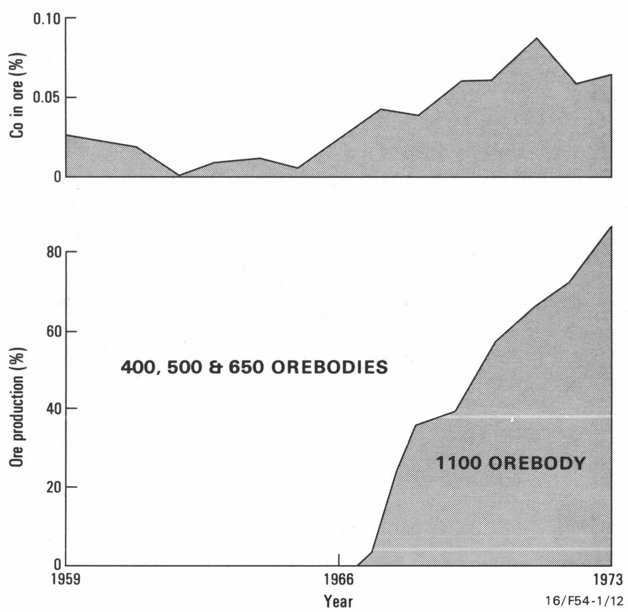

Figure 12. Cobalt head grades relative to orebody production.

Copper ore associates

Other than variable amounts of coarse-grained pyrite and pyrrhotite, which could have formed as a residue to the fine-grained pyrite/chalcopyrite dissolution and replacement process, the other significant sulphide present with the copper ore is cobaltite. Cobalt in various forms described by Croxford (1974) is common in the 1100, 1900, 3000, and 3500 Orebodies. It is closely associated with the copper mineralisation and has its greatest concentrations in the areas where there has been a reduction in the amount of fine-grained pyrite (Fig. 11). Croxford (1974) concluded that alloclasite had been deposited at the same time as the fine-grained pyrite. This conclusion is based on similar zonal growth features occurring both in the alloclasite and the fine-grained pyrite. Cobaltite is now the dominant mineral and has been interpreted as a metamorphic regeneration from the original cobalt mineralisation. Commonly, it contains cores of rounded to euhedral fine-grained pyrite (Croxford, 1974).

No significant cobalt accumulations have been found outside the copper ores. The non-random distribution of cobalt within the copper orebodies (Fig. 12) further supports a hypothesis involving depositional control by the sedimentary sequence.

Conclusions

The mineralising solutions that formed the copper orebodies at Mount Isa contained copper, silica, and cobalt in variable proportions, whose deposition was controlled by the sulphur-rich species present in the Urquhart Shale. The significance of sulphates described by McClay & Carlile (1978) in the chalcopyrite deposition can only be surmised. These minerals have been pseudomorphed by quartz and dolomite and therefore sulphur has been released. In a reducing environment, the sulphur could have been used in sulphide formation. The most significant and evident control is the pyrite. In the areas of massive fine-grained pyrite accumulations next to the solution feeder zone, the pyrite underwent dissolution and replacement, and the released sulphur and iron were used in the formation of the chalcopyrite. Similarly, these areas of pyrite concentration formed a suitable environment for silica and cobalt deposition.

Acknowledgements

I am indebted to the management of Mount Isa Mines Limited for permission to present and publish these data. I thank L. Payne for drafting the original figures and J. Isaacson for the manuscript preparation. I also acknowledge the helpful discussion received from past and present members of the geological staff of Mount Isa Mines Limited.

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