A STUDY OF THE "GREENSTONE" BASEMENT AT MOUNT ISA MINES, QUEENSLAND.

by

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ABSTRACT

The "greenstone" basement at Mount Isa Mines consists of basic volcanics, with minor interbedded sediments, and it appears to be a block of Eastern Creek Volcanics which has undergone intense alteration. Four basic rock types have been recognized - Altered Volcanics, Sediments, High Carbonate Rocks and Sheared "Greenstone", each with a fairly distinctive petrography and chemistry. It is considered that the Altered Volcanics, like the basalts of the Eastern Creek Volcanics, are tholeiitic in origin.

The alteration present is predominantly chloritization, accompanying the introduction of silica (± carbonate) into the "greenstone". This alteration and introduction of silica (± carbonate) is thought to represent the passage of mineralizing fluids through the "greenstone", during which copper was removed from the "greenstone". This copper-rich fluid then passed into the more permeable "silica-dolomite", where the copper, silica and carbonate were deposited in bulk, forming the rich and unique copper ores of Mount Isa.

1. INTRODUCTION

The Mount Isa (Queensland) Lead-Zinc-Silver and Copper orebodies lie in a meridional belt of sediments and volcanics of Lower to Middle Proterozoic age. This thesis is a study of a suite of generally green, schistose rocks, which underlie the copper orebodies and host material (the "silica-dolomite"), and are known locally as the "greenstone basement" (or simply "greenstones"). The study is an attempt to determine the constitution of these basement rocks, and to see if they can be related to a thick sequence of dominantly basic volcanics which occur to the east of Mount Isa, the Eastern Creek Volcanics. As the "greenstones" are spatially associated with the orebodies, the relationship of these rocks to the mineralization is also investigated.

Samples were collected by the author from the lower levels of the mine in January, 1974. These specimens were later supplemented by samples from DDH V26 Edecline 16/L #1, the drillcore being kindly supplied by M.I.M. through the agency of Malcolm Bridges. Specimens from the Eastern Creek Volcanics, and from the Native Bee-Crystallena Block (to the south of Mt. Isa) were also supplied by Malcolm Bridges. All specimen localities are shown in Figures 2, 3 and 5.

It should be noted that only a limited number of samples have been taken, and hence any conclusions made are tentative and subject to amendment when further studies are made. However, the number of samples is considered to be enough to give some indication of the history of the "greenstone". It should also be noted that the samples taken from the "greenstone" are relatively close to the copper mineralization, and a full representative section is not available.

2. GEOLOGICAL SETTING

The orebodies at Mount Isa are located in a sequence of North-South striking Lower to Middle Proterozoic sediments and volcanics, in which economic mineralization is limited to one stratigraphic horizon, the Urquhart Shale. The whole sequence is bounded to the east and to the west by higher grade metamorphic and granitic complexes, the volcano-sedimentary sequence generally being of a greenschist facies of metamorphism. There has been regional sodium metasomatism, affecting rocks predating and including the Myally-Judenan Beds. There has also been localized potassium metasomatism and granitization (Stratigraphy is summarised in Figure 5).

The Urquhart Shale is composed of light and dark grey dolomitic and volcanic shales, fine grained bedded dolomites, and pyritic shales. Sulphides, especially pyrite, form an integral part of the rock. The majority of the beds are finely laminated, the bedding plane parting being facilitated by carbonaceous material. Within the formation there are a number of distinctive beds known locally as "Tuff Marker Beds", which consist predominantly of potash feldspar and dolomite, and retain their thicknesses over great distances throughout the mine workings. Croxford (1964) has suggested a tuffaceous origin for these beds.

Mineralization

Both the copper and silver-lead-zinc mineralization is confined to the Urquhart Shale, the silver-lead-zinc orebodies being restricted to virtually unaltered shale, while the copper mineralization occurs in zones of highly brecciated and recrystallized shales, which is known locally as "silica-dolomite". Both types of orebodies occur as distinct entities, and are mined as such, although they may be contiguous or within several feet of each other. The orebodies occur on the western limb of a northerly plunging anticline, the Urquhart Shale having a N-S strike and a dip of 60 - 65°W in the mine area.

Silver-lead-zinc mineralization is concordant with the bedding of the host shales, and occurs discontinuously through a stratigraphic width of 1000 metres. Galena, sphalerite and pyrite occur in distinct concordant bands throughout the shale, the mineralization being associated with concentrations of framboidal pyrite. In plan and in section the orebodies are arranged en echelon. The southern and lower portions are richer in galena and silver, while the northern and upper parts are richer in pyrite and sphalerite.

The copper sulphide orebodies are restricted to the "silica-dolomite" body, which is roughly lensoid in shape, but terminates at depth against the "greenstone" body, especially in the southern sections of the mine. In plan and in section the "silica-dolomite" is broadly transgressive to the shale bedding, having an axial orientation subparallel to the axis of major fold trends in the mine. In cross-section the "silica-dolomite" exhibits tongue or lobe-like structures in the higher levels of the mine (that is, up dip), but it widens in depth to its greatest development, at the contact with the "greenstone". (see Fig. 4). It will be discussed in greater detail later in the thesis.

Copper mineralization is known throughout the "silica-dolomite", the economic concentrations being arranged vaguely en echelon in both plan and section. The chalcopyrite is closely associated with both quartz and carbonates, and to a lesser degree with pyrite.

Structure

As mentioned earlier, the orebodies are situated on the western limb of a northerly plunging anticline, the host rock (the Urquhart Shale) having a N-S strike and a dip of 60^o - 65^oW. About 600 metres west of the mine, this western limb has been truncated by the Mount Isa Fault. This is a prominent structural feature which has been traced over a distance of 70km in a N-S direction, and separates the chloritic zone of the Mount Isa Group (in the east) from higher grade metamorphic rocks in the west (including biotite, biotite-cordierite and sillimanite zones). Within the mine area itself, two general types of faults have been recognized, these being:-

1. Faults represented by a structural break confined to a single plane;
2. Faults whose gross displacement is the summation of a number of smaller movements across a set of shear planes (i.e., shear zones).

Bennett (1970) also recognizes penecontemporaneous faults, which is represented by the contact between the Mount Isa Group and the "greenstone", although Wilson (1973) has indicated that this contact (at the surface) postdates the first generation of folding in the area. This can be interpreted as the "plateau-type" (viz. underground) contact being penecontemporaneous, and the western block contact (which is expressed at the surface) as being post-folding (refer to Previous Work for contact types).

Faulting in the mine area generally parallels the regional pattern.

Folding in the mine area has been controlled to a large degree by the heterogeneous nature of beds within any width of strata. The variety and pattern of folding indicates that folding is a function of movement over a considerable period of time, in which the sediments are only partly lithified. Bennett (1970) suggests that the major folding reflects parasitic folding which is related to the regional folding, while the minor folding probably represents gravity-induced sliding of heavy, mobile sulphides before consolidation. The axial planes of the major folds generally dip 80°W, the strike of the fold axes being 335° to 360° with a plunge of 15° to 85° in that direction. However, there are irregularities, and Bennett considers these to be related to the preconsolidation movement as described above. This movement is well displayed by sulphide rich horizons. Within the "silica-dolomite", the folding pattern is similar, although it is not as clear, due to intense brecciation and recrystallization.

3. PREVIOUS WORK

These "greenstones" have previously been studied and described by numerous authors, in varying detail. Most often the study forms only a minor portion of a larger work, and hence descriptions are sometimes inadequate. Research geologists at M.I.M. have also described the "greenstone" as a matter of routine, however, very few have aided in the overall knowledge of these rocks. The most notable report is by O'Toole (1964), in which he has classified the "greenstone" mainly on the basis of mineralogy, into three groups. This classification is published in Bennett (1965, p.237), and will be iterated later. A more recent classification, with an emphasis on alteration, is published in Smith and Walker (1971, p.20-21). The most recent study of the "greenstone" is included in Mathias and Clark (1974).

The following description is based on these three sources:-

The "greenstones" consist dominantly of volcanics, which can be classified petrologically, and associated sediments. They have a layering (which is often defined by chlorite), which dips to the west and strikes approximately N-S. This is thought to represent a primary layering, although it should be noted that this direction is approximately parallel to the axial planes of folds in the area. Previously published classifications of the volcanics are as follows:

A. Albitic "greenstone": Rich in albite laths, which interlock in a chloritic groundmass. Titan-magnetite (partially replaced by sphene) is a major constituent of the rock. Ilmenite, calcite and quartz are accessories.

B. Chloritic "greenstone": Chlorite is more abundant than albite, the titaniferous mineral being rutile, with minor hematite and limonite. Quartz, calcite and potassium feldspar are locally important.

C. Epidote-Actinolite "greenstone": Consists of epidote, actinolite, chlorite and albite, with minor titan-magnetite, sphene, and calcite. Potassium feldspar is locally abundant.

D. Least altered "greenstone", without deformation: Consists mainly of clear albite laths and glomeroporphyritic albite in a chloritic base. Original textures are typically basaltic. Relict amygdules, where present, contain epidote, chlorite, calcite and quartz. A few rocks contain pale green mica. Opaques are evenly distributed throughout.

E. Most altered "greenstone", without deformation: Mineralogically, these are completely reconstituted, showing more intense type "D" alteration, the only textural evidence of a basaltic origin being relict feldspar laths. Plagioclase is commonly replaced by turbid alteration products, which include calcite, epidote and sericite; and the ferromagnesian minerals are replaced by chlorite. Minor amounts of alkali feldspar, quartz, light brown mica and tourmaline are present. Opaques are evenly distributed. The rocks are cut by veins filled with calcite, chlorite, quartz and alkali feldspar.

F. Altered "greenstone", showing deformation: Almost completely reconstituted and distinctly schistose. The rock consists mainly of pale green chlorite enclosing lenticular aggregates of fine granular feldspar and quartz, although occasional crystal outlines of relict feldspar laths, glomeroporphyritic aggregates, or igneous opaque iron minerals may be recognizable. The opaque minerals tend to be strung out, defining a lineation. Veins contain chlorite, quartz and feldspar; and tend to follow the direction of mineral lineation.

Groups A, B and C are equivalent to 1, 2, 3 of O'Toole (1964) (and Bennett (1965)), and D, E, F are equivalent to (a), (b), (c) of Smith and Walker (1971).

Smith and Walker (1971, p.21 & 22) also report dolerite intrusions within the "greenstone". These dolerites are undeformed, and apparently postdate the regional folding. However, they are hydrothermally altered, in some cases extensively. These dolerite intrusions are similar, both in type and alteration, to intrusions in the Eastern Creek Volcanics.

The sediments include a coarsely bedded, fine grained, buff greenish-grey to white quartzite, which is well developed at the south end of the mine. Bennett (1965) also reports arenites, chloritic shales, dolomites and sericitic shales. (The quartzite is thought to correlate with the Lena Quartzite of the Eastern Creek Volcanics).

Mathias and Clark (1974) and Bennett (1965) discuss the contact zones of the "greenstone" to the "silica-dolomite" and shale. Mathias and Clark define four contact rock types (see Figures 2, 3), these being:-

(a) Siliceous "Greenstone": This embraces metamorphosed, silicified rocks which may be either volcanic or sedimentary in origin. They are typically quartz-chlorite-muscovite rocks, and generally lie close to the contact areas or to large Buck Quartz masses.

(b) Carbonaceous Mylonite: This is a black, well foliated rock, derived predominantly from the overlying "silica-dolomite" and carbonaceous shale, but it may also be derived from the underlying "greenstone". In the latter case the "mylonite" consists of a matrix of chlorite and carbonaceous material, with associated rock fragments. Magnesite may be developed locally.

(c) Buck Quartz: This is a white, coarsely crystalline quartz, with minor chalcopyrite and pyrite, and is often interlayered with carbonaceous mylonite. It occurs as fault fill at the south end of the mine. (The quartz contains abundant fluid inclusions).

(d) Slaty Shale: This consists of dark grey to black dolomitic shale or siltstone with penetrative cleavage. It occurs in a zone above shallow dipping "greenstone" contacts. It is the author's opinion that this slaty shale is derived from normal Urquhart Shale and "silica-dolomite" material.

Both Mathias and Clark (1974) and Bennett (1965) discuss the contact types between the "greenstone" and the overlying rocks. Mathias and Clark define four types, these being:

(1) Plateau Type: This is typically sharp, with little development of contact rock types. It is generally gently dipping and undulating. Geographically, it is generally present beneath the hanging wall of the 1100, 1900 and 3000 orebodies. Mathias and Clark consider that this may represent the initial contact between the "greenstone" block and the Urquhart Shale, as discussed by Smith (1969). Occasional wedges of carbonaceous

mylonite do occur.

(2) Scarp Type: This contact generally dips eastwards (striking about 345°), commonly with associated carbonaceous mylonite (of variable thickness). The "greenstone" with which this contact is associated often shows varying degrees of silicification. This contact type is developed beneath the footwall of the 1100 orebody and the footwall lens of the 3000 orebody. Combination of the Plateau and Scarp-type contacts gives the "greenstone" an overall stepped or folded appearance. (see Fig. 2(b), 4)

(3) Quartz-filled type: This is typified by carbonaceous mylonite and Buck Quartz, and is best developed at the south end of the mine. The contact dips gently to the west or the north-west.

(4) Western Block Contact: This contact is defined by a generally wide breccia zone, with an intermixing of Mt. Isa Group sediments and "greenstone". It is the only contact which is visible at the surface, and dips steeply (generally to the east) from the surface to a depth of about 1200 metres. Along this contact the "greenstone" is in juxtaposition to The Magazine Shale, Kennedy and Spear Siltstones, and The Urquhart Shale formations.

Bennett (1965) defines five contact types, however, his definitions have been superceded by Mathias and Clark's descriptions. Bennett also suggests a distribution of the petrological types of "greenstone" - to the west are the epidote-actinolite, chloritic and albitic types, with minor sediments and prominent zones of potassium feldspar, and to the east are the chloritic with minor albitic types. At that time he attributed the change in composition and mineralogy to stratigraphic variation, as he considered the "greenstones" to be a separate unit which overlay the Urquhart Shale. However, he later refuted this (Bennett 1970).

Smith and Walker (1971) carried out a geochemical investigation of the orebodies and the surrounding rocks, which included the "greenstones", with the intent to identify them with respect to established regional igneous activity, to determine the compositional distinction between the regional basic igneous rocks and the greenstones, and to investigate their alteration and its possible relationship to mineralization at Mount Isa. Their study has been used as a background for this study.

A study of the Eastern Creek Volcanics has been carried out by Robinson (1968). He suggests that they are spilitic basalts with interbedded sediments and tuffs, which have undergone low-grade regional metamorphism. In more detail, the volcanics consist of basalts, amygdaloidal basalts, porphyritic basalts and flow-top breccias, whereas the sediments are mainly quartzites, epidote quartzites, olive cherts and grey to purple siltstones and sandstones.

The unit can be divided into four distinct subunits:

Pickwick Beds (760m thickness): Basalts, amygdaloidal basalts, flow-top breccias, quartzites and tuff beds.

Lena Quartzite (610m thickness): Quartzite with dolerite at base.

Paroo Beds (1830m thickness): Basalts, amygdaloidal basalts, flow-top breccias, sandstones, siltstones and cherts.

Cromwell Beds (2140m thickness): Basalts, amygdaloidal basalts and flow-top breccias.

4. "SILICA-DOLOMITE"

The "silica-dolomite" is a large zone of recrystallized shales, dolomite, chert and siliceous shales, which acts as host to the copper mineralization. In cross-section it is roughly lensoid, exhibiting tongue or lobe-like structures up-dip (see Figure 4), but it widens at depth, and is at its greatest development at the contact with the "greenstones". In plan and in section it is broadly transgressive to the bedding of the undeformed shales. Despite this, most contacts with the Urquhart Shale recorded are conformable, and many are quite gradational. It has been possible in several places to trace tuff-marker beds and other horizons (including mineralized horizons) into (and through) the "silica-dolomite" masses. In the case of mineralized horizons, the silver-lead-zinc mineralization is completely lost upon entry into the "silica-dolomite", and is accompanied by a local increase in pyrrhotite content.

The "silica-dolomite" mass consists of several component types. Bennett (1965, 1970) defines four major rock types, these being:

(1) Crystalline dolomite.
(2) Irregularly brecciated dolomitic shale in a crystalline carbonate-quartz matrix.
(3) Partly recrystallized shale.
(4) Fractured and brecciated siliceous shales.

However, Van Den Heuvel (1969), defines four other rock types. These are:-

(1) Crystalline dolomite
(2) Chert
(3) Cherts and dolomites
(4) Marginal siltstones.

As can be seen, the classifications are correlatable to some extent, however, as Bennett emphasises recrystallization and brecciation, and Van Den Heuvel infers a chemical control, the classifications are distinct. All rock types are intimately associated within the "silica-dolomite".

Copper mineralization occurs throughout the "silica-dolomite", the chalcopyrite being very closely associated with both quartz and carbonates, and to a lesser degree with pyrite. Breccia and vein textures are dominant within the "silica-dolomite" (O'Meara, 1961), thus suggesting that the mineralization is introduced, and controlled by fracturing and brecciation of shale.

However, relic framboidal pyrite occurs within the "silica-dolomite" mass (in relatively unaltered shale), with associated bedded pyrrhotite and minor bedded chalcopyrite. Hence it is conceivable that the copper mineralization is sedimentary, and that its present form is simply due to extensive brecciation and recrystalliztion of the original rock type (which may be shale, but due to the shape of the "silica-dolomite", may be something such as a reef or reef-breccia).

Thus there are two major theories on the origin of the mineralization, either an epigenetic model (as suggested by Smith and Walker (1971)) in which the sulphides and/or the "silica-dolomite" are introduced, and a syngenetic model (as suggested by Bennett (1970)) in which intense brecciation and recrystallization has occurred after deposition of the sulphides.

It is the author's opinion that the "silica-dolomite" represents a breccia of some form; whether it is due to movement of the "greenstone" along the faulted contact, or whether it is associated with a reef-type structure is debatable. It is apparent that movement has occurred within the "silica-dolomite" after deposition, which has probably resulted in some brecciation and fracturing. The presence of bedded sulphides within the "silica-dolomite" suggests that the "silica-dolomite" body was present during deposition of the Urquhart Shale, and probably during the period of silver-lead-zinc mineralization. However, the segregation of the copper mineralization from the lead-zinc-silver mineralization suggests some physico-chemical control over the copper mineralization, which did not affect the silver-lead-zinc mineralization. This may lead to consideration that the copper mineralization is distinct from the silver-lead-zinc mineralization, as is suggested by a chemical zoning around the "silica-dolomite". (Smith and Walker (1971)). The exact nature and cause of this control is unknown, but factors which may contribute are:

(1) The "silica-dolomite" body itself
(2) Brecciation within the "silica-dolomite".
(3) Proximity of the "greenstone" to the copper mineralization.

These factors will be considered further when final discussion is carried out and conclusions made.

5. THE EASTERN CREEK VOLCANICS

As it is considered that the "greenstones" were initially Eastern Creek Volcanics, it is necessary to investigate the petrology and geochemistry of the Eastern Creek Volcanics, in order to test if this is so, and assuming that this is so, determine differences between the Eastern Creek Volcanics and the "greenstones", which may give and indication as to events which have affected the "greenstone."

The formation, as described by Robinson (1968), consists of interbedded volcanics (predominantly basalts), sediments and tuffs, which have undergone low-grade regional metamorphism. The sediments are mainly quartzites, epidote quartzites, cherts, siltstones and sandstones. Robinson also divided the Eastern Creek Volcanics into four units, generally on the basis of the proportion of sediments to volcanics.

Petrographically, the volcanics consist of laths of albite, enclosed by a groundmass of epidote-actinolite or chlorite, which is replacing the original ferromagnesian minerals. Opaques (dominantly leucoxene and sphene) form a significant proportion of the rock. Occasionally, a few megacrysts of feldspar occur, these tending to be glomeroporphyritic. Quartz is a common constituent, although it does not occur in great quantities. It occurs filling amygdules, and as pods within the rock. These pods could represent recrystallized glass, which originated from a residual liquid.

This petrography is consistent with a tholeiitic origin, as is suggested by the analyses, which are presented in Table 1. Smith and Walker (1971) also consider the Eastern Creek Volcanics to be tholeiitic, on a purely chemical basis. From the analyses it is apparent that CaO in the basalts is generally lower than that for a typical tholeiite, although it is variable. A simple explanation can be put forward - as the area has undergone regional soda metasomatism (Carter et. al. 1961), the calcic feldspars typical of tholeiites have reacted with the metasomatic liquids, thus forming albite, with the Ca^{++} ions going into solution. Undoubtedly much of this calcium has remained in the vicinity in the form of epidote and actinolite, but some would have escaped from the bulk of the rock, probably to form localized concentrations of calcite and the like. This metasomatism would also be expected to increase the Na_2O content of these rocks. Using 432/046 as an example, this is indeed the case - a high Na_2O value (5.12%) with a very low CaO value (0.53%), which is very suggestive of replacement of CaO by Na_2O as described above, with virtually all of the CaO being removed from the rock(in solution). The mineralogy also confirms the chemistry - the mafic mineral is chlorite (which contains virtually no CaO), whereas in the other rocks the predominant mafic minerals are epidote and actinolite (which contain significant CaO). (The slight depletion in CaO may also be due to weathering).

Hence the visible effects of the metasomatism on the Eastern Creek Volcanics can be summarized: Firstly, the mafic mineral is chlorite, not an epidote-actinolite assemblage. Secondly, a high Na_2O value is accompanied by a very low CaO value. No other chemical changes are seen. The effects of the metasomatism are widespread, but generally localized. It should be noted that the Na-Cl metasomatic episode is later than the regional metamorphism (Carter et. al. 1961).

Robinson (1968) describes the Eastern Creek Volcanics as follows: (p.93):

"The basalts examined consist predominantly of albite, chlorite (biotite) actinolite, epidote and quartz, with sphene titanomagnetite and apatite as accessories. The vesicles are filled with quartz, calcite, epidote and albite. Occasionally relicts of labradorite and andesine occur with the albite crystals."

And also on p. 93:

"The apparent source of the basalt is from fissure-type vents which are now represented by extensive dyke systems ..... These dyke systems generally associated with plateau or flood basalts of non-orogenic continental regions."

Thus, combining the observed petrography and the above descriptions, it appears that the Eastern Creek Volcanics are tholeiitic flood basalts.

6. THE "GREENSTONES"

The "greenstones" studied consist of 3 petrographic and chemically distinct rock units, these being:-

1. Sediments
2. Altered Volcanics
3. High Carbonate rocks.

Of the rocks studied, the Altered Volcanics are dominant, with the Sediments constituting most of the remainder. The High Carbonate rocks form only a minor proportion of the "greenstone". The Altered Volcanics and the Sediments appear to have a stratigraphic control, but the High Carbonate rocks, because of their nature, appear to have a more random distribution.

Each rock unit in turn will be discussed, followed by a discussion on the rocks of the "greenstone" as a whole.

1. The Sediments

The sediments can be divided into two groups, cherts (which are very minor), and detrital sediments, on the basis of both petrography and geochemistry. Analyses are presented in Table 2, and petrographic descriptions are presented in Appendix 1.

Petrographically, the detrital sediments are characterized by an abundance of quartz, which occurs as angular to sub-rounded detrital grains in a fine-grained quartz matrix. Albite, zircon, leucoxene, and ?xenotime are other minor detrital components. Chlorite, muscovite, calcite and pyrite are the other constituents, however, chlorite is the only mineral to be present in significant quantities. This may represent an initially argillaceous matrix.

Chemically, the sediments are typically high in SiO_2 ($\simeq$ 80%), low in CaO (generally $< 1\%$), K_2O ($< 1\%$), TiO_2 ($< 1\%$) and P_2O_5 ($\leqslant 0.10\%$). With respect to trace elements, Rb is consistent at 20-30ppm, as is Cr at 200-350ppm, and Zr is high ($>$ 350ppm) for the detrital sediments, and low (30-70ppm) for the cherts. Note that 432/V374 and 432/V376 do not fit into this classification. However, they are chloritic, and probably represent a greater volcanic influence.

The cherts consist of a mosaic of fine grained quartz, which is recrystallized to varying degrees (often forming veins), with anhedral calcite dispersed through the section on occasions. Muscovite, chlorite and pyrite form a minor part of the section. Chemically they are similar to the detrital sediments, except for a slightly higher SiO_2 ($>$ 85%), a much lower Na_2O ($<$0.20% c.f. $>$1.5% for detrital sediments), TiO_2 ($\leqslant$0.05% c.f. $>$ .35%) and Zr (as mentioned above).

The clasts of quartz and feldspar suggest a granitic-type source area. This is surprising when one considers that the sediments are closely associated spatially with volcanics. However, the feldspars are relatively fresh, and in combination with a chloritic (?argillaceous) matrix suggests at least a minor volcanic influence. The presence of the siliceous matrix can be interpreted in either of two ways. It may represent fine-grained detrital quartz, or it could represent a chert-like cement, which has been precipitated during deposition (or diagenetically). However, Robinson (1968) reports intra-formational breccias, graded bedding, small scale cross-bedding and ripple-marks in sediments within the Eastern Creek Volcanics, and as it is considered that the "greenstones" were initially Eastern Creek Volcanics, the presence of chert seems anomalous, especially as a matrix to clastic material. Thus it appears that the matrix represents detrital quartz, although no definite conclusion can be made. The cherts may represent initial chemical precipitates during periods of quiescence, or they may represent concentrations of quartz which has been introduced into the "greenstone". Their association with the Buck Quartz masses (as described by Mathias and Clark (1974), and the fact that there does not seem to be any stratigraphic control, suggests that the cherts represent, at least in part, concentrations of quartz which has been introduced into the "greenstone".

2. The Altered Volcanics:

These are, in general, chloritic rocks which form the bulk of the "greenstone", and from the textures it is apparent that they were once basic volcanics, which have since undergone extreme alteration. Chemically, they are very interesting, as they show a depletion in Fe_2O_3, Na_2O, K_2O, TiO_2, Zn, Sr, and Pb. CaO and Cu show a great depletion, (although some very high values of Cu occur). They are enriched in MgO and H_2O^+. (Depletion and enrichment relative to Eastern Creek Volcanics).

In thin section the Volcanics consist of laths of albite, enclosed by a chloritic groundmass, which contains leucoxene, and often biotite. Pods and veins of quartz are common, and often calcite is associated with this quartz, either as inclusions within the quartz veins, or as anhedral to euhedral "porphyroblasts" within the pods. The quartz pods occur in two forms - firstly fine grained (comparable to the quartz pods in the Eastern Creek Volcanics), which is apparrently an original igneous texture, and secondly, as recrystallized, coarser grained quartz in which fluid inclusions and/or calcite may be abundant. This second form is considered to represent recrystallization of the original quartz pods (the first form).

The abundance of albite in these rocks is variable. In some rocks, albite forms only a minor portion of the section (or it may be absent altogether), while in others it constitutes a major part of the rock (e.g., 432/V81, in which feldspar constitutes 70% of the section - see Appendix 1). Similarly the amount of mica (both biotite and muscovite) visible in thin section is variable, the micas being significant (is > 10%) often enough that a potassium rich "sub-group" can be postulated. (This potassium-rich "sub-group" may be important, especially as potash metasomatism has taken place. This "sub-group" could also represent an original compositional variation).

Chemically, these Altered Volcanics show many interesting characteristics. As mentioned before, they show a depletion in Fe_2O_3, Na_2O, K_2O, TiO_2, CaO, Zn, Sr, Pb and Cu, and an enrichment in MgO and H_2O^+ relative to the Eastern Creek Volcanics (and hence to normal tholeiites). Smith and Walker (1971) state that: "Relative to typical tholeiites, the greenstones are high in Mg and low in Ba, Ca, Co, Cu, Mn, Ni, and Sr. In some greenstones Fe, Ti, and Zn values are lower than those of typical tholeiites." (p.44). Thus it appears, that if these rocks are Eastern Creek Volcanics, which seems likely, they have undergone an intense and extreme alteration. Figures 6 and 7 show plots of the Ti, Zr, and Y content of these basic volcanics and the Eastern Creek Volcanics, in an effort to determine their nature. However, all that can be said is that the "greenstone" volcanics are similar to the Eastern Creek Volcanics. (concept after Pearce and Cann (1973)). This alteration will be discussed in some detail later in the thesis.

No single element or group of element will distinguish the Altered Volcanics from the other units of the "greenstones". Perusal of the analyses presented in Table 3 will give an indication to the variation of values and the average value for each element. As the Altered Volcanics make up the bulk of the greenstone, the recommended procedure to classify the rocks is to determine which samples are sediments, and which are "High Carbonate Rocks", and to consider those not classified as being Altered Volcanics. However, inspection of the analyses should take place, to prevent misclassification.

3. <u>High Carbonate Rocks</u>:

These rocks form only a minor portion of the "greenstone", but it is considered that their presence is significant, in respect to the alteration of the greenstones. In thin section, they are characterized by at least 20% carbonate (usually calcite), which is replacing chlorite, and quartz. Petrographically (and chemically) two varieties can be recognized - one in which the carbonate is porphyroblastic (and euhedral), and is associated with chlorite, and a second in which the carbonate is replacing quartz. The former variety has a very low SiO_2 ($\lesssim$ 30%), with a very high H_2O^+ (> 15%), while the latter variety has a composition which is comparable to a normal Altered Volcanic, although allowances must be made for the high carbonate values (e.g., low MgO, high CaO, high MnO, high H_2O^+, high Sr).

This latter variety thus probably represent Volcanics which have been intensively replaced by quartz and carbonate. (It should be noted that carbonate is present in most sections, but generally to a minor degree (i.e., 1-5%)). The former variety are unusual in that they contain virtually no quartz.

These rocks probably represent loci of deposition of carbonate (with or without quartz), during the alteration of the "greenstone" as a whole. As such, they are significant, and, as these rocks are very high in CaO, but have a higher than 'normal' value for Cu, and as it appears that the alteration involves gross depletion of these elements, their presence may represent variation in physico-chemical conditions during this period of alteration. (This alteration will be discussed later).

A fourth, minor rock type was detected petrographically. It consists primarily of recrystallized quartz, often with pods and granules of chloritic material. The quartz generally shows undulose extinction, and appears to be a vein-type quartz. Fluid inclusions are abundant. It is considered that these rocks represent sheared "greenstone", with associated quartz veining. They would probably represent areas of faulting and shearing within the "greenstone", and possibly areas of folding.

It should also be noted that Bennett (1965) observed a distribution of the types of "greenstone" (as defined by O'Toole (1964)) which may also be related to this alteration of the "greenstones". It is as follows:

"The western ..... volcanics ...... contain the epidote-actinolite, chloritic and albitic types ...... Wide zones rich in potassium feldspar are prominent .... and carbonate veins with minor amounts fo chalcopyrite are abundant. The eastern .... contains mainly chloritic and minor albitic types ..... Quartz is the predominant vein material. Potassium feldspar ...... generally minor". (p.237)

Quartz Veining within the "greenstone" consists of two predominant types, one consisting of quartz containing carbonate grains and inclusions and another consisting of quartz containing abundant fluid inclusions. It is considered that the quartz-carbonate veining may be related to the simultaneous introduction of quartz and carbonate into the "greenstone", and that the veining with fluid inclusions is much later, and probably related to the Buck Quartz. Recrystallization of original quartz has also resulted in the formation of fluid inclusions. Whether these two stages of fluid inclusions are related is unknown.

Smith and Walker (1971), in their study at Mount Isa, determined that the "greenstones" are easily distinguishable from sediments of the Mount Isa Group, on the basis of their composition. There are significant differences in Ni, Sc, Ti, V and Zr (which are higher in the "greenstones"), and in Ba, Ca, Mn and Sr (which are lower). The most diagnostic are Sc and V. The "greenstones" all have Sc > 25ppm and V > 90ppm. (but a few sediments also have V > 90ppm).

It appears that the volcanics of the "greenstone", at least, have been highly altered at some stage of their history. They are extensively veined (dominantly by quartz with carbonate), are predominantly chloritic, and are generally extremely depleted in CaO and Cu with respect to the Eastern Creek Volcanics (and normal tholeiites). MgO and "H_2O^+" are higher. Exceptions to the normal pattern occur, notably the occurrence of the "High Carbonate" rocks (hence high CaO) and of occasional high concentrations of Cu (e.g., 432/015, 432/V43).

The alteration process thus appears to have added principally MgO and 'H_2O^+', while CaO and Cu have been depleted. Elements which have been affected, but not to as great an extent are: Fe_2O_3, Na_2O, K_2O, TiO_2, Zn, Sr, Pb, Ba, and Ni (all depleted). No elements analysed for (apart from MgO and "H_2O^+") show a consistent pattern of enrichment (SiO_2 is on the average, higher than that of the Eastern Creek Volcanics, but the values vary from 45% to 64% SiO_2).

It is noteworthy that all of the chalcophile elements analysed for are depleted relative to the Eastern Creek Volcanics, and it is more noteworthy that where Cu is enriched (as in 432/015, 432/V43), the Co, Ni, Pb, and Zn values remain virtually unchanged. This suggests two things. Firstly, the alteration was responsible for redistribution (or removal) of sulphide elements (and thus probably sulphides themselves), and secondly, copper was affected to a very great extent, relative to the other elements.

Similarly for CaO, as where it is enriched, the other major elements (excepting MgO and MnO), are not affected, except where the amount of CaO and "H_2O^+" (and sometimes MgO) is high enough to affect these values (e.g., 432/006, 432/017). It is also noteworthy than abnormally high values of Cu occur in the cherts (432/026, 432/V43), possibly suggesting an association of copper with quartz.

Figure 8 shows some association of log Cu with SiO_2, although the relationship is not obviously apparent. However, an immediately obvious association cannot be expected, as carbonate also appears to be associated with both silica and copper. Hence, a relationship may be there, but it is not obvious, due to an outside factor (i.e., carbonate), and possibly due to lack of samples.

Thus the major problem is: did the alteration result in redistribution of the elements only (especially CaO, Cu), or was it responsible for removal of these elements from the "greenstone", to be deposited elsewhere? With an orebody and host rock as large and as unusual as the "silica-dolomite" and its copper ores so close spatially to the "greenstones", one must be tempted to postulate that this alteration is at least partly responsible for the formation of the copper orebodies, and possibly for the introduction of material into the "silica-dolomite". The alteration is petrographically and chemically similar to that observed in Canadian Volcanogenic Massive Sulphide deposits, in which the alteration consists of chlorite, disseminated sulphides, magnetite, sericite, silica and carbonate; sericitization and chloritization being the most common. (Sangster, 1972).

Chemically the Canadian-type alteration results in an increase in Fe, Mg and S, with a decrease in Si, K and Na. The two alterations are thus comparable, with the exception of the decrease in SiO_2 and the increase in Fe_2O_3, (and possibly S) and possibly the presence of magnetite. It should be noted, however, that the changes in SiO_2 and Fe_2O_3 are slight (3-4%), and that magnetite (?titanmagnetite) is present in the "greenstone".

It thus appears that a process such as mineralizing solutions (?dominantly silica + carbonate) passing through the "greenstone" body could have resulted in its present overall petrology and geochemistry, and could have deposited copper sulphides, along with quartz and carbonate in a suitable physico-chemical environment, such as the "silica-dolomite". However, before such a process can be considered, the origin and significance of the high concentrations of carbonate and copper must be determined.

The copper anomalies may represent initial concentrations of copper in the initial volcanic rock, however, it is surprising that it has not been depleted to the same level as the rest of the "greenstone". The only other explanation is that the mineralizing solutions deposited the copper in these localities, due to physico-chemical conditions. In this case, one would also expect abnormal concentrations of carbonate and/or silica (as these major elements appear to be associated with the Cu mineralization within the silica-dolomite, and they appear to have been introduced into the "greenstone", and one must also seek an explanation for these conditions. However, as only limited work has been done, nothing conclusive can be put forward. Those samples of anomalous copper are comparatively high in CaO (432/015) or SiO_2 (432/V43). (It may also be of note that 432/026 is a chert, with a Cu value of 141ppm, and that 432/037 is a volcanic, extensively veined by quartz (SiO_2 = 63.76%), and has a Cu value of 215ppm). It thus appears that the high Cu values are associated with introduced material (either silica or carbonate, but predominantly silica).

The high carbonate rocks probably represent loci of deposition of carbonate, although no cause can be postulated. It is interesting to note that the two samples of low SiO_2 (viz. 432/006, 432/017) are relatively close to the contact zones, whereas 432/V686 and 432/V905, with a "normal" SiO_2 value, are well away from the contact. This distribution may be significant in that concentrations of SiO_2 only and carbonate only occur close to the contact zone, whereas the concentrations of both SiO_2 and carbonate occur away from the contact zone. There is no suggestion as to the cause.

Hence it seems that the alteration present in the "greenstone" is due to mineralizing solutions which have passed through, removing Cu, the bulk of which has been deposited in the "silica-dolomite". This solution was silica-rich, resulting in an association of introduced silica with anomalous concentrations of Cu, both in the "silica-dolomite" and within the "greenstone". These solutions may also be responsible for a general redistribution of CaO, in the form of carbonate, although some was almost certainly transferred into the "silica-dolomite".

The alteration also resulted in an increase in MgO and H_2O^+ in the "greenstone", which is consistent with the chloritic alteration seen petrographically. This may give further indication as to the composition of the mineralizing fluid.

7. SUMMARY AND CONCLUSIONS

These rocks, although extensively altered, appear to be Eastern Creek Volcanics which have been caught up in the depositional and later history of the Mount Isa Group. Their structural history has not been investigated, but it is considered that the "greenstone" block was emplaced during sedimentation of the Mount Isa Group (as suggested by Smith (1969)). At some time after emplacement, silica-rich solutions passed through the "greenstone", removing Cu and transporting it into the "silica-dolomite", where it was deposited. Presumably in this same event, CaO was removed from the original minerals, and redeposited, both within and without the "greenstone".

MgO and H_2O^+ were also introduced into the "greenstone".

The timing of this event is unknown. Smith and Walker (1971) consider it to be a late diagenetic-early deformational event, whereas Croxford (1974) considers that both the copper and lead-zinc ores are contemporaneous, both being sedimentary. Isotopic studies suggest that, for both copper and lead-zinc ores, the sulphur is biogenic (Solomon and Jensen, 1965). It may thus be feasible that the alteration observed in the "greenstone" represents the introduction of copper (in solution) into the "silica-dolomite" where, in the presence of sulphate-reducing bacteria, copper sulphides were deposited. However, the problem is, in what form was the copper transported? This is an important aspect of the oregenesis, and, at present, no solution can be suggested.

Recommendations

Although this thesis has classified the constitution of the "greenstone", and a model for ore genesis has been proposed, further work should be done, primarily to give a better picture of the ore genesis. The structural history of the "greenstone" must be determined, and it must be compared with the known structural events which have occurred in the "silica-dolomite" and Urquhart Shale. This would hopefully give the timing of emplacement of the "greenstone", and possibly could give the timing of the alteration described in this thesis. An intense study of the isotopic composition of the sulphides, and of fluid inclusions, both in the "silica-dolomite" and "greenstone", would give an indication as to the contributions of biogenic and hydrothermal sulphur to the ore deposition and also to the composition of the mineralizing fluids. Thirdly, an investigation into the "silica-dolomite" would hopefully give an indication as to its significance with respect to regional geology and mineralization.

Finally, the composition and petrography of all of the varieties of the "greenstone" must be related to the Eastern Creek Volcanics, to determine if the "greenstone" and the Eastern Creek Volcanics are equivalent. (It is suggested that the epidote-actinolite variety may give the best results, as it is of the same mineralogy as the Eastern Creek Volcanics). It is also suggested that the relationships of the different varieties of the "greenstone" should be investigated.

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BIBLIOGRAPHY

BENNETT, E. M., 1965. Lead-zinc-silver and Copper Deposits of Mount Isa. In: Geology of Australian Ore Deposits (Ed. J. McAndrew) p.233-246. 8th Commonwealth Mining and Metallurgical Congress: Sydney. Vol. 1.

BENNETT, E. M., 1970. History, Geology and Planned Expansion of Mount Isa Mines Properties. Am. Inst. Min. Eng. World Symposium on Mining and Metallurgy of Lead and Zinc. Vol. 1. p.139-169.

BRIDGES, M. C., 1969. Faults in the 1100 Orebody Mount Isa Mines. B.Sc. (Hons) Thesis, Univ. of Adelaide (unpublished).

CARTER, E. K., BROOKS, J. H., and WALKER, K. R., 1961. The Precambrian Mineral Belt of North-Western Queensland. Bureau Mineral Resources (Aust.) Bulletin 51.

CROXFORD, N. J. W., 1964. Origin and Significance of Volcanic Potash-rich rocks from Mount Isa. Trans. Inst. Mining. Metallurgy 74 p.33-43.

CROXFORD, N. J. W., 1974. Cobalt Mineralization at Mount Isa, Queensland, Australia, with References to Mount Cobalt. Mineral. Deposita 9 (2) p.105-115.

HEINRICH, E. Wm., 1965. Microscopic Identification of Minerals. McGraw-Hill.

MATHIAS, B. V. and CLARK, G. J., 1974. The Mount Isa and Hilton Orebodies. (in print).

O'MEARA, A. E., 1961. Contributions to the study of Mount Isa Copper Orebodies. Proc. Aust. Inst. Min. Metall. 197 p.163-92.

O'TOOLE, A., 1964. Petrographic Description of the Greenstones, Mount Isa Mines Ltd. Rep. (unpublished).

PEARCE, J. A., and CANN, J. R., 1973. Tectonic Setting of Basic Volcanic Rocks Determined Using Trace Element Analyses. Earth. Planet, Sci. Letters 19 p.290-300.

BIBLIOGRAPHY (Cont.)

ROBINSON, W. B., 1968. Geology of the Eastern Creek Volcanics in the Mount Isa District. Proc. Aust. Inst. Min. Metall. 226, p.89-96.

SANGSTER, D. F., 1972. Precambrian Volcanogenic Massive Sulphide Deposits in Canada: A Review. Geol. Survey Canada. Paper 72-22.

SMITH, S. E. and WALKER, K. R., 1971. Primary Element Dispersions Associated with Mineralization at Mount Isa, Queensland. Bureau Mineral Resources (Aust.) Bulletin 131.

SMITH, W. D., 1969. Penecontemporaneous Faulting and its likely Significance in Relation to Mt. Isa Ore Deposition. Spec. Publs. Geol. Soc. Aust. 2, p.225-235.

SOLOMON, P. J. and JENSEN, M. L., 1965. Sulphur Isotopic Fractionation in Nature with Particular Reference to Mount Isa, Queensland. 8th Commonwealth Mining and Metallurgical Congress (Sydney). Vol. 6. Proceedings General p.1275-1286.

STANTON, R. L., 1972. Ore Petrology. McGraw-Hill.

TURNER, F. J. and VERHOOGEN, J., 1960. Igneous and Metamorphic Petrology. McGraw-Hill.

VAN DEN HEUVEL, H. B., 1969. Sedimentation, Stratigraphy and Post-depositional Changes in the Sediments of the Upper Formations of the Mount Isa Group, North-West Queensland. Ph.D. Thesis, Univ. of Queensland (unpublished).

TABLES

TABLE 1: CHEMICAL ANALYSIS OF EASTERN CREEK VOLCANICS

	432/039	432/040	432/044	432/046	[3]SW5	[3]SW6	Continental[1] Tholeiite	Oceanic[2] Tholeiite
SiO_2	50.80	51.47	50.75	50.11	48.39	46.22	50.61	50.45
Al_2O_3	12.13	13.72	14.72	15.49	13.14	14.67	13.58	14.94
$**Fe_2O_3$	16.18	12.70	13.35	15.03	2.90	2.50	3.19	3.38
FeO	—	—	—	—	9.46	13.05	9.92	7.55
MnO	0.24	0.15	0.15	0.06	0.30	0.20	0.16	0.08
MgO	4.29	7.86	6.82	6.70	3.84	5.52	5.46	7.67
CaO	6.65	3.18	6.54	0.53	8.48	8.56	9.45	9.17
Na_2O	2.72	2.06	3.22	5.12	2.76	1.88	2.60	2.84
K_2O	1.10	0.47	1.13	2.11	0.96	0.60	0.72	0.35
TiO_2	3.09	3.02	1.39	1.65	3.72	2.74	1.91	2.33
P_2O_5	0.45	0.39	0.13	0.15	0.65	0.44	0.39	0.27
$*H_2O^+$	2.17	4.92	3.06	3.40	2.39	3.88	2.13	0.73
$*H_2O^-$	—	—	—	—	0.25	0.24	—	0.23
$*CO_2$	—	—	—	—	3.23	—	—	—
							Cr_2O_3	0.05
Total	99.82	99.94	100.26	100.35	100.48	100.50	100.12	100.04

Trace Elements (ppm)

Co	42	39	49	104	37	47
Ni	43	50	92	102	60	105
Cu	431	78	435	234	160	225
Zn	288	193	153	52	—	—
Sr	164	40	183	117	140	130
Rb	46	34	37	60	—	—
Zr	283	286	136	129	520	290
Y	106	116	30	14	88	60
Cr	156	144	298	232	—	—
Pb	50	10	10	7	—	—

* H_2O^+ is weight loss on ignition (at 1,000°C), and includes CO_2 (for samples prefixed 432/ .)
Where H_2O^- and CO_2 absent, values are included in H_2O^+; when CO_2 is absent, values included in H_2O^+.

** All Fe as Fe_2O_3 for samples prefixed 432/....

1. Average of 11 Deccan basalts (from Turner and Verhoogen (1960), Table 15, No. 1 (p.208)).
2. Average of 10 basalts, Koolau Series, Oahu, Hawaii (from Turner and Verhoogen (1960), Table 18, No. 1 (p.220)).
3. Analysis of Eastern Creek Volcanics, from Smith and Walker (1971), Tables 14, 15, Nos. 5, 6.

TABLE 2

CHEMICAL ANALYSES OF SEDIMENTS

	432/003	432/026	432/032	432/V43	432/V374	432/V376
SiO_2	81.24	88.96	80.54	86.03	76.12	65.72
Al_2O_3	10.13	1.83	6.42	2.79	9.52	10.79
*Fe_2O_3	0.70	2.29	4.21	4.43	3.83	7.38
MnO	0.01	0.03	0.03	0.01	0.04	0.03
MgO	0.86	0.68	3.53	2.80	3.26	8.34
CaO	0.35	1.75	0.14	0.19	0.19	0.21
Na_2O	5.49	0.15	1.58	0.06	3.16	1.34
K_2O	0.25	0.60	0.17	0.02	0.27	0.38
TiO_2	0.37	0.00	0.42	0.05	0.75	0.69
P_2O_5	0.10	0.01	0.04	0.01	0.07	0.13
**H_2O^+	0.81	3.05	2.35	2.72	2.02	4.20
Total	100.31	99.35	99.43	99.11	99.23	100.92

Trace Elements (ppm)						
Co	25	12	18	64	16	31
Ni	9	15	19	20	20	35
Cu	39	141	27	2177	10	12
Zn	20	14	53	33	28	53
Sr	31	8	19	4	34	19
Rb	24	30	23	21	25	30
Zr	389	68	529	38	358	181
Y	76	4	12	8	19	36
Cr	276	305	324	298	218	131
Pb	14	4	6	21	4	6

* Total Fe as Fe_2O_3.

** H_2O^+ is weight loss on ignition (at 1,000°C), and includes CO_2

TABLE 3

CHEMICAL ANALYSES OF ALTERED VOLCANICS

	432/005	432/012	432/015	432/019	432/004	432/031	432/037	432/V81	432/V302	432/V451	432/V756	432/V796	432/V832	432/V605
SiO_2	46.85	46.47	51.55	45.51	53.98	51.84	63.76	51.05	47.13	56.18	58.63	56.83	54.29	59.55
Al_2O_3	14.37	16.49	12.67	13.56	13.80	13.24	10.36	16.14	14.51	13.41	13.08	12.89	14.40	12.99
Fe_2O_3	15.19	13.49	14.21	18.39	10.24	11.10	10.26	16.60	14.27	8.82	12.17	9.40	10.17	12.20
MnO	0.09	0.09	0.10	0.12	0.08	0.06	0.06	0.07	0.09	0.09	0.06	0.08	0.09	0.06
MgO	13.76	11.39	5.90	11.08	14.01	11.36	8.30	10.58	11.59	10.76	4.46	9.29	10.70	4.74
CaO	0.32	0.48	3.39	0.97	0.22	0.85	0.18	0.29	1.07	0.73	1.07	0.32	0.31	0.56
Na_2O	0.02	4.91	2.60	1.16	1.37	1.40	0.90	3.49	1.98	2.34	4.69	3.00	3.19	5.20
K_2O	0.17	0.59	1.84	0.87	0.14	0.17	0.48	0.58	2.00	0.45	0.41	0.37	0.29	0.87
TiO_2	2.00	1.92	1.23	2.01	1.31	1.94	0.87	1.63	1.76	1.28	1.36	1.55	1.57	1.32
P_2O_5	0.18	0.24	0.13	0.20	0.12	0.16	0.10	0.16	0.20	0.14	0.17	0.17	0.18	0.20
H_2O^+	6.79	5.87	5.63	6.29	6.10	7.84	4.97	5.34	5.77	5.45	2.68	4.69	5.27	2.45
Total	99.74	101.94	99.25	100.16	101.44	99.96	100.24	99.93	100.37	99.65	98.78	98.59	100.46	100.14

Trace Elements (ppm)

Co	33	44	42	53	34	ND	63	51	44	28	24	46	46	28
Ni	59	60	45	73	75	ND	63	51	62	39	32	37	45	39
Cu	4	7	6645	3	3	7	215	6	5	4	2	2	2	3
Zn	115	100	103	168	85	ND	23	64	87	64	70	100	93	64
Sr	11	46	65	20	12	16	9	24	29	56	43	17	22	56
Rb	25	28	39	29	24	24	27	27	59	35	27	27	25	35
Zr	149	205	107	167	160	131	115	149	185	195	208	231	248	195
Y	31	48	5	60	43	50	17	38	59	33	147	63	72	33
Cr	113	210	211	196	76	221	179	201	160	100	101	51	68	100
Pb	9	9	10	10	8	ND	8	8	8	6	4	6	8	6

(continued)

TABLE 3 (Cont.)

	SW17[1]	SW18[1]	SW19[1]	SW20[1]	SW21[1]
SiO_2	50.34	41.99	58.42	49.34	50.51
Al_2O_3	13.04	16.17	10.17	14.43	15.76
Fe_2O_3	10.38	12.45	13.07	14.91	10.52
MnO	0.03	0.05	0.08	0.10	0.09
MgO	15.71	17.44	10.94	11.83	11.78
CaO	0.28	0.49	0.24	0.32	0.33
Na_2O	0.00	0.00	0.06	0.83	1.81
K_2O	0.38	0.04	0.00	0.09	0.77
TiO_2	1.55	2.65	1.11	1.77	1.72
P_2O_5	0.15	0.40	0.18	0.24	0.23
H_2O^+	—	—	—	—	—
Total	—	—	—	—	—

Trace Elements (ppm)

Co	21	25	31	14	33
Ni	95	70	50	58	57
Cu	12	7	58	10	6
Zn	15	40	45	95	70
Sr	5	4	3	5	14
Rb	—	—	—	—	—
Zr	242	420	285	440	518
Y	56	71	58	61	61
Cr	—	—	—	—	—
Pb	—	—	—	—	—

1. Analyses from Smith and Walker (1971), Tables 14, 15, Nos. 17 to 21.

TABLE 4

CHEMICAL ANALYSES OF HIGH CARBONATE ROCKS

	432/006	432/017	432/V686	432/V905
SiO_2	25.03	16.33	54.84	41.82
Al_2O_3	12.50	4.13	9.33	13.89
$*Fe_2O_3$	15.57	6.40	13.35	14.37
MnO	0.30	0.48	0.12	0.13
MgO	19.20	6.90	1.51	5.96
CaO	8.18	33.75	8.36	7.46
Na_2O	0.08	0.09	4.37	4.98
K_2O	0.20	0.02	0.66	0.79
TiO_2	0.85	0.52	1.42	1.11
P_2O_5	0.11	0.21	0.15	0.14
$**H_2O^+$	18.70	31.09	0.36	7.77
Total	100.72	99.92	100.47	98.42

Trace Elements (ppm)				
Co	38	23	15	44
Ni	36	26	22	69
Cu	7	36	24	34
Zn	146	86	35	23
Sr	45	309	140	153
Rb	28	24	35	33
Zr	633	105	218	153
Y	41	38	61	45
Cr	79	60	137	61
Pb	14	20	10	10

* Total Fe as Fe_2O_3.

** H_2O^+ is weight loss on ignition (at 1,000°C), and, in this case is predominantly CO_2.

APPENDICES

1. DESCRIPTION OF SECTIONS
2. ANALYTICAL TECHNIQUES
3. TREATMENT OF DATA

APPENDIX 1

Description of Sections

72 thin sections were prepared, consisting of:

57	"Greenstone"
8	Eastern Creek Volcanics
4	"Mylonite"
2	Buck Quartz
1	"Silica-dolomite" material

However, not all of these have been described, due to lack of time, but those which are not described (all of which are "greenstones") have been classified into rock types on a brief examination.

Polished sections were prepared of three specimens, 432/023, 432/029, and 432/020, all of which would be classified as copper ore. These have all been described. No polished sections were prepared of "greenstone" material, as the opaque minerals were identifiable in hand specimen and in oblique reflected light (from a thin section).

The sections will be presented in the following way:- firstly divided into "greenstone", "Eastern Creek Volcanics", etc., and within each lithological division the mineralogy will be discussed first, followed by a dominantly textural description of each section. If necessary, within each major division (e.g., "greenstones"), subdivision into rock types will be done.

1. The "Greenstones"

Mineralogy:

Chlorite: Generally pale green, and slightly pleochroic (to colourless). In most cases it exhibits anomalous interference colours (generally brown, sometimes green). This suggests it is pennine.

It occurs generally as a groundmass to albite laths, quartz grains, etc., and is often associated with biotite and leucoxene. It may replace feldspar, and is present as inclusions in quartz and feldspar, and is also present in quartz veins. In many sections it shows a preferred orientation. (grainsize variable).

Feldspar: The predominant feldspar present in these rocks is albite, although some minor potassium feldspar occurs. The albite generally occurs as laths (averaging ≃ 0.1mm long), showing simple albite twinning. It is often being replaced by chlorite, and in some cases (e.g., 432/014, 432/015), it is being replaced by sericite and carbonate. Some albite showing checkerboard twinning is present in 432/003. This represents albite formed due to Na metasomatism.

Quartz: Quartz occurs in many forms - as detrital grains, chert-like, in veins, and recrystallized forms of these. Two major varieties can be recognized - original quartz (detrital grains, chert-like), and introduced quartz (e.g., veins). In many cases quartz is associated with carbonate, and, especially in vein quartz and in recrystallized quartz, fluid inclusions occur. (grainsize variable).

Carbonate: Carbonate is present in most sections, although generally as a minor constituent. In most cases it is believed that this carbonate is calcite, although the analyses indicate that significant Mg is present in some cases (especially in "High Carbonate" rocks). It is most often associated with quartz (either as discrete grains or as inclusions within quartz veins). In some sections it is euhedral to subhedral, but in most cases it is anhedral to subhedral. It may replace chlorite, and feldspar. (grainsize variable).

Biotite: Biotite is present in a few sections, as pleochroic green-brown to yellow grains associated with chlorite. It shows typical interference colours, and may show preferred orientation on occasions. (grainsize ≃ 0.2mm).

Muscovite: Muscovite is not as abundant as biotite, but it shows a preferred orientation more often. It also shows typical second to third order interference colours, and in some sections appears to be associated with carbonate "porphyroblasts". It may also replace feldspars as sericite. (grainsize ≈ 0.1mm).

Leucoxene: This is opaque in thin section, but can be recognized by a white to cream colour in random reflected light. It is present in most sections as fibrous and skeletal grains, and also as grains disseminated through the section. It is virtually always associated with chlorite (grainsize ≈ .05mm).

Pyrite: Pyrite is present in most sections, as subhedral to euhedral grains. It is often associated with quartz (the quartz may occur as strain shadows). Other sulphides may occur (e.g., chalcopyrite and pyrrhotite in 432/037 and 432/015).

Zircon: Zircon is present in the sediments as detrital grains, generally in trace amounts only. (grainsize ≈ .1mm)

Magnetite: This is present in a few sections, generally in highly altered basalts (e.g., 432/V686, 432/V756). It is recognized by a black colour under random reflected light, and is often altered to leucoxene, thus suggesting that it is titanium rich.

Hornblende(?): This occurs in very few sections. It is pleochroic yellow-dark green, length slow, and has mottled interference colours of a moderate magnitude.

Epidote: Very minor, occurs associated with (?) hornblende (in 432/006), and as detrital grains in 432/032.

1. Sediments

432/003: Consists of a fine grained (.01mm) matrix of quartz and feldspar, with larger detrital grains of quartz and albite (0.6-0.1mm). Carbonate is dispersed through the section (0.6mm). In places recrystallization occurs, resulting in a marked increase in grainsize. The section is crossed by veins of recrystallized quartz with fluid inclusions. Feldspar occurs as two varieties - well formed, anhedral - subhedral with distinct twinning (albite), and as anhedral grains, with "checkerboard"-type twinning, which appear to be detrital.

Quartz	47%	Zircon	tr.
Feldspar	47%	Chlorite	1%
Carbonate	8%	Leucoxene	1%
Muscovite	2%		

432/026: Chert-like matrix (.01mm) with dispersed grains of anhedral carbonate (0.01-0.4mm). Crossed by veins of recrystallized quartz with fluid inclusions. Muscovite is scattered through the section, showing a preferred orientation, and is apparently associated with carbonate. Subhedral to euhedral pyrite (0.6mm) constitutes a minor part of the section, and has associated strain shadows of quartz.

Quartz	70%
Carbonate	20%
Muscovite	10%
Pyrite	1%

432/032: Consists of detrital grains of quartz (0.2mm), in a dominantly quartz-rich, fine-grained (.01mm) matrix. Detrital grains of epidote, zircon and feldspar (? microcline) (0.2mm) occur. The fine-grained matrix is being replaced, in part, by anhedral to euhedral carbonate, leaving the coarser, detrital grains intact (as "inclusions" within the carbonate).

Muscovite shows a preferred orientation, and occurs associated with the fine grained quartz matrix, recrystallized quartz, and with the carbonate. The section is invaded to a great extent by quartz veins (width ≈ 2mm) (with associated fluid inclusions). Some of the recrystallized quartz shows a preferred (dimensional) orientation, which is approximately parallel to the muscovite orientation. Leucoxene and subhedral pyrite constitute a minor proportion of the section.

Quartz	83%	Zircon	tr.
Carbonate	10%	Epidote	tr.
Muscovite	5%		
Opaques	2%		

432/V43: Fine, even grained (.01mm) chert-like quartz-chlorite, crossed by numerous veins of recrystallized quartz (± pyrite). The recrystallized quartz contains inclusions of subhedral carbonate, and opaques (probably pyrite). Some of the fine-grained quartz contains inclusions.

Quartz	95%
Chlorite	3%
Pyrite	2% (0.2mm) (? chalcopyrite-high Cu value).

432/V374: Numerous angular to subangular grains of quartz (0.1mm) in a much finer grained, quartz rich matrix (.01mm grainsize). Many of the detrital grains show composite and undulose extinction. A few grains of zircon occur (grainsize 0.1mm). Both muscovite and biotite occur (grainsize 0.1mm), muscovite showing a preferred orientation. Fibrous and granular leucoxene occurs, often associated with chlorite. A few larger (0.1mm) grains of pyrite occur. Chlorite is intermingled with fine-grained matrix.

Quartz	55%	Biotite	tr.
Chlorite	40%	Leucoxene	4%
Zircon	tr.	Pyrite	tr.
Muscovite	1%		

432/V376: Laminated, alternating bands of coarse (0.04mm) and fine (0.01mm) grained sediments. Section is crossed by a quartz vein, and some pods of recrystallized quartz occur. Quartz often shows undulose extinction. Green, elongate biotite occurs, showing a definite preferred orientation. Chlorite and leucoxene occurred scattered through the section. Few grains of zircon, pyrite.

Quartz	60%	Leucoxene	10%
Biotite	10%	Pyrite	tr.
Chlorite	20%		
Zircon	tr.		

432/013: Grains of quartz and albite in a chloritic groundmass, pods and veins of quartz (± carbonate) are common. Inclusions occur in the quartz where it is associated with carbonate. The chlorite defines a preferred orientation. Magnetite and leucoxene are scattered through the section.

Quartz	20%	Leucoxene, Magnetite	5%
Albite	20%		
Chlorite	50%		
Carbonate	5%		

432/V371: Consists of angular to subrounded grains of quartz, feldspar (albite and microcline) and chlorite, in a fine, even-grained quartz-rich matrix. Minor ? xenotime, biotite, ? hornblende and muscovite occur. Many of the quartz grains show undulose extinction, and some grains contain inclusions (both fluid and carbonate). Quartz veins contain fluid and carbonate inclusions, and occasionally pyrite grains.

Quartz	85%	Pyrite, Leucoxene	1%
Chlorite	10%	Others	tr.
Albite	4%		
Microcline	tr.		

432/011: Was classified as a sediment, although no description is presented.

2. Altered Volcanics

432/004: Chloritic groundmass crossed by numerous quartz veins, the chloritic groundmass enclosing fine grained quartz, with traces of albite. There are a few pods of fine-grained quartz, and also pods and veins of recrystallized quartz (with fluid inclusions). Leucoxene is associated with chlorite, and pyrite with quartz veins.

Chlorite	55%
Quartz	43%
Leucoxene, Pyrite	2%
Albite	tr.

432/005: Chloritic groundmass with pods and veins of quartz (generally recrystallized, but some fine-grained quartz pods occur). Fine-grained quartz, with undulose extinction occurs within the groundmass. Leucoxene is associated with chlorite. Fluid inclusions are abundant in recrystallized quartz.

Quartz	30%
Chlorite	65%
Leucoxene	5%

432/012: Chlorite-biotite-leucoxene groundmass, enclosing laths and megacrysts of albite, with pods and veins of quartz (both recrystallized and fine grained) scattered through section. The chlorite tends to concentrate into bands. Recrystallized quartz contains fluid, carbonate and minor chlorite inclusions.

The albite laths show multiple twinning, and often show effects of deformation. The megacrysts are being sericitized, and are generally only simply twinned. Carbonate is generally associated with quartz, both as inclusions and as discrete grains.

Quartz	33%	Carbonate	1%
Chlorite	33%	Leucoxene	2%
Feldspar	33%		
Biotite	1%		

__432/015__: Chlorite-quartz-albite-leucoxene groundmass, crossed by veins of quartz (± carbonate). A few megacrysts of albite occur, (up to 10mm) which are extensively sericitized. Quartz occurs as recrystallized pods and veins, with fluid and carbonate inclusions, and as grains in the greenstone . Laths of albite are generally sericitized to some degree. Traces of microcline occur. Leucoxene and magnetite are associated with chlorite.

Quartz	10%	Leucoxene, Magnetite	5%
Chlorite	35%	Muscovite (sericite)	5%
Albite	35%		
Carbonate	10%		

__432/019__: Laminae of chlorite, containing opaques (leucoxene, magnetite), quartz grains, albite, hornblende - definite preferred orientation of chlorite seen. Veined by quartz (± carbonate) (also pods of quartz). Laths of albite show twinning, and some glomeroporphyritic texture occurs. A megacryst of albite is being replaced by chlorite-quartz. Green biotite and ? hornblende are associated with chlorite. Euhedral to subhedral magnetite, and leucoxene are scattered through the section.

Chlorite	50%	? Hornblende	5%
Quartz	20%	Biotite	tr.
Albite	15%		
Magnetite, Leucoxene	10%		

432/031: Chlorite groundmass, with associated muscovite, leucoxene and albite, extensively veined by quartz. Anhedral to euhedral carbonate is dispersed through the section. Quartz appears to be replacing albite in places.

Chlorite	40%	Leucoxene	1%
Quartz	40%	Muscovite	1%
Carbonate	15%		
Albite	5%		

432/037: Dominantly chloritic groundmass, which is extensively invaded by quartz veins and pods. Muscovite is associated with chlorite and shows a distinct preferred orientation. Sulphides (chalcopyrite, pyrrhotite, pyrite) are associated with the quartz veining. Leucoxene is associated with chlorite.

Quartz	45%	Sulphides	1%
Chlorite	45%		
Muscovite	7%		
Leucoxene	2%		

432/V81: Laths of albite of diverse orientation, in chloritic groundmass, with albite megacrysts (2-6mm) which are being sericitized. Crossed by veins of recrystallized quartz, with fluid, carbonate and pyrite inclusions. The albite megacrysts show vague twinning, and are being extensively veined and replaced by chlorite and sericite, whereas the laths invariably show twinning, and are also being replaced by chlorite. Leucoxene is dispersed through the section.

Albite	65%
Chlorite	25%
Quartz	5%
Leucoxene, Pyrite	5%

432/V302: Chloritic groundmass, enclosing laths of albite, with a few megacrysts of albite. Brown biotite is associated with chlorite, and shows a preferred orientation. A few pods of fine-grained quartz. Quartz grains also scattered through section. Subhedral to euhedral carbonate is scattered through the section. Leucoxene is associated with chlorite and is dispersed through the section. A few thin veins of quartz occur.

Chlorite	35%	Carbonate	15%
Albite	20%	Leucoxene	5%
Biotite	20%		
Quartz	15%		

432/V451: Chloritic groundmass, with associated biotite and leucoxene, showing a definite preferred orientation. Minor albite laths enclosed by chloritic groundmass. Veins and pods of quartz (both recrystallized and fine grained). Occasional grains of quartz occur through section. Carbonate is generally associated with fine grained quartz. Leucoxene is scattered throughout the section.

Chlorite	45%	Leucoxene	5%
Quartz	30%	Carbonate	5%
Biotite	10%		
Albite	5%		

432/V605: Diversely oriented albite laths enclosed by even-grained, chloritic groundmass, with pods and veins of recrystallized quartz, and euhedral to subhedral carbonate dispersed through the section. Few grains fine-grained quartz scattered through groundmass. Leucoxene is scattered through the section. Magnetite is euhedral to subhedral, and may show skeletal forms.

Albite	35%	Leucoxene, Magnetite	10%
Quartz	25%	Biotite	tr.
Carbonate	15%		
Chlorite	15%		

432/V756: Intermixing of dark, chloritic material enclosing albite laths and quartz-rich material with a sedimentary-type texture. Minor quartz veins and pods occur. The quartz-rich part consists of angular to subrounded grains (≃ 0.1mm) in a much finer grained quartz-chlorite matrix (grainsize 0.01mm). Along with laths of albite, a few megacrysts occur in the chloritic portion. Biotite occurs associated with chlorite, and carbonate "porphyroblasts" occur both in the chloritic and quartz-rich material. Leucoxene and ? magnetite form a significant proportion of the chloritic part. Pyrite occurs as scattered grains through the section. A few pods of chlorite occur. The intermixing of sedimentary and volcanic material could be due to stress, which caused disruption of the layers.

Quartz-rich:	Quartz	60%	Chloritic:	Chlorite	40%
	Chlorite	30%		Albite	30%
	Carbonate	5%		Opaques	20%
	Opaques	5%		Carbonate	10%

432/V796: Even-grained, dominantly quartz-chlorite, and divisible into 2 sections - one section containing pods of fine-grained quartz, the other without. At the contact recrystallized quartz and chlorite occur. Crossed by many small quartz veins. Chlorite shows a good preferred orientation, and has associated with it biotite and leucoxene. Anhedral to subhedral pyrite is often associated with quartz.

Quartz	45%	Pyrite	3%
Chlorite	45%		
Biotite	tr.		
Leucoxene	7%		

432/V832: Consists of intermixing of sediment-like material and volcanic-like material (similar to 432/V756). Sediment-like material consists of detrital-looking quartz grains in quartz-chlorite matrix, whereas volcanic-like material consists of albite laths in a chloritic groundmass (a few megacrysts of albite also occur). A few grains of quartz occur within the chloritic material. Biotite and leucoxene are associated with chlorite. Pyrite is scattered through the section, and has strain shadows of quartz (+ carbonate) associated with it.

"Sediment-Like":	Quartz	55%
	Chlorite	30%
	Biotite	10%
	Opaques	5%
Volcanic-like:	Chlorite	50%
	Albite	30%
	Biotite	10%
	Opaques	10%

432/V47: Chloritic groundmass with grains, pods and veins of quartz, which is often recrystallized. Leucoxene associated with chlorite. Some of the quartz veins have a folded appearance. Minor amount of carbonate.

Quartz	40%
Chlorite	40%
Leucoxene	20%
Carbonate	1%

432/V56: Chloritic groundmass, with grains, pods and veins of quartz, with anhedral carbonate and opaques (pyrite, leucoxene) scattered through the section. Some of the quartz pods are fine-grained, some are of recrystallized quartz. Carbonate appears to be replacing quartz, and is often associated with pyrite.

Chlorite	45%	Carbonate	8%
Quartz	45%	Leucoxene, Pyrite	2%

432/V134: Chloritic groundmass, extensively veined by quartz (± Carbonate). The chlorite of the groundmass shows a preferred orientation. Fluid inclusions are fairly abundant in the quartz veins. Carbonate, chlorite and leucoxene may occur in the quartz veins.

Quartz	65%
Chlorite	30%
Carbonate	4%
Leucoxene	1%

432/V184: Chloritic groundmass enclosing albite laths and biotite, crossed by semi-concordant quartz veins. Several pods of quartz occur. Albite laths are plentiful in the groundmass, and often show effects of deformation. Leucoxene, pyrite and ? magnetite are scattered through the section.

Chlorite	40%	Leucoxene, Pyrite, Magnetite	1%
Albite	30%		
Quartz	20%		
Biotite	10%		

432/V334: Chlorite-albite-biotite-quartz groundmass, with pods and veins of quartz (with inclusions of carbonate, fluid, ? Hematite, chlorite). Lath-like albite being replaced by carbonate and quartz. Anhedral to euhedral carbonate scattered through the section. Leucoxene (sometimes skeletal) is associated with chlorite, and scattered through the section.

Chlorite	30%	Biotite	10%
Quartz	20%	Opaques	5%
Albite	20%		
Carbonate	15%		

432/V406: Chlorite-leucoxene-quartz (fine grained) groundmass, with larger quartz grains of variable size and shape. A few pods of fine-grained quartz. A rough layering is defined by chlorite.

Chlorite	50%
Quartz	40%
Leucoxene	10%

432/V438: Vaguely layered - alternation of albite-quartz and chlorite-albite layers. Albite tends to be glomeroporphyritic in the lighter (albite-quartz) area. Chlorite may occur as pods and associated with veins, as well as in groundmass. Some cross-cutting quartz veins.

Quartz	30%
Albite	45%
Chlorite	20%
Leucoxene	5%

432/V489: Chloritic groundmass, with numerous veins and pods of recrystallized quartz, quartz-carbonate, and fine grained quartz. Biotite is associated with chlorite, as is leucoxene. Minor albite occurs (as megacrysts). Carbonate is associated with quartz (both as discrete grains and as inclusions). A few grains of pyrite.

Quartz	50%	Albite	1%
Chlorite	45%	Leucoxene, Pyrite	1%
Biotite	2%		
Carbonate	1%		

432/V578: Even grained, chloritic groundmass, scattered with leucoxene. Occasional small pods of quartz (± carbonate). Quartz and albite occur within the chloritic groundmass. Carbonate is associated with quartz, especially pods of quartz.

Chlorite	45%	Carbonate	2%
Albite	30%		
Quartz	20%		
Leucoxene	3%		

432/V600: Intermixing of quartz-albite material and chlorite-biotite material (similar to 432/V756 and 432/V832).

Some albite and quartz occur in the chloritic material. Leucoxene is scattered through the section, but is generally associated with the quartzo-feldspathic areas.
Minor pyrite.

Chlorite	30%	Leucoxene, Pyrite	3%
Albite	40%		
Quartz	17%		
Biotite	10%		

432/V610: Chlorite-biotite groundmass, with discrete pods of recrystallized quartz (with fluid and carbonate inclusions). Albite and quartz are enclosed by the groundmass, the albite showing 'checkerboard' twinning (hence metasomatic), and the quartz is fine grained. The albite tends to concentrate into veins. Green biotite is associated with chlorite.

Quartz	40%	Leucoxene	1%
Chlorite	30%		
Albite	25%		
Biotite	5%		

432/V900: Intermixing of chlorite-leucoxene-albite and quartz-albite regions, with minor biotite and carbonate, carbonate being associated with quartz and biotite with chlorite. Some grains of pyrite are associated with undulose quartz. Cross-cutting vein of recrystallized quartz, with pyrite, chlorite and minor biotite and carbonate. Some of the pyrite grains in this vein are cracked. There are strain shadows of quartz around pyrite.

Quartz	35%	Pyrite	1%
Chlorite	30%	Carbonate	tr.
Albite	25%	Biotite	tr.
Leucoxene	10%		

432/V918: Chloritic groundmass, with laths of albite, and localized quartz grains, and occasional pods of quartz (± carbonate), which appear to be vein-like. There are some euhedral "porphyroblasts" of carbonate, associated with fine-grained quartz. Leucoxene is scattered through the section.

Chlorite	40%	Leucoxene	2%
Quartz	35%		
Albite	20%		
Carbonate	3%		

432/007: Chloritic groundmass, with veins and pods of recrystallized and fine grained quartz which have associated carbonate. Biotite is associated with chlorite, and shows a preferred orientation (as does chlorite). Pyrite is associated with both varieties of quartz. Quartz is also present as small grains in the chloritic matrix.

Chlorite	40%	Leucoxene	2%
Quartz	40%	Pyrite	tr.
Biotite	15%		
Carbonate	5%		

432/009: Chlorite-biotite groundmass, with a few veins and pods of quartz (± carbonate). The groundmass encloses grains of quartz and albite. Leucoxene is associated with chlorite.

Chlorite	50%	Leucoxene	5%
Quartz	25%	Carbonate	5%
Biotite	10%		
Albite	5%		

432/010: Laths of albite, along with scattered quartz grains, enclosed by chloritic groundmass. Leucoxene is scattered through the section. A few grains of pyrite occur. A few quartz veins are present.

Chlorite	45%
Albite	30%
Quartz	20%
Leucoxene, Pyrite	5%

432/014: Chlorite-leucoxene groundmass, enclosing albite laths which have been extensively sericitized (some have also been replaced by carbonate). Minor quartz veins (± carbonate).

Chlorite	45%	Leucoxene	10%
Muscovite (Sericite)	20%	Carbonate	5%
Albite	10%	Pyrite	tr.
Quartz	10%		

432/018, 432/021, 432/033, 432/034, 432/035 and 432/016 have been classified as Altered volcanics, although no descriptions are presented.

3. High Carbonate Rocks

432/006: Chloritic groundmass with numerous "porphyroblasts" of subhedral to euhedral carbonate. Grains of biotite, quartz and ?hornblende occur. Minor epidote occurs, associated with hornblende. The carbonate "porphyroblasts" contain fluid inclusions, and inclusions of chlorite. Note that the analyses suggest that the carbonate is dolomite.

Chlorite	40%	Biotite	tr.
Carbonate	40%	Epidote	tr.
Hornblende	15%		
Quartz	5%		

432/017: Dominantly carbonate, which appears to be replacing a chloritic rock. Quartz appears to be associated with carbonate - some carbonate gives an undulose-type extinction. Opaques are leucoxene, pyrite and ? magnetite. Some pods of quartz occur.

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Carbonate	70%	Chlorite	15%
Quartz	15%	Leucoxene, Pyrite, Magnetite	2%

432/V686: Pods of carbonate-quartz, sometimes enclosing chlorite, with minor albite, enclosed by dark, chloritic material. The pods appear to be an "intergrowth" of quartz grains which are being replaced by carbonate. The chloritic material consists of chlorite, ?magnetite, leucoxene, quartz and minor albite, with some carbonate. Trace of microcline.

Quartz	30%	Albite	tr.
?magnetite, leucoxene	30%	Microcline	tr.
Carbonate	25%		
Chlorite	15%		

432/V905: Introduced carbonate-quartz, into a chlorite-leucoxene (magnetite) groundmass which also contains albite and biotite. Fine-grained quartz is abundant (± carbonate). Leucoxene, ?Magnetite dispersed through section. Euhedral pyrite, with inclusions of quartz. Biotite associated with chlorite. Opaques may form local concentrations.

Carbonate	40%	Biotite	2%
Quartz	30%	Leucoxene, magnetite	6%
Chlorite	20%	Pyrite	tr.
Albite	2%		

432/V260: Chloritic groundmass, crossed by veins of quartz, with subhedral to euhedral "porphyroblasts" of carbonate (sometimes with "inclusions" of quartz grains). Leucoxene disseminated through groundmass. Quartz also occurs as grains in chloritic groundmass. Minor feldspar. Carbonate appears to be replacing quartz.

Chlorite	40%
Quartz	30%
Carbonate	20%
Leucoxene, ?magnetite	10%

4. Sheared Greenstone, Vein Quartz

432/008: Predominatly quartz, both recrystallized (with numerous inclusions) and fine grained, with "pods" of chlorite-quartz (i.e., "greenstone"). - Intense intermixing of recrystallized quartz, fine grained quartz and "greenstone". Recrystallized quartz has inclusions of fluid, carbonate and chlorite. Leucoxene occurs in pods and stringers of "greenstone". A few grains of pyrite occur.

Quartz	85%
Chlorite	15%
Leucoxene	tr.
Pyrite	tr.

432/024, 432/028, 432/036, 432/038 and 432/V219 were classified as "sheared greenstone", although no descriptions are presented.

2. Contact Rocks (viz. Buck Quartz, "Mylonite").

Mineralogy:

Quartz: occurs in veins (recrystallized), and as a constituent of material caught up in the "Mylonite". Abundant fluid inclusions.

Carbonaceous Material: occurs as stringers in Buck Quartz, and is common within the "Mylonite". Opaque in thin section.

Chlorite: present in "Mylonite", as a constituent of material caught up during shearing. Green, pleochroic.

Muscovite: minor constituent.

Sulphides: predominantly subhedral to euhedral pyrite.

432/001: Very coarse grained quartz (grainsize ≥ 2-3cms.), sometimes strained, and "choc-a-bloc" full of fluid inclusions. Minor fine grained quartz occurs at the grain boundaries.

Quartz	100%

432/002: Consists almost wholly of quartz, with a few pods of softer material (? carbonaceous). The quartz is often strained, and there are not as many fluid inclusions as in 432/001.

Quartz	95%
Carbonaceous Material	5%

432/020: Consists of larger rock fragments (< ≈5mm) within a much finer grained dark matrix. Quartz veins are common, often cutting across the rock fragments. The rock fragments consist of dominantly quartz-rich sediments, with minor muscovite. The grainsize is variable both within and between rock fragments. - fragments appear to be from both underlying "greenstone" and overlying Urquhart Shale. The matrix consists of quartz, muscovite, with stringers and disseminations of dark (carbonaceous) material. - Matrix derived from same rocks as are rock fragments. Quartz veins contain pyrite, with minor chlorite and muscovite.

Quartz	30%	Chlorite	tr.
Carb. Material	60%	Epidote	tr.
Muscovite	5%		
Pyrite	5%		

432/022: Stringers of chlorite and muscovite, in a matrix of quartz, which is of a very variable grainsize. Areas of recrystallized and coarser grained quartz occur, rather than as distinct grains. Chlorite-muscovite also in matrix. Occasional pyrite. Some leucoxene is associated with chlorite.

Quartz	85%
Chlorite	10%
Muscovite	5%
Pyrite	tr.

432/025: Anhedral to euhedral pyrite, in matrix of chlorite-muscovite. Quartz very minor. ? Talc associated with pyrite. Leucoxene as stringers.

432/027: Mixture of quartz, euhedral pyrite, carbonaceous material, carbonate and muscovite. The carbonaceous material generally occurs as stringers and disseminations, which are often cut by quartz (± muscovite). Quartz may be chert-like, as veins, recrystallized, and as strain shadows accompanying pyrite. Carbonate occurs as anhedral grains and in veins. It is often associated with quartz. Muscovite is associated with carbonaceous material. Some fluid inclusions occur in the quartz.

Carbonaceous material	30%	Carbonate	5%
Quartz	50%		
Pyrite	10%		
Muscovite	5%		

3. Eastern Creek Volcanics

Mineralogy:

Actinolite: Pleochroic, blue-green or green to nearly colourless. Moderate birefringence. Replacing ferromagnesian minerals.

Epidote: Yellowish, non-pleochroic, moderate birefringence (sometimes mottled). Replacing ferromagnesian minerals, and may also replace plagioclase feldspar.

Feldspar: Generally as laths, often twinned. May show effects of deformation. Occasional megacrysts. May be glomeroporphyritic. Altering to biotite, chlorite, and may be replaced by epidote. Is plagioclase feldspar, probably albite.

Chlorite: Green, slightly pleochroic, very low birefringence (pseudo-isotropic). Suggests that it is clinochlore. Replacing ferromagnesian minerals. Variable abundance.

Quartz: Often as small fine grained pods which may represent an original glassy residue. Also occurs as veins. May also fill vesicles and amygdules, both occurrences of which are rimmed by epidote.

Olivine: Occurs in minor amounts, as relics of grains which have been replaced by actinolite-epidote-chlorite. High relief, high birefringence.

Biotite: Green, pleochroic, associated with chlorite. Minor.

Sphene: Brown, altering to leucoxene. Minor.

Leucoxene: As alteration product of sphene and ? magnetite. Cream-white in random reflected light.

? Magnetite: Subhedral to euhedral, altering to leucoxene and hematite. Black in random reflected light. Predominantly titan-magnetite (altering to leucoxene).

Hematite: Reddish, alteration product of ? magnetite.

432/039: Actinolite-chlorite groundmass, enclosing laths of albite, in a relic subophitic to ophitic-type texture. Some pods of fine grained quartz. Epidote is scattered through the section. A few megacrysts of albite - some feldspars show effects of deformation. Minor chlorite. ? Magnetite subhedral to euhedral, altering to leucoxene. Associated hematite staining.

Actinolite	45%	Chlorite	1%
Albite	30%	Epidote	tr.
Magnetite-leucoxene	20%		
Quartz	5%		

432/040: Interlocking chlorite-albite, even grained. Albite occurs as laths, and a few megacrysts. Pods of chlorite, rare pods of quartz. Leucoxene associated with chlorite, and forms a major part of the section.

Chlorite	20%
Albite	30%
Leucoxene	50%

432/041: Laths of albite enclosed in epidote-actinolite groundmass. Few relict grains of olivine - along with other ferromagnesian minerals has been replaced by epidote-actinolite. (Some albite is also being replaced).

Magnetite subhedral to euhedral, altering to leucoxene. Quartz occurs along cracks, etc.

Actinolite	35%	Quartz	5%
Epidote	25%	Chlorite	5%
Albite	15%		
Magnetite-leucoxene	15%		

432/042: Groundmass of epidote-chlorite, enclosing feldspar laths which have been completely replaced by epidote. Chlorite-epidote replacing ferromagnesian minerals. Quartz interstitial to other grains - may represent residual liquid. Euhedral to subhedral magnetite, altering to leucoxene. Some skeletal forms.

Chlorite	40%
Magnetite-leucoxene	30%
Epidote	20%
Quartz	10%

432/043: Chloritic groundmass, enclosing pods of quartz. Chlorite shows definite preferred orientation. Quartz pods are recrystallized, and are elongate. Leucoxene, magnetite, hematite also elongate. Strain shadows in quartz behind hematite-parallel to preferred orientation of chlorite. Chlorite is pleochroic, with anomalous birefringence - pennine.

Chlorite	60%
Quartz	20%
Magnetite, Hematite, Leucoxene	20%

432/044: Albite laths in a chloritic groundmass, which also contains sphene, olivine, epidote, leucoxene and magnetite. Some larger albite grains, tending to be porphyritic. Quartz filling amygdules; with rims of epidote. Sphene minor, altering to leucoxene.

Albite	70%	Quartz	1%
Chlorite	15%	Olivine	tr.
Magnetite, Leucoxene	10%	Epidote	tr.
Sphene	5%		

432/045: Laths of albite in dominantly chloritic groundmass, which also contains abundant fine-grained leucoxene. Some megacrysts of albite-corroded - attacked by chlorite and fine-grained quartz. A few pods of fine-grained quartz. Trace of biotite.

Chlorite	45%	Biotite	tr.
Albite	30%		
Quartz	15%		
Leucoxene	10%		

432/046: Chlorite-biotite groundmass, enclosing laths of albite (with a few megacrysts). Vague preferred orientation of albite (? flow texture). Opaques (leucoxene, magnetite) scattered through section. Albite altering to chlorite, biotite. Some skeletal crystals of ? magnetite.

Albite	67%
Chlorite	15%
Biotite	15%
Magnetite-leucoxene	3%

4. "Silica-dolomite" Material and Copper Ore

Mineralogy:

Quartz: Present as fine grained (chert-like), and as recrystallized grains and veins. Associated with carbonate.

Carbonate: Minor in section studied - associated with quartz.

Chlorite: Minor.

Sulphides: Chalcopyrite, pyrrhotite and pyrite dominant. All can form considerable proportion of rock.

432/023: (Both thin and polished section): Consists dominantly of quartz, which varies from chert-like to recrystallized, with minor carbonate and minor chlorite. Trace amounts of ? sphalerite detected in polished section - generally associated with pyrrhotite.

Quartz	65%	Chalcopyrite	20%
Carbonate	5%	Pyrrhotite	10%
Chlorite	tr.	? Sphalerite	tr.

432/029: (Polished section only): Consists of alternating layers of chalcopyrite-rich and pyrrhotite-rich material, with a separate, pyrite-rich region. Pyrite appears to be associated with chalcopyrite more than pyrrhotite. Pyrite grains may have indistinct edges - suggests it may be derived from framboidal pyrite. Boundary between pyrite mass and layered chalcopyrite-pyrrhotite is quite sharp, but a few euhedral pyrite grains may be enclosed by chalcopyrite.

Chalcopyrite	40%	
Pyrrhotite	40%	
Pyrite	20%	(overall percentages)

432/030: (Polished section only): Banded chalcopyrite-pyrrhotite, with a few subhedral to euhedral pyrite grains invariably associated with chalcopyrite). Pyrite may show skeletal textures, often enclosing grains of chalcopyrite, but it is always enclosed by chalcopyrite. Framboidal-type chalcopyrite may occur in gangue material (silica with minor carbonate). Minor framboidal pyrite.

Chalcopyrite	50%
Pyrrhotite	50%
Pyrite	1%
Gangue	tr.

Note: Numbering of sections:

432/001 - 432/030 were collected by the author from the lower levels of the mine.

432/031 - 432/038 were collected by Malcolm Bridges from 19 Level.

432/039 - 432/046 are surface samples of the Eastern Creek Volcanics, collected by Malcolm Bridges.

432/V... are samples from DDH V26 Edecline 16/L #1, supplied by M.I.M. via Malcolm Bridges. The number following the V, e.g., 43, 56 (as in 432/V43, etc.) is the footage from which the sample was taken.

For more precise location of samples see Figures 2, 3 and 5.

APPENDIX 2

Analytical Techniques

1. Preparative Procedures

Whole Rock Analysis: The powdered sample was dried overnight at ≈ 100°C to remove absorbed water. The samples were then weighed into vitreosil crucibles, and ignited at 1,000°C for 6 to 8 hours. (Note that several samples fused at 1,000°C; these were repeated at 830°C). After this period, the samples were removed, allowed to cool in a dessicator, and weighed. The weight per cent loss on ignition was thus obtained. This loss represents H_2O^+, CO_2, S. (It is assumed equivalent to H_2O^+).

The ignited sample was mixed with $NaNO_3$ and flux in the following proportions:

$NaNO_3$	0.020g
Sample	0.280g
Flux	1.500g

(Flux 9 was in general used, but Flux 10 was used for five of the duplicates (viz. duplicates of 432/V302, 432/044 (twice) 432/015, 432/V905).

The mixture was then fused and pressed into buttons, ready for analysis.

Na_2O was analysed by flame photometry. The solutions were prepared in the following manner: The powdered sample was dried for 2-3 hours at 105°C. Approx. 50mg of the sample was dissolved in 10mls HF, plus 2mls of 50% H_2SO_4, in platinum crucibles. The crucibles were placed on a sand bath, covered with lids, and left overnight on low heat. In the morning, the lids were removed (the condensate being washed back into the crucibles), and the crucibles heated strongly to reduce the volume. When 1-2mls of the solution remained, the crucibles were transferred to a hot plate, and heated until white fumes of H_2SO_4 appeared. This heating was allowed to continue for

3-5 minutes, allowing time for all of the HF to be removed. The crucibles were then allowed to cool. After cooling, water was added, and the solutions were heated gently for about ½ hour, until the solutions were clear. The solutions were then cooled, and after cooling transferred to a volumetric flask, filled to 100mls and transferred to a clean plastic bottle. This procedure should give a solution of 5-15ppm Na_2O.

Analysis of the solutions was by flame photometry. Each solution was measured 6 to 8 times against a solution of a known Na_2O concentration, to ensure a good precision. Blanks and standards were also run as a control.

The whole rock analyses have been recalculated from the raw percentages calculated:

(1) $Fe_2O_3 = Fe_2O_3(\text{raw}) \times 1.03$ (instrumental error)

(2) $MO = MO \times (1 - H_2O^+)$ (MO metal oxide, not Na_2O)
- done because it is considered that H_2O^+ is an essential constituent, as chlorite and carbonate is a very common constituent.

Trace Elements (a) X.R.F.: A minimum of 5 grams of the powdered sample were pelletized, using a backing of boric acid.

(b) Atomic Absorption: 1.00 grams of the powdered sample was weighed out, and 10mls of perchloric acid was added. The acid-sample mixture was heated at 240-250°C for about 36 hours, after which the acid was evaporated off at 350-370°C, until 1-2mls of solution remained. Distilled water was added to the hot acid mixture, and the solution was allowed to cool for about ½ hour. The volume was then made up to 20mls, and the solutions were allowed to stand for about 8 hours to permit any solid material to settle to the bottom of the test tubes. The solutions were then ready for analysis. Blanks and standards were prepared at the same time as a control.

2. Analytical Conditions:

(1) Xray Fluorescence.

Analysed on Seimens SRS:

SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O, TiO_2, Cr, P_2O_5.

Analysed on Phillips PW/1540 Spectrograph: Mn, Cu, Sr, Rb, Zr, Y.

(See Tables on next page).

Conditions for PW/1540:

Element	Tube (kV/mA)	Crystal	Counter	Collimator	Vacuum?	Peak Angle	B.g. Angle	Time (secs)	FS Factor
Mn	Mo(60/40)	LiF_{200}	F.P.	Coarse	Yes	62.91	—	20	10.57
Cu	Au(55/35)	LiF_{220}	Sci.	Coarse	No	65.56	64.56	40	—
Sr	Mo(60/40)	LiF_{220}	Sci.	Fine	No	35.87	34.87	40	—
Rb	Mo(60/40)	LiF_{220}	Sci.	Fine	No	37.99	36.99	40	—
*Zr	Au(50/40)	LiF_{220}	Sci.	Fine	No	32.12	33.12	100	—
*Y	Mo(60/40)	LiF_{220}	Sci.	Fine	No	33.93	34.93	40	—

*Zr and Y have been corrected for Sr and Rb respectively.

Mass absorptions were calculated from whole rock analyses.

(2) Atomic Absorption: Co, Ni, Zn, Pb, Cu and Cr were analysed by atomic absorption. However, as Cu and Cr were also analysed by Xray fluorescence (which gave higher values), these conditions are not presented here.

Conditions:

Element	Line (nm)	Lamp Current (mA)*	Slit Width (mm)*	Comments
Co	240.73	12, 7	10	analysed twice (average taken)
Ni	232.00	10, 5	10, 20	analysed twice (average taken)
Zn	213.86	5	50	diluted 5x, analysed twice, corrected for blanks (average taken)
Pb	217.00	5	100	analysed once.

*Two values indicates two analyses at different lamp current or slit width.

3. Duplicate Analyses

(1) Duplicate Na_2O: 432/003A 5.68% Na_2O
432/003 5.29% Na_2O
accepted value taken as mean, viz. 5.49% Na_2O.

(2) whole rocks (including complete analysis of BHN(2) (standard)).

	BHN(2)	432/012	432/015(A)	432/V302	432/V905(A)	432/044	432/044(A)
SiO_2	53.21	46.71	51.48	47.87	43.26	50.21	50.24
Al_2O_3	16.96	16.73	12.66	14.61	14.40	19.37	14.58
Fe_2O_3	10.28	13.09	14.48	14.47	14.91	13.26	13.19
MnO	0.15	0.08	0.09	0.09	0.11	0.19	0.15
MgO	4.93	11.80	5.95	11.37	6.54	6.98	6.89
CaO	8.98	0.46	3.39	1.06	7.58	6.47	6.48
Na_2O	2.72	4.91	2.60	1.98	4.98	3.22	3.22
K_2O	2.69	0.58	1.85	2.03	0.82	1.11	1.13
TiO_2	1.28	2.13	1.23	1.85	1.12	1.43	1.39
P_2O_5	0.45	0.22	0.11	0.20	0.15	0.12	0.13
H_2O^+	-0.17	5.87	5.63	5.77	7.72	3.06	3.06
	102.48	102.58	99.47	100.37	101.04	105.42	100.41

Co	14
Ni	34
Cu	176
Zn	94
Sr	575
Rb	97
Zr	118
Y	24
Cr	140
Pb	13

APPENDIX 3

Treatment of data:

The data collected was not sufficient in number to be the subject of a full statistical analysis. However, some statistical analysis was attempted to give an indication as to what could be expected if more data were available. The analysis done was Principal Component Analysis (via computer program PRINCA , during which correlation coefficients were calculated) which separated the "greenstones" into two distinct groups - sediments and altered volcanics. Best results were found if the data was normalized, (viz. mean of 0 and a standard deviation of $1/\sqrt{(m-1)}$, where m is the number of samples).

C.I.P.W. Norms were computed from whole rock analysis, and these are presented at the end of the appendix. It should be noted, especially in the case of some of the High Carbonate rocks, excess CaO resulted in failure of the program, and hence no C.I.P.W. Norms are presented for these.

C.I.P.W. NORMS

	003	026	032	V43	V374	V376	039	040	044	046
Q	46.60	82.37	65.25	81.05	51.64	43.96	14.07	20.26	3.30	1.55
C	0.43	—	3.48	2.35	3.85	8.10	—	4.98	1.40	4.18
OR	1.48	3.55	1.00	0.12	1.60	2.25	6.50	2.78	6.56	12.47
AB	46.46	1.27	13.37	0.51	26.74	11.34	23.02	17.43	27.25	43.32
AN	1.08	2.55	0.43	0.88	0.48	0.19	17.64	13.23	31.31	1.65
DI.WO	—	1.96	—	—	—	—	1.08	—	—	—
EN	—	1.69	—	—	—	—	0.94	—	—	—
WO	—	0.57	—	—	—	—	—	—	—	—
HY.EN	2.14	—	8.79	6.97	8.12	20.77	9.75	19.57	17.38	16.69
MT	—	0.10	—	—	—	—	—	—	—	—
IL	0.02	—	0.06	0.02	0.09	0.06	0.51	0.32	0.41	0.13
HM	0.70	2.22	4.21	4.43	3.83	7.38	16.18	12.70	13.26	15.03
RU	0.36	—	0.39	0.04	0.70	0.66	—	2.85	1.22	1.58
AP	0.23	0.02	0.09	0.02	0.16	0.30	1.05	0.91	0.28	0.35
TN	—	—	—	—	—	—	6.92	—	—	—

(continued)

	005	012	015	019	004	031	037	V81	V302	V451	V756
Q	25.40	—	13.69	17.41	24.52	24.75	44.21	12.59	9.93	23.64	21.32
C	14.00	7.48	0.55	9.43	11.33	9.59	8.27	9.63	7.71	8.08	3.38
OR	1.00	3.49	10.87	5.14	0.83	1.00	2.84	3.43	12.00	2.66	2.42
AB	0.17	41.55	22.00	9.82	11.59	11.85	7.62	29.53	16.72	19.80	39.69
AN	0.41	0.81	15.97	3.50	0.18	3.17	0.24	0.39	3.95	2.71	4.20
HY.EN	34.27	22.77	14.69	27.59	34.89	28.29	20.67	26.35	28.32	26.80	11.11
OL.FO	—	3.92	—	—	—	—	—	—	—	—	—
IL	0.19	0.19	0.21	0.26	0.28	0.13	0.13	0.15	0.19	0.19	0.13
HM	15.19	13.49	14.21	18.39	10.24	11.10	10.26	10.60	14.47	8.82	12.17
RU	1.90	1.82	1.12	1.87	1.16	1.87	0.80	1.55	1.75	1.18	1.29
AP	0.42	0.56	0.30	0.46	0.33	0.37	0.23	0.37	0.46	0.33	0.40

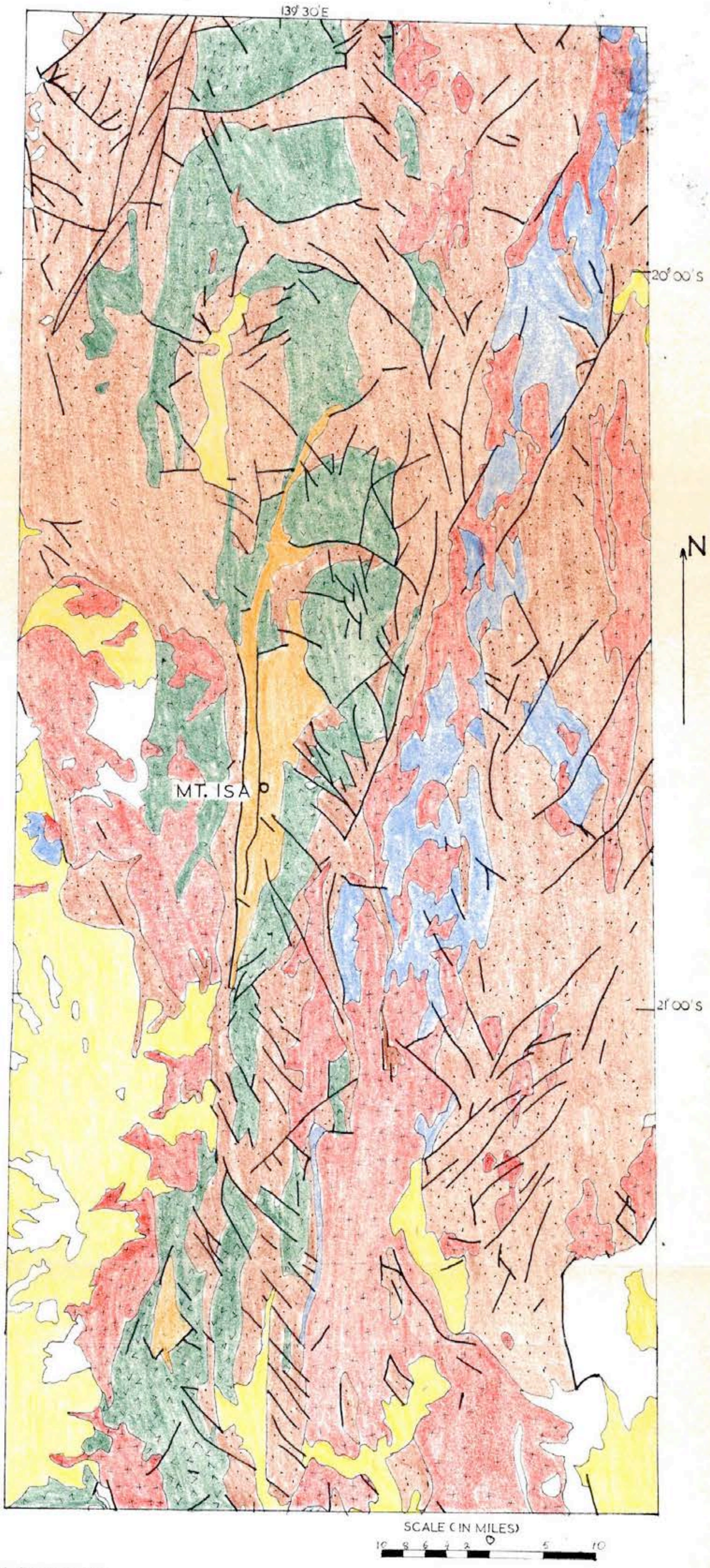
(continued)

	V796	V832	V605	006	017	V686	V905
Q	23.91	18.52	18.27			15.06	—
C	7.38	8.71	2.96	EXCESS		—	—
OR	2.19	1.71	5.14	CAO		3.90	4.67
AB	25.39	26.99	44.00			36.98	27.64
AN	0.48	0.36	1.47			3.89	13.21
NE	—	—	—			—	7.86
DI.WO	—	—	—			4.35	8.15
EN	—	—	—			3.76	7.05
WO	—	—	—			9.06	—
HY.EN	23.14	26.65	11.80			—	—
OL.FO	—	—	—			—	5.46
IL	0.17	0.19	0.13			0.26	0.28
HM	9.40	10.17	12.20			13.35	14.37
TN	—	—	—			3.15	—
PF	—	—	—			—	1.64
RU	1.46	1.47	1.25			—	—
AP	0.40	0.42	0.46			0.35	0.33

Note: TN ≡ Sphene

PF ≡ Perofskite

REGIONAL GEOLOGY OF THE MOUNT ISA AREA



LEGEND

🟨 Cainozoic alluvium and soil cover.

☐ Palaeozoic and Mesozoic sediments.

🟥 Granites and granitic material.

🟩 Eastern Creek Volcanics.

🟧 Proterozoic sediments (including Mount Isa Group).

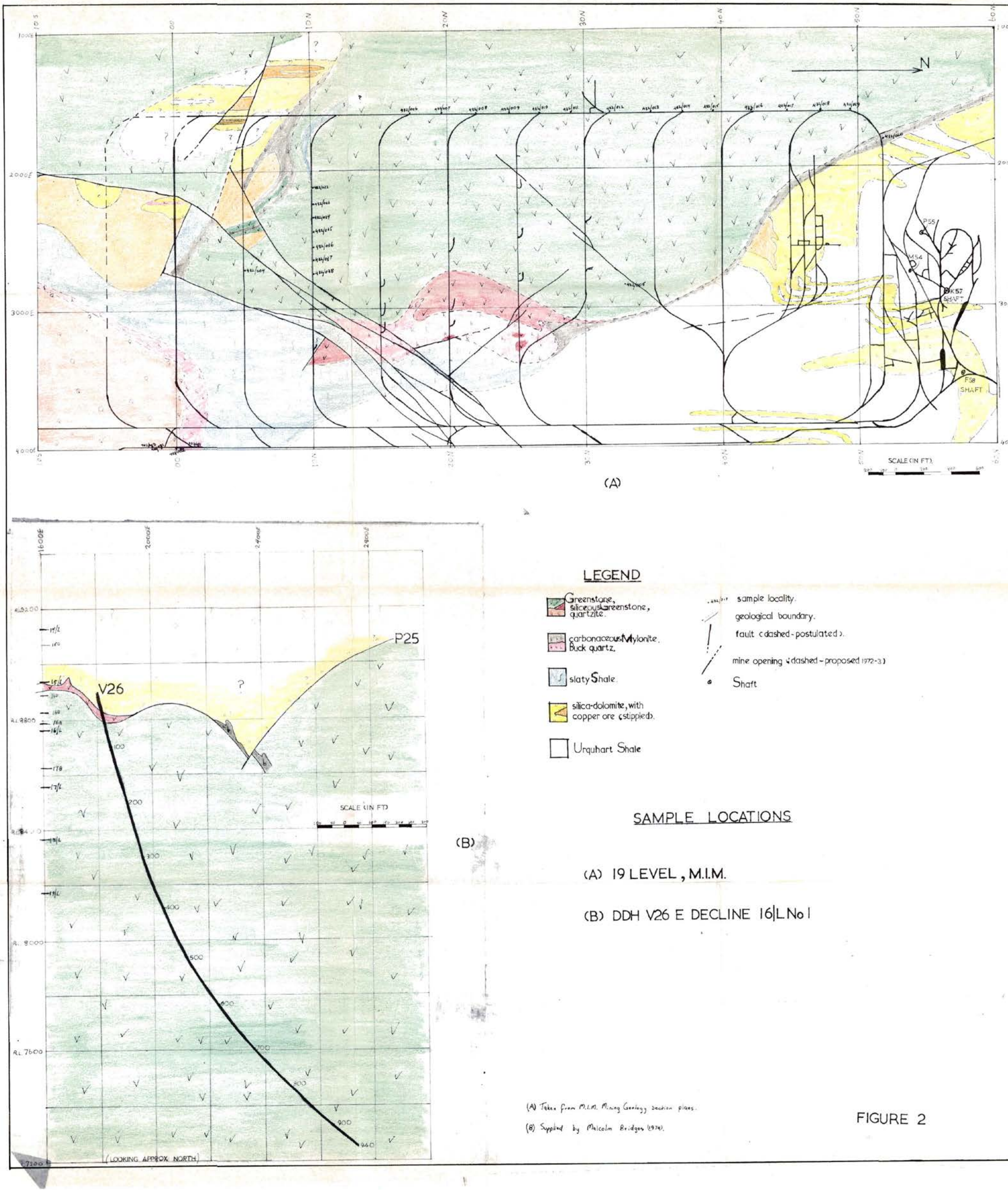
🟦 ?Archaean Metamorphics.

/ Fault

/ Geological boundaries

Simplified from Carter et al (1961), Plate 1.

FIGURE 1



SAMPLE LOCATIONS

(A) 19 LEVEL, M.I.M.

(B) DDH V26 E DECLINE 16|L No 1

(A) Taken from M.I.M. Mining Geology section plans.

(B) Supplied by Malcolm Bridges (1974).

FIGURE 2

(A)

(B)

LEGEND

🟩	Greenstone (dashed-sheared)
🟨	silica-dolomite, with copper ore (stippled), and sheared material (dashed)
⬛	carbonaceous Mylonite
🟦	slaty Shale
•432/027	sample locality
╱	geological boundary
┐┌	mine opening

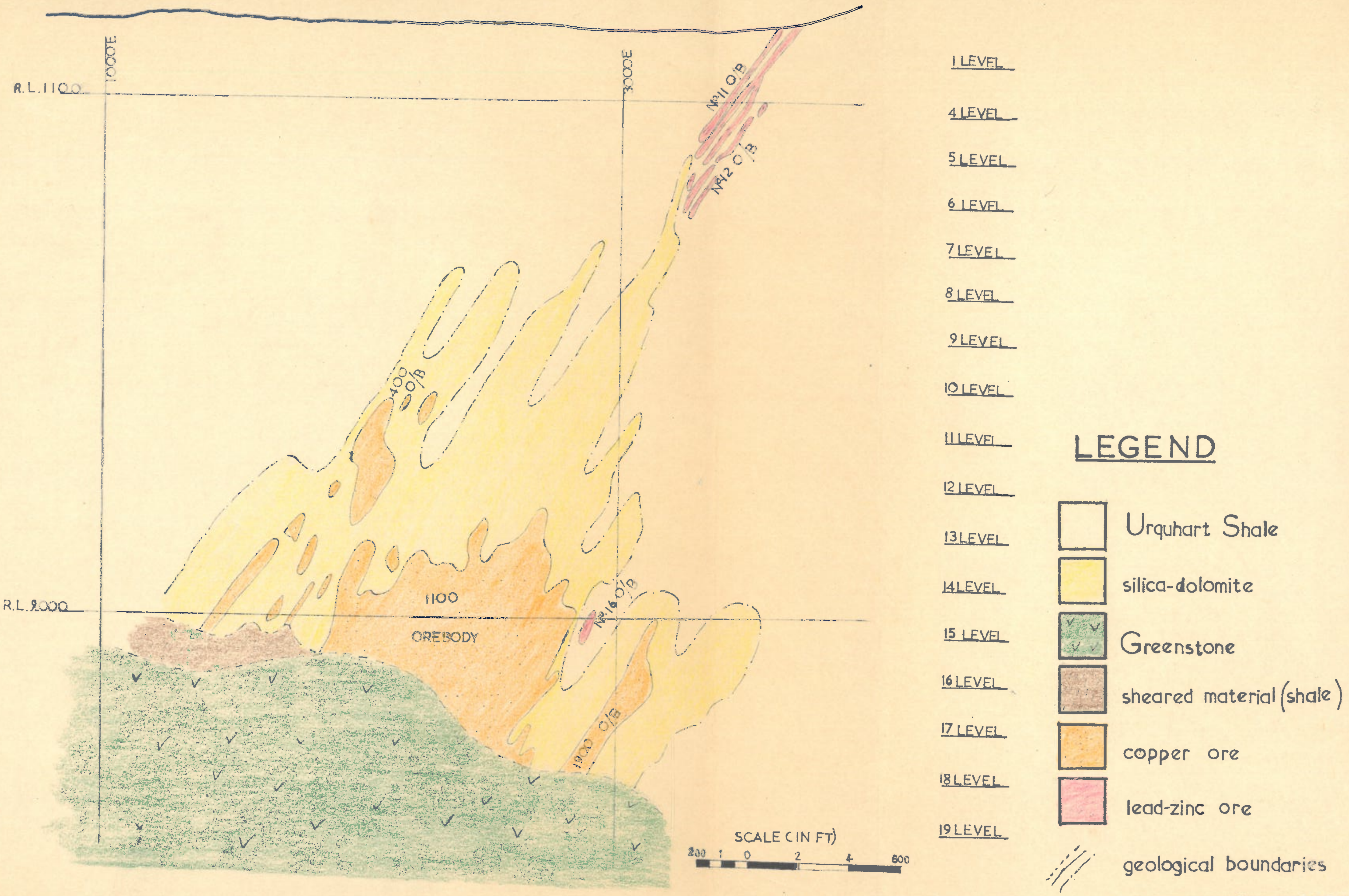
SAMPLE LOCATIONS

(A) 18B SUB-LEVEL, M.I.M.

(B) 18E SUB-LEVEL, M.I.M.

FIGURE 3

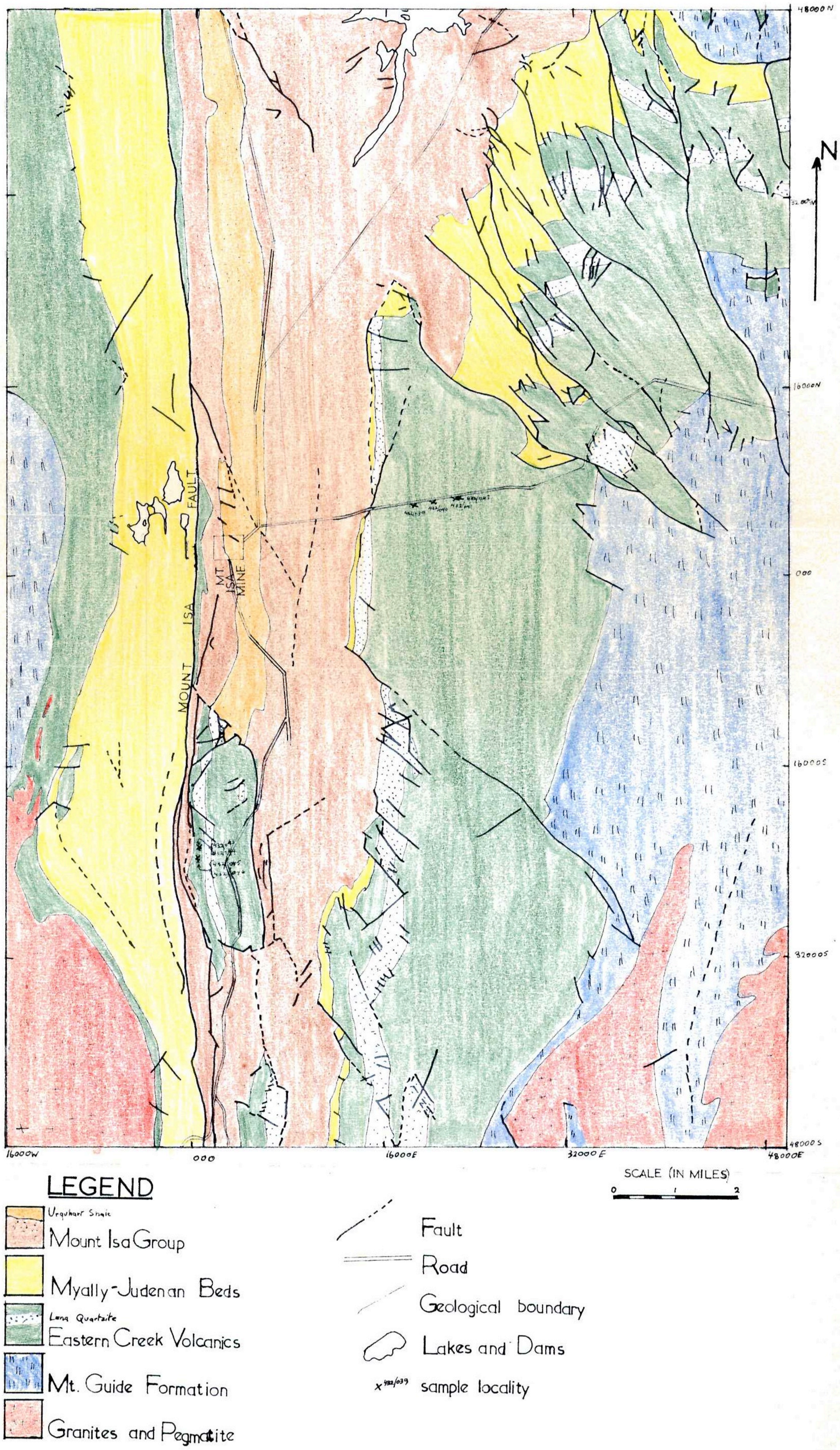
Both (A), (B) taken from M.I.M. Mining Geology Section plans.



CROSS-SECTION AT 2400N, LOOKING NORTH.

FIGURE 4

LOCAL GEOLOGY OF THE MT. ISA DISTRICT



Simplified from Smith and Walker (1972)

FIGURE 5

TiO$_2$-Zr-Y DIAGRAM

FOR DISCRIMINATION

OF BASALTS

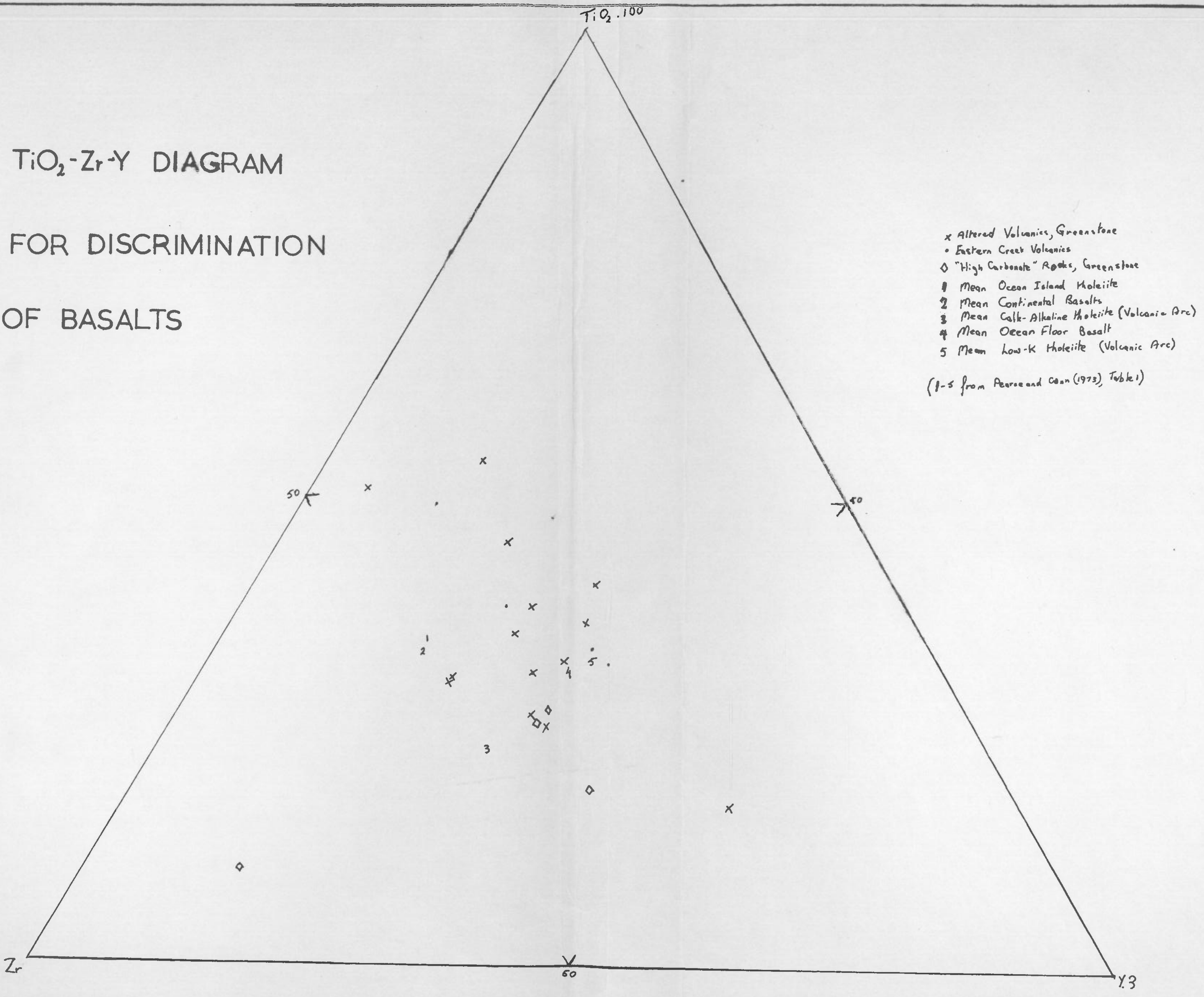


FIGURE 6

FIGURE 7

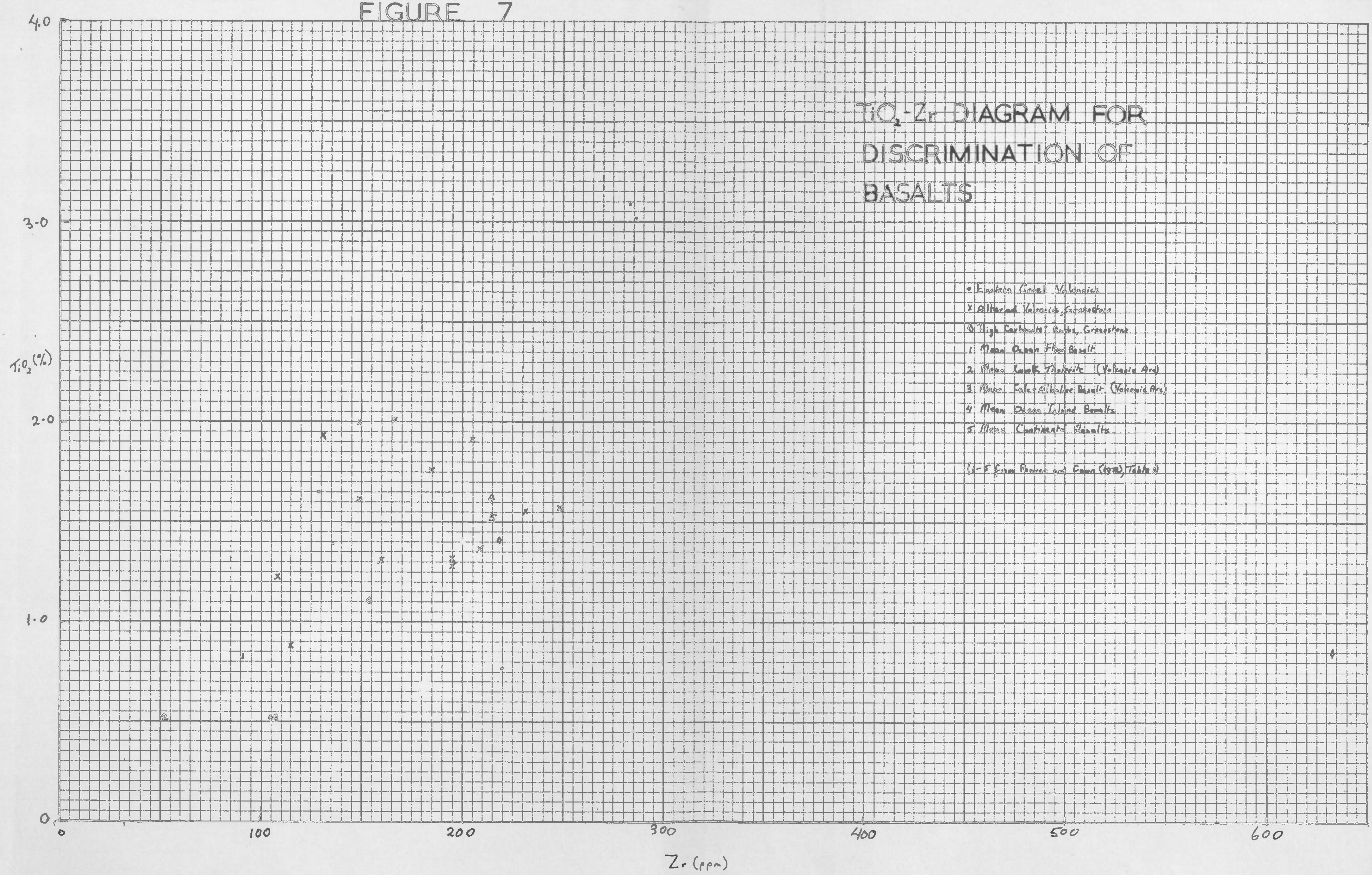
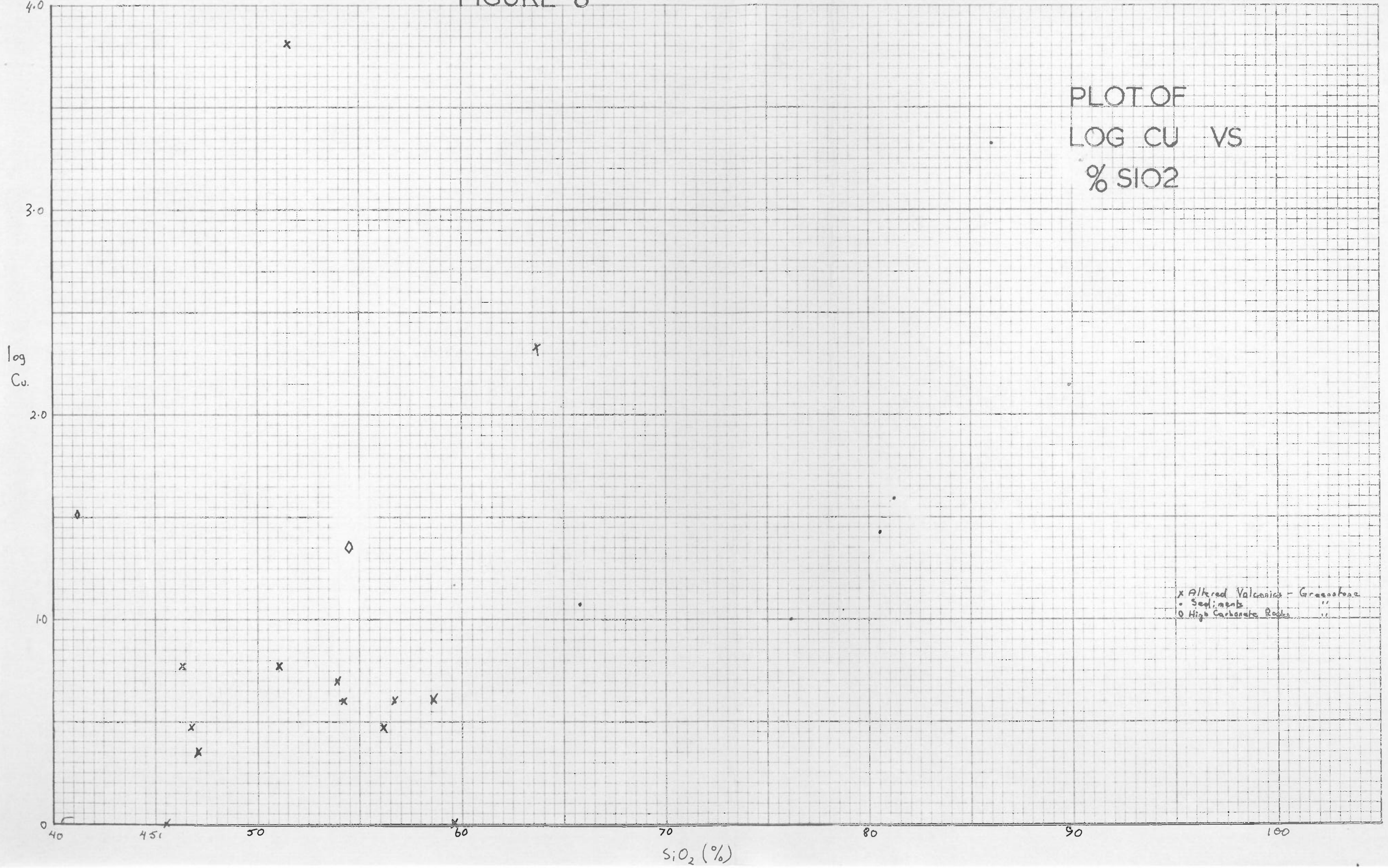

TiO₂-Zr DIAGRAM FOR DISCRIMINATION OF BASALTS
• Eastern Creek Volcanics
X Altered Volcanics, Greenstone
◊ "High Carbonate" Rocks, Greenstone
1 Mean Ocean Floor Basalt
2 Mean Low-K Tholeiite (Volcanic Arc)
3 Mean Calc-Alkaline Basalt (Volcanic Arc)
4 Mean Ocean Island Basalts
5 Mean Continental Basalts
(1-5 from Pearce and Cann (1973), Table 1)
TiO₂ (%)
4.0
3.0
2.0
1.0
0
Zr (ppm)
0
100
200
300
400
500
600
1
2
3
4
5

FIGURE 8


PLOT OF
LOG CU VS
% SIO2
log
Cu.
4.0
3.0
2.0
1.0
0
40
45
50
60
70
80
90
100
SiO_2 (%)
x Altered Volcanics - Greenstone
• Sediments ''
◊ High Carbonate Rocks ''