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April 24, 1972.

Mr. J.H. Courtright,
Chief Geologist,
TUCSON OFFICE.

J. H. C.
APR 2 1972

Dear Sir,

1971 EXPLORATION CONFERENCE TOPIC
P.N. WALKER

Pursuant to your recent letter this will serve to transmit copy of Mr. P.N. Walker's paper: "Localization of Major Stratiform Ore Bodies" presented at the title-subject conference.

Yours very truly,

David M. Fletcher

cc TCOsborne)
PNWalker) with encl.

Encl.

H.C. Copy 3

LOCALIZATION OF MAJOR STRATIFORM ORE BODIES

Ever since the discovery of base metal sulphide of ore grade in sediments in the median trough of the Red Sea, geologists who have worked on the Mt. Isa deposits have been impressed by the striking similarities between the Mt. Isa mineralization and the Red Sea mineralization. The present consensus of opinion of these geologists is that the Mt. Isa lead-zinc orebodies have been formed by similar mechanisms to those operating in the Red Sea. So we have the situation where we can examine the modern metal depositing system and using some discretion apply uniformitavianism principles to show which features of Mt. Isa and the other similar Proterozoic orebodies are significant in localization of these deposits and to further show other features which may be of considerable use in exploration but have not been fully appreciated when the ore deposits are studied on their own. I would also like to consider briefly the Salton Sea geothermal system which is of relevance to this discussion.

I will also consider features of orebodies of this type other than Mt. Isa. This includes the McArthur River deposit, Broken Hill and probably the Sullivan mine in British Columbia and the Balrat-Edwards deposits in New York State.

Red Sea

I will first describe some of the pertinent features of the two geothermal systems, beginning with the Red Sea system as it is forming deposits more closely analogous with the known orebodies than the Salton Sea, however this may be due to an accident of geography.

The Red Sea rift with its median trench formed where Africa and Arabia are moving apart is shown in Fig. 1. In a basin known as the Atlantis II Deep in the median trench, fine grained base metal sulphides occur in recent sediments. The sulphides are principally sphalerite, chalcopyrite and pyrite and occur in similar size range and habit to the McArthur River sulphides. The Atlantis II deep is filled with a hot brine which appears to be replenished by a vent zone within the basin. In the brine trace metals are approx. 1000 times their concentration in sea water whereas chlorine is only 8 times its concentration in sea water.

The Red Sea is a zone of major crustal separation where Arabia and Africa are moving apart at a rate of approx. 1.6cm/yr. The thickness of sediments (clastics, evaporites and pyroclastics) range from 7 km. at either side of the sea to 1 km. along the axis in the median trough. This trough is a zone of anomalously high heat flow of 1.5 to 8 times the world ocean floor average and the Atlantis II deep itself shows very high heat flows, ranging up to 80 times world ocean floor average. A positive gravity anomaly exists along the trough and it is postulated that there has been an inflow of basalt to fill the gap left by the movement.

The chemical and isotopic evidence suggests that the brines obtained the major salts from evaporites and minor element content from interbedded shales. The delta S34 values of the sulphides are in the range $+3 \longrightarrow +11$ suggesting high temperature reduction of sulphide by organic matter probably in underlying shales, rather than by sulphate reducing bacteria at the brine-water interface. The sediments also contain anomalously high free carbon (approx. 4% on a sulphide free basis). The rate of sedimentation of the metalliferous sediments is approx. 40 cm/1000 yrs.

On the floor of the basin seven distinct sediment facies occur:-

1. Detrital Consists of foram tests and other organic debris. Dominantly carbonate and is the normal sediment in the area.

2. Iron-montmorillonite Montmorillonitic clays with iron oxides and sphalerite. Occurs at the present sediment-brine interface.

3. Goethite-amorphous Altered to hematite at south end of Atlantis II deep probably due to heating near a vent.

4. Sulphide Consists of iron monasulphide, marmatite or sphalerite, chalcopyrite and pyrite. Some coarsely crystalline barite and anhydrite also occur in this facies.

5. Manganosiderite

6. Anhydrite Consists of white coarsely crystalline massive beds up to 20 cm. thick.

7. Mangerite

Lead values parallel the copper-zinc concentrations and Pb, Zn, Cu, Fe, Ag and Ba show strong covariance throughout the deposit.

Salton Sea

I will briefly summarize the main features of the Salton Sea geothermal system as described by White.

This is situated near the axis of the major structural trench running north from the Gulf of California (see Fig. 2). This trench represents the continuation of the East Pacific Rise onto the North American continental block and in the Salton Sea area is bounded by faults of the San Andreas system. Fourteen thousand feet plus of deltaic sediments (dominantly sands and silts) fill the trough. Temperatures in the centre of the geothermal system are 300°C at 3000ft. and 360°C at 7000ft. indicating an extremely high heat flow in this area.

Metallic sulphides are being deposited in the near surface discharge pipes of brine wells. The deposits consist of amorphous silica containing Fe, S and Mn as well as copper and silver bearing sulphides including bornite, chalcocite, chalcopyrite, tetrahedrite, pyrite, arsenopyrite and native silver. Apparently insufficient sulphide ions are available so lead and zinc which have less affinity for available sulphide remain in solution. Sphalerite, chalcopyrite, galena, pyrrhotite and abundant pyrite occur in the reservoir rocks in sub-economic quantities. It appears that as metal bearing brines escape from the reservoir the decrease in temperature decreases stability of the metal chloride complexes and when local concentration of metal and sulphide ions sufficiently exceed saturation metal sulphides precipitate. The brines show considerably higher potassium concentrations than the Red Sea brines.

Summary of present systems

The principal relevant features of these two geothermal systems are:-

1. They both occur in zones of crustal separation.

2. The metals are transported as chloride complexes in high density brine, but cannot be discharged subaerially, as at the Salton Sea, due to their high density, but can be discharged under submarine conditions as in the Red Sea.

3. They are both zones of extremely high heat flow.

4. They are both situated in fault bounded structural troughs within the major zone of crustal separation.

I will now look at some features of the McArthur and Mt. Isa deposits and consider the implications for exploration derived from the comparison between the deposits and the modern geothermal systems.

McArthur

The McArthur River deposit occurs in a mid Proterozoic sedimentary sequence in the Northern Territory of Australia. It is situated at the eastern margin of an elongate fault bounded depositional trough, the Mallapungah trough (see Figs. 3 & 4). This trough forms the eastern boundary to the large area of Proterozoic shelf sedimentation known as the Zimmer geosyncline which extends from Darwin to Cloncurry in Queensland. Province studies indicate that the Mallapungah Trough received detrital material from both east and west.

The McArthur deposit is confined to a small depression within the Mallapungah trough - the Bulburra depression which is adjacent to the eastern bordering fault (the Emu fault) see Fig. 5. Fig. 6 shows a typical cross section through the deposit. The H.Y.C. beds which are the ore hosts are dominantly pyritic and bituminous shales interbedded with turbidites, sedimentary breccias, dolomites and tuffaceous beds. The ore minerals are sphalerite and galena of average grain size less than 10 microns. The high pyrite concentrations in the shales show a considerably greater lateral extent than the base metal concentrations.

At least 6 tuff horizons 2-3 cms. thick occur within the mineralized sequence and further tuffs underlie the ore beds. However this volcanic material constitutes an extremely small percentage of the local stratigraphic sequence, particularly in relation to the volume of base metal sulphides. Volcanism at McArthur may have been associated with an area of strong heat flow that fuelled a geothermal system that transported the metals. It has been suggested that pyroclastic piles formed by penecontemporaneous volcanism in this area could easily be leached of metals by brines.

A significant feature of the deposit is the marked grouping of minor metal showings (see Fig. 7), particularly of lead and zinc near the deposit. These all occur in the dolomites that form the bulk of the sedimentary sequence in the McArthur area. In contrast to the very fine grained sulphides of the McArthur deposit itself, these showings are dominantly of coarse grained galena in fractures in dolomite and between fragments in dolomite breccia and are often associated with minor barite and fluorite. The deposits tend to be monometallic either lead rich or zinc rich. The best known of these showings is the discovery outcrop which consists of crystalline hemimorphite in a dolomite breccia being an oxidised sample of this type of occurrence.

The mode of occurrence and mineral assemblages of these minor deposits show a marked similarity with Mississippi valley type deposits.

Mt. Isa

The main features of this deposit are widely known so I will only briefly describe some of the features pertinent to this discussion.

Typical cross-sections through the northern and southern mine areas are shown in Figs. 8 and 9 respectively.

The host rocks for mineralization are dolomitic and locally carbonaceous shales. One of the most distinctive features of the mineralized sequence is the high total sulphide content, particularly the high pyrite content. The Pb-Zn beds pass laterally into high pyrite beds which are considerably more extensive than the lead-zinc mineralization. These pyrite beds outcrop as silicified limonitic masses which can be seen particularly well in the Hilton Mine area.

Other distinctive features of the mineralized sequence are the presence of tuffaceous horizons and the high potassium content. The tuffaceous horizons (tuff marker beds) constitute only a minute part of the mine sequence and may well be as common in other unmineralized members of the Mt. Isa group. The potassium content of the mineralized sequence appears to be significantly higher than that of the other formations (7.5% in lead heads on a sulphide free basis) and this suggests that

the depositing agent may have been a potash rich brine similar to the Salton Sea brines. The mine sequence is also anomalously high in manganese as is the McArthur sequence.

The structural and tectonic position of the Mt. Isa deposit is most significant. Fig. 10 shows the position of the Mt. Isa and Hilton deposits and of other minor metal showings in the area and the position of the faults which appear to bound the depositional trough i.e. the Mt. Isa and Gorge Creek fault complexes. The Mt. Isa and Hilton deposits occur in narrow elongate sedimentary trough within a sequence of dolomitic and shaley sediments. They are situated adjacent to the Mt. Isa fault complex which constitutes a major regional structure and has been a zone of persistent fracturing.

The Mt. Isa group sediments occupied a unique position in the paleoenvironment as stated by Carter, Brooks and Walker (1961) "The Mt. Isa shale appears to have occupied a special tectonically active position between the foreland and a tectonic welt to the east".

Fig. 11 shows the approximate relationships immediately following Mt. Isa group sedimentation showing the fault bounded trough enclosing Mt. Isa group sediments. Fig. 12 shows the Mt. Isa group in the narrow fault bounded trough within a larger north-south elongated basin.

Structural Features

The dominant structural feature that is apparent when the modern systems are compared with the ore deposits is the position of both the modern geothermal systems and the ore deposits in elongate structural trenches or rifts which are associated with major faults bounding the trenches.

These faults are:

1. Red Sea

   The major system of bounding faults.

2. Salton Sea

   Elements of the San Andreas system.

3. McArthur River

Emu and Tuwallah faults.

4. Mt. Isa

The Mt. Isa and Gorge Creek fault systems.

These faults are all major crustal structures and mark zones of differential crustal movement and certainly in the modern systems zones of crustal separation. The fossil troughs probably represent zones of minor crustal separation.

Physical and Chemical Characteristics of Deposits

The Red Sea deposits themselves are remarkably similar to the Proterozoic sulphide deposits, I have described and this is one of the bases for comparison of the deposits. In view of the gross structural similarities, it is reasonable to assume that similar mechanisms played a major part in the deposition of the Mt. Isa and McArthur deposits. The prime requisites for metal deposition of this type on a large scale in a submarine environment appear to be the availability of a chloride brine, capable of transporting metals in solution, a high heat flow to provide the driving energy for the system and a restricted environment of deposition with anerobic conditions prevailing. All these conditions occur in zones of crustal separation.

While evidence of chloride brines may be obtained from fluid inclusion studies and chemical data eg. the anomalous potassium contents at Mt. Isa and McArthur, these do not represent normally practical or feasible exploration methods. Similarly evidence of former high heat flows may be subtle and difficult to detect. Luckily the major structural relationship that I have described can be recognized and also mineralogical and lithological features distinctive of this type of mineralization and its environment can be identified and I believe used as valid exploration tools and criteria.

In particular the Red Sea deposits can be used to define criteria and features that do not appear in the Mt. Isa and McArthur deposits and I will first discuss some of the lithological features.

Lithologies

While the reducing conditions in a brine pool are not conducive to carbonate formation, the formation of economic stratiform sulphide deposits of this type can only take place in a zone of greatly restricted clastic sedimentation, so that on a regional scale chemical and (or) biochemical sedimentation will predominate in a favourable area. However the zone of sulphide formation itself may well be carbonate deficient as in the Red Sea and at McArthur River. The carbonates that do exist will probably be dolomitic as the Red Sea deposits show scavenging of magnesium from the brine to form dolomite.

A feature of McArthur and to a much lesser extent of Mt. Isa is the high content of organic carbon indicating a high level of anerobic organic activity, although this is not the case in the Red Sea deposits these still show anomalous organic carbon (4%). Biochemically precipitated carbonates and silica such as stromatolite biostromes are unfavourable hosts for ore as the oxygenated conditions required for their formation are incompatible with sulphide deposition. However the presence of algal bioherms and biostromes may be a favourable feature as these may restrict water circulation and back reef basins with anerobic conditions may form. If such a basin includes or is adjacent to a brine vent (probably on a fault zone) then this basin may be a focus for metal deposition.

I will now describe some of the features that are not found at McArthur and Mt. Isa but do occur elsewhere, as the Mt. Isa and McArthur tectonic environments have been previously defined in broad terms and the association with highly pyritic sequences in areas of chemical and biochemical sedimentation and of significant carbon content has been recognized and searched for intensively in Northern Australia.

Mineralogy

In particular I will consider some of the mineralogical features of the Red Sea deposit and show that these features can be of some use in exploration. The features are the dominant iron oxide formation compared with iron sulphide at McArthur and Mt. Isa and the presence of the other chemically deposited minerals particularly anhydrite, barite and the manganese minerals. The problem is whether we can draw a valid comparison and therefore can the presence of these other minerals be significant in exploration.

I have used Mt. Isa and McArthur as the principle examples principally because I am far better acquainted with them but when we look at other examples of this type of deposit we can see these mineral associations occurring.

The other deposits I will consider are Broken Hill in N.S.W., Australia, Mt. Oxide and Lady Annie in Queensland and the Balmat-Edwards deposits in New York state.

The Broken Hill deposit occurs in a high grade metamorphic terranes and most of the characteristic structural features have been obliterated although a major fault (Globe-Vauxhall fault) does occur adjacent to the deposit. The mineralization occurs within a distinctive rock sequence which can be recognized elsewhere in the Willyamma block and always constitutes the host sequence for Broken Hill type mineralization in other minor occurrences in the area. Characteristics of this sequence include the high manganese content, the presence of highly felspathic gneisses (Potosi gneiss) believed to represent the metamorphosed equivalent of acid tuffs and the occurrence of banded iron formations which in this area are highly siliceous and ferruginous beds containing iron as hematite and magnetite together with minor manganese. Studies of these banded iron formations indicate that they are the result of metamorphism of a parent sediment of very similar grass composition and of dissimilar composition from the other well known B.I.F. occurrences i.e. the Lake Superior type which are very low in manganese. These Broken Hill banded iron formations appear to be of a similar type to the ferruginous Red Sea sediments. Another feature of Broken Hill mineralization is the association with unusual barium rich felspars.

At Mt. Oxide, 80 miles north of Mt. Isa, the only other known stratiform copper deposit in the Mt. Isa-Cloncurry district occurs. Immediately above the ore horizon a large lens of stratiform hematite exists which forms a very prominent outcrop readily visible on the ground and on coloured aerial photographs.

The Lady Annie deposit in the same general area is a stratiform lead zinc deposit of the Mt. Isa type with significant associated barite. I will discuss this deposit in more detail at another point.

The Balmat-Edwards deposits in New York state also occur in a moderately high grade metamorphic terrane which appears to have obscured most of the structural features. However the deposits do show a close spatial relationship with large anhydrite lenses which occur within the mineralized sequence.

These samples illustrate that the other mineralogical associations seen in the Red Sea also occur in association with major ore mineralization and so can be utilised in exploration.

Two other features that I would like to discuss briefly are the associations of this type of ore body with major metal provinces and with pene-contemporaneous volcanism.

Metal Provinces

The source of metals in both the Red and Salton Seas appears to be the sediments through which the brines pass and no magmatic source is necessarily implied although not excluded. So are deposits of this type need not occur in major metal provinces, where there are considerable crustal concentrations of metals apparently derived from deep seated sources.

The McArthur deposit, for instance, does not occur in a major metal province, in fact almost every known base metal showing within a 150 mile radius of McArthur occurs within 8 miles of the deposit itself in a very prominent grouping.

Mt. Isa does occur in an extensive copper province but all the known lead-zinc occurrences in the Mt. Isa area occur adjacent to the Mt. Isa fault between Mt. Novitt to the south and Hilton to the north.

Volcanism

Tuffs, dominantly of acid composition are associated with Mt. Isa, McArthur and probably Broken Hill. They constitute a very small part of the sequence at McArthur and Mt. Isa. Volcanic material has not been found to date in the Red Sea deposits, but recent volcanics do occur in the region. Volcanic activity has been postulated as the direct source of the metals in these deposits, but the minute amount of

volcanic material compared with enormous quantity of metallic sulphides indicates that any relationship is probably indirect. The two most likely associations are first that volcanism tends to occur in the zones of strong heat flow which are also favourable for metal deposition and second that piles of pyroclastic material could easily be leached by circulating brines.

Certainly in the deposits at Mt. Isa and McArthur the manifestations of volcanism are so insignificant and subtle that they were only recognized well after the discovery of these deposits.

Exploration Criteria

Exploration should be focused on zones where elongate depositional troughs have formed and are bounded by major faults which will probably show evidence of penecontemporaneous movement with sedimentation. In areas of poor outcrop or later cover these boundary faults may be obscured, but may be indicated by a prominent alignment of minor metal showings and lineations. Where a deposit is known on one side of a trough, the other bounding fault should be searched for and the zone explored.

Within a trough, favourable zones will occur where chemical and (or) biochemical sedimentation dominates adjacent to a bordering fault. This sedimentation will usually be dolomitic but breaks in the dolomitic sequence where carbonaceous shales occur should be carefully examined. The presence of reef complexes can be favourable for mineralization.

Once a broad target zone is defined further features that should be looked for are:

1. A clustering of minor base metal showings. These may have been described as minor Mississippi Valley type occurrences.

2. The presence of very high iron horizons and lenses whether pyritic or hematitic. Minor hematite occurrences of this type are often described in government survey publications.

3. The presence of other distinctive minerals, in particular, the presence of stratiform bodies of anhydrite and barite. Again these are often recorded in the literature.

The lower and mid Proterozoic appear to be most favourable for the formation of this type of deposit. The reasons for this are a subject for speculation and is probably related to the relative movements of plates at this time. Exploration methods used will be dependent on local climatic and topographical conditions, but two techniques that have not been used to their full extent in searching for this type of deposit are:

1. The use of coloured aerial photographs which can often delineate zones of high iron content.

2. The use of I.P. as a broad regional tool to locate the large pyrite zones which are often associated with mineralization.

Lady Annie

The Lady Annie area north of Mt. Isa is a very good example where application of the suggested criteria would have defined the target area far more efficiently and quickly than the somewhat fortuitous discovery that did occur.

Fig. 13 shows some principal features of the area. A depositional trough filled with dolomitic sediments including prominent algal biostromes occurs. This is bounded on the east by the major Mt. Gordon fault zone which shows evidence of faulting contemporaneously with sedimentation. A prominent alignment of copper prospects and small mines occurs along this fault zone. The western side of the trough is very poorly exposed due to younger covering rocks and extensive lateritization. However another prominent alignment of copper prospects occurs and a marked alignment of the faults, which can be observed in this poor outcrop area, can be seen and it appears that this is the western bounding fault zone.

Along the Mt. Gordon fault zone the copper deposits are mainly fault fill types, but one stratiform copper deposit does occur at Mt. Oxide. This deposit consists of primary chalcocite in a black shale lens within a dolomite sequence. The copper mineralization is confined to one horizon immediately underlying a prominent stratiform hematite lens.

Along the western boundary zone much difficulty has been experienced separating gossans

from residual lateritic ironstones. However one occurrence of crystalline barite in ironstone had been reported in Bureau of Mineral Resources Publications. This consists of bands of crystalline barite in ironstone parallel to the strike of the adjacent dolomitic shales. The occurrence had been known and neglected for at least 30 years although it is situated only 1 mile from a small producing copper deposit.

Recent drilling of this outcrop by Placer has shown that it is the outcrop of a major Mt. Isa type orebody which is still in an early stage of testing. To date it appears that drilling has indicated in the order of 20 million tons of medium to high grade ore (20% - 30% combined lead-zinc). The barite which distinguished the outcrop occurs in the primary ore as thin concordant coarsely crystalline bands. Host rocks for ore are dolomitic and carbonaceous shales which occur in a dominantly dolomitic sequence. Minor tuff beds occur, but once again these were only recognized well after the discovery of the deposit.

This area is a zone where the proposed criteria would have lead to an earlier and cheaper discovery as the occurrence of dolomitic sediments and algal biostromes in a Proterozoic depositional trough defined a favourable environment and the recorded distinctive association of barite and high iron concentrations would have defined a priority target in the area.

Finally I would like to suggest that one of the regions where this approach to exploration for this type of stratiform deposit may be most successful is the North American continent, where comparatively little directed effort has gone into exploration for this type of stratiform deposit.

P.N. Walker

Typed at Perth
April 21, 1972.

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Mr. J.H. Courtright
Chief Geologist
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P.O. Box 5747
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Palm Springs Paper

Dear Sir:

Transmitted herewith is a typed copy of the talk I gave at Palm Springs.

Very truly yours,

Stephen Von Fay

Stephen Von Fay

SVF/pn
Enclosure

COMMON FACTORS IN STRATIFORM COPPER BODIES AND THEIR SIGNIFICANCE AS EXPLORATION GUIDES

The upper mile of the earth's crust contains about 7×10^9 tons of copper at grades of better than .25% Cu, according to J. David Lowell; as Porphyry Coppers, Magmatic Segregations, Massive Magnetite, and Red Bed and Stratibound deposits, with a little less than half as the "Red Bed and Stratibound" Type. It is probable that the proportions are wrong, and that there is more as "stratibound" copper. For my purposes, "stratibound" means a deposit is confined to a thin stratigraphic unit, bound to it; while "stratiform" means a deposit has the shape of strata, but is not necessarily bound to it. Translations of Russian papers use the terms "sandstone coppers," or "copper sandstones" for the same kind of deposit, but the original Russian word is better translated as "stratiform."

Much of the copper mined to date, from porphyry coppers and from stratiform deposits, is in the form of chalcocite, There is general agreement that chalcocite ore in the porphyry coppers is the product of cold water dissolution of small amounts of copper, then movement of the copper bearing fluid through permeable rocks, and precipitation of copper as chalcocite at and beyond the oxidation-reduction front; in other terms, at the geochemical barrier. In addition to copper, at least sulfur and uranium, probably iron, and other elements migrate in the same manner within this environment. Essential components of this system are a source of copper, water, and permeable rocks; and an oxidation-reduction barrier. This theory, possibly "catechism," has the status of Holy Writ, and has not been challenged for many years.

Many papers, and much conversational speculation, are offered about original amounts of copper in porphyritic rocks, and various chemical equations and combinations are printed purporting to show what happens chemically in the system; thought is often devoted to speculating on why a chalcocite blanket develops in one place and is not present in another place.

The absolutely essential physical property of the rocks is permeability, which can be measured and defined, but does not get much attention. Papers are written on the vertical and lateral migration of supergene copper in igneous rock, but the physical details and parameters which permit this are seldom described.

Most porphyry copper geologists are still unreconstructed hydrothermalists for the primary emplacement of copper. It would seem at least possible that hydrothermal fluids can only pass through permeable rocks, and that further, if such fluids move, they require a fluid input to the system and fluid output, which in turn require a complete hydraulic system within permeable rocks.

In the fall of 1971, it is generally accepted by uranium geologists that uranium ore bodies in clastic rocks are formed by fluid dissolution of small amounts of uranium, then movement of the uranium bearing fluid through permeable rocks, and precipitation of uranium as uraninite and coffinite at and beyond an oxidation-reduction front, or in other terms, at the geochemical barrier. Other metals which are known to migrate and concentrate in these occurrences are molybdenum, copper, silver, selenium, vanadium, chromium, nickel, some iron, silica, calcium, sulfur, occasionally lead and zinc, and there may be many others.

There are no differences (other than position in space) in the critical factors that control ore deposition in the systems of origin for stratiform uranium deposits and supergene porphyry copper chalcocite, that is: dissolution of small amounts of metal, transportation of that metal in a fluid through a permeable media, and deposition at an area of chemical and/or physical change.

In 1910, Lindgren with L.C. Graton, and others, published the classic "Ore Deposits of New Mexico," based on work done in preceeding years. Lindgren, senior author, and premier proponent of hydrothermal origin for ore deposits, was very careful to exclude stratiform copper deposits in New Mexico from any hydrothermal origin. He further states that stratiform copper deposits in adjacent states, and in Permian and Triassic deposits in Europe are a series of very similar deposits, and probably have a similar origin. He briefly states that "the copper deposits in the 'red beds' are believed due to concentration of minute traces of copper in certain strata, or on fissures, by circulating atmospheric waters charged with chloride and sulphate." Lindgren amplifies the statement and explains that copper sulphides are precipitated from water when organic matter or H_2S from organic matter is added to the system. Lindgren thus had three controlling factors in the system: dissolution of small amounts of copper, transportation of copper in a fluid through permeable rocks, and deposition of copper at a reducing or geochemical barrier. These are the same three factors that are invoked to explain porphyry copper chalcocite blanket ore development and uranium ore concentration.

I should point out that Lindgren initially thought that bedded copper deposits in New Mexico were syngenetic. However, after further study he formed the opinion that they are "beyond all doubt epigenetic." The copper was assuredly not deposited with the sediments. Simply, the chalcocite replaces carbonaceous material, or kaolinitic or calcareous material; replaces quartz grains, feldspars in the host, and it also fills voids and fissures in the rock. Lindgren also felt it unreasonable and unnecessary to ascribe such deposits to warm waters rising along faults, although he carefully considered such a possibility. He also noted other significant criteria, primarily that outcropping copper bearing beds are bleached, feldspars are argillized, organic material is commonly present, chalcocite is the characteristic sulphide mineral, and that careful study might show that barite is a consistent accompanying mineral. Russian work now indicates that barite may be depleted in the copper bearing unit.

Butler in "Ore Deposits in Utah," 1920, believed that Lindgren's hypothesis of origin is correct, and also used the same hypothesis to explain silver deposits in sandstones and uranium and vanadium deposits. Butler pointed out the close association of these deposits with major structural features, such as anticlines. He believed that the then very popular syngenetic theory could not explain the association with structure, continental and near shore rocks, replacement phenomena and filling of fissures, which only develop when the rock is strong enough to break, and so on.

Russian literature ascribes an origin for uranium deposits similar to that held by US Geologists, and now ascribes a similar origin to some major stratiform copper deposits. The Zechstein deposits in southwestern Poland contain over a billion tons of 3% copper and occur in sandstones (about 44%), and in shales and marls above the porous sandstones (about 56%).

Stratiform bodies in clastic rocks consist of uranium, uranium-vanadium, uranium-copper, copper with small amounts of uranium, and copper ore types. There are also uranium-molybdenum, and molybdenum ore deposits. Copper ores normally have recoverable amounts of silver. In addition, there are lead-copper and copper-silver-lead occurrences. Clearly, there are a variety of recoverable metal types.

If the controversial African coppers have a similar genesis, there are also copper and copper-cobalt types. Uranium and molybdenum are common constituents of African ores. In this connection I might point out that the lower Roan, host for many ore bodies in Africa, by recent age dating varies from 750 to 900 million years old. Age dates on uranium minerals with ore indicate an age of 600 million years. This at least suggests mineral introduction.

In any event, several of the African deposits show clear evidence of chalcocite enrichment in the porphyry copper sense, so there is agreement that processes operated in part in the manner I am discussing.

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The shales, called such at mines such as Roan Antelope, contain almost no clay. At that mine host rocks are quartz-sericite rocks that were originally porous. Ore is generally found in the coarse, sandy, lower layers. Beds above the ore are fine-grained, have clay, and are impermeable. Grain size of ore reflects the grain size of the original pore space. The ore is typically zoned, with chalcocite-bornite-chalcopyrite-pyrite. Veinlets of ore cross cut the beds.

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One of the African ore bodies cited by Garlick as sygenetic is Chibuluma West. The ore body occurs in the lower Roan. The section consists of basal schists, uncomformably overlain by lower Roan, in turn uncomformably overlain by upper Roan, with numerous disconformities in both units and with substantial cobalt present. Where the ore rests on basement schist, it is in schist for about 20 feet, which is bleached to a green color, and original biotite is bleached white.

Where the ore is in contact with basal conglomerate, that unit is also mineralized and bleached, with ore in the matrix of the conglomerate.

The ore bed at Chibuluma West named "ore member," is an arkose, containing 15-30% feldspar and ranges up to 60 feet in thickness. The general setting may be a river channel. Beds, where mineralized, show no physical differences except in sulfide content, between ore and not ore. Sulphides abruptly change into cobaltiferous pyrite beyond ore.

The non ore-bearing hangingwall rocks are red-brown arkoses and argillites, which are stated to be porous and "bleached." They contain copper sulphides and oxides and are water bearing. The hangingwall rocks, above the unconformity, show discontinuous copper, but in rich concentrations, and considerable low grade disseminated chalcocite. MoS_2, uranium, and other minerals are also present. MoS_2 occurs in crests of small folds, in broken zones, with grades of better than 6% locally. Ore mineral joint fillings are also present.

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1. They occur in basinal areas of deposition, commonly on the flanks of domal or anticlinal structures, which for copper deposits are generally younger than the time of deposition of the beds. In lead-zinc areas pre-existing domes frequently result in stratigraphic pinchouts of sandstones which localize ore.

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Organic material seems to be ubiquitous in African deposits. Kilembe is not known to have carbon, but the rocks are strongly metamorphosed. Roan Antelope descriptions do not mention organic material, but similar rocks have carbon elsewhere.

In the US, uranium deposits, bedded coppers of the Southwest, White Pine, and Boleo all have considerable carbon. Such carbon may vary in type from plant debris to hydrocarbons and from light oils to asphaltites to methane, or appear as carbon in organic shales. The Zechstein deposits in southwestern Poland were discovered while drilling for oil, and the amount of methane in drifts is a major operating problem. Ambrosia Lake is believed to be a dead oil field. Oil is a common fluid inclusion in Mississippi Valley deposits. Chalcopyrite is evident in the southeast Missouri area where it replaces asphaltite, overlying "high grade" galena.

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This evidence of metallization, copper, uranium, lead, or whatever, normally shows great persistence in individual beds, or at least beds of identical lithology and stratigraphic position within a formation, as in Africa or the Permian in the US.

Boleo, of Pliocene Age, North America's major stratiform deposit until about three years ago, with 600,000 tons of copper produced, appears to be the only significant exception to this widespread stratigraphic evidence of metal, and in the case of Boleo large scale faulting is probably present.

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The two major known North American stratiform coppers, White Pine and

Boleo, are typical examples of this. In the case of Boleo, ore occurs at contacts between conglomerates and a black organic tuffaceous clay. In the clay, cobalt, nickel, zinc, and silver are present. The lowest copper bearing bed, and also the least mineralized, is at a contact with fossiliferous limeatone. White Pine ores are in siltstones, with lesser shales, above a contact with conglomerate.

White Pine and essentially all the US uranium, much of the "red bed" copper in the US, and at least over half of the African coppers, are directly associated with arkose and feldspathic sandstones. The arkoses are normally bleached, continental and channel deposits, and are red in color away from ore. The arkosic material itself is the ore bed, or beds, as at Mufulira, Chibuluma, and so on. In the case of Mufulira, the argillites are unfavorable host rocks, and according to Garlick, barren, whereas in the case of White Pine, the siltstone and shale just above the contact with the arkosic conglomerate contains the ore.

Gray, and then green, and then black are the dominant reduction colors with the ore. Black colors are due primarily to disseminated sulfide, and in part to carbon. Katanga coppers are excellent examples of color zoning, where blacks due to carbon also control mineral zoning. Chalcopyrite is in the black beds which have a high amorphous carbon content, and bornite and chalcocite are in the bleached, reduced gray and green beds.

In the carbonate rock suite, Mississippi Valley deposits show similar relationships to permeable strata.

The southeast Missouri district ores are associated with pinchouts of an underlying sandstone, which is bleached white in the upper portions, and is red at times at depth. Ore is at dolomite-limestone contacts between the sandstone and an overlying impermeable shale.

Illinois-Wisconsin ores directly overlie the Saint Peter sandstone and underlie a thick shale, associated generally with an "oil rock" which has a high hydrocarbon content. In the Tri State district and Tennessee, ore occurs on the walls and within debris of an integrated Karst system in a dolomite which is both an acquifer and host. Fluid inclusions reflect alkaline, saline, warm-water fluids, such as those represented by oil field brines. Such warm saline fluids are common in rocks today. Temperatures and salinities of depths of about a half mile in east Texas oil fields are of the type measured in fluid inclusions. Warmer temperatures, over 200°C, are indicated in deep-well drilling in the Anadarko Basin.

Fluids moving, of course, require basic physical parameters such as water entering the rock system, passing through the system, and water leaving the rock system , or there is no movement and a static system develops. If such fluids are carrying metal ions in soulution, such metal must precipitate as sulphides when sufficient sulfur ion is available to exceed the solubility point.

Flow rates within such a system can be low. Slow rates are significant in fluid flow through so called "impermeable" rock, which actually, in fact are directionally permeable. Such rocks include many shales, with directional permeability along bedding planes.

In uranium deposits, and in descriptions of copper deposits in Africa, etc., up dip, outcropping, clastic rocks normally have no magnetite, although overlying and underlying beds have detrital magnetite grains. Iron is present as limonite, whereas beyond ore, both pyrite and magnetite many be present, and up dip feldspars are commonly kaolinized. In Africa there are small amounts of copper on the up dip side, near the outcrop. Core assays from the literature show variations of .01-.1% Cu throughout so called barren up dip sections of African deposits.

It appears that to find such ore bodies, one should first determine that the desired metal is present in the section and is widespread in small amounts. Sedimentary and structural patterns should indicate that host units are thick enough to contain ore tonnages. In addition, the lenticularity of bedding and anticlinal closures affecting hydraulic flow, in addition to traps for hydrocarbons, are important considerations. Finally, carbon and/or sulfur in quantity is no doubt mandatory.

Copper or uranium ores occur between down dip pyrite and up dip iron oxides in the same horizon, at an oxidation-reduction interface. Garlick strongly emphasizes this important fact, and regards the discovery of down dip pyrite in a drill hole as the first step leading toward discovery of an African copper ore body.

Highest grades of uranium, or of copper in a porphyry copper chalcocite blanket, or of bedded chalcocite at Mufulira, are just beyond the redox interface, on the reduced side.

Precise mineral zoning in uranium is a well-known control of ore. Zoning in many stratiform coppers is just as important, with chalcocite-bornite-chalcopyrite-pyrite the standard metallogenic sequence as penetration into the reduced zone is gained . If lead or zinc is in the system, the system goes chalcocite-bornite-chalcopyrite-pyrite and galena-sphalerite-pyrite.

This characteristic zoning is a function of available sulfur and available copper ions being transported into the barrier, and the solubility products of copper sulfides, the most insoluble precipitating first in a sulfur limited system. Zoning or replacement of other minerals is also common.

In descriptions of African deposits, the old shoreline is defined on the basis of changes in lithology. Zoning of copper minerals is then related to spatial position from the ancient shoreline. Apparently this is another way of saying copper mineral zoning is related to lithology, or lithologic change, and is downdip from the shoreline. In these literature claimed syngenetic deposits,

Garlick states, "Detrital deposition of sulfides, as the major process, must therefore be rejected." Garlick believes that copper precipitates from marine water as some undefined "copper sulphide."

After precipitation of this sulphide, it is then converted "during diagenesis and metamorphism" into "the sulphide minerals now observed in the general arrangement-chalcocite, bornite, chalcopyrite, and pyrite." "Iron sulphide subsequently combined with the copper sulphide, present in the sediments, to form bornite or chalcopyrite."

It seems to me that such mineral combination, and chemical conversion, necessarily requires movement and a chemical system similar to the system operating in the epigenetic deposits. The only significant point of dispute is the source of the copper ion, marine water, or ground water. Even here, Garlick states, "all evidence points to streams in an arid environment transporting--specifically metals in solution to the acqueous repositories." Streams are part of the ground water regimen, and transporting copper in ground water to a reducing zone rather than in surface streams avoids dilution of small amounts of copper with the detrital load also brought to the acqueous repository by the same copper bearing stream. The zoning sequence chalcocite-bornite-chalcopyrite-pyrite is accomplished at the time of copper deposition from ground water, rather than in an undefined manner and time during diagenesis and metamorphism.

Bleaching and leaching of copper bearing strata are pronounced in the US, and commonly occur in Africa. However, this fact is sometimes obscure in literature descriptions, as at White Pine, where chloritization is the more common feature.

Bleaching with characteristic color zoning, pervasive permeability, silicification, etc., can be evident in Mississippi Valley deposits. Thin sulfide tails, the haloes of dispersed metal values, are common features adjacent to Mississippi Valley ore. Metal zoning and position location around reducing centers deep within a basin, however, are difficult to predict and locate, although there is local correlation with upwarp such as domes, anticlines, etc.

Regardless of genetic theory, known stratiform copper ore bodies occur as follows: in sedimentary basins known to contain sub-ore grade copper bearing beds; are in an oscillating (cyclic) sedimentary sequence with copper concentrated at an interface between water lain and continental beds, or beds of two different permeabilities; are in permeable clastic rocks such as arkoses and sandstones; or in less permeable rocks such as shales at the contact with the permeable beds; are associated with disseminated organic material; may show a spatial relationship to uranium, vanadium, molybdenum, zinc, and lead in the same beds; and show many other characteristic similarities.

Regardless of the indirect source of the copper ions (from ocean waters or formation waters), copper mineralogy is exactly controlled by the solubility

of particular metalliferous minerals, and the existing copper minerals can be read to define the oxidation-reduction state of the copper bearing beds.

It follows that to find stratibound copper ore, the exploration geologist should determine that host rocks are known to contain copper and have enough spatial volume to bear ore in sufficient tonnages; determine structural patterns; determine the amount and variation of carbon, permeability, etc.; test by drilling to locate the position of the oxidation-reduction interface, and/or determine location within the reduced zone; and test laterally along or within this zone for the desired favorable mineralized lithology and structure.

If it is feasible to search for laterally limited porphyry coppers (or their characteristic haloes) below post mineral cover, it is also feasible to search for stratiform coppers or (their characteristic alteration haloes) below younger sediments.

BIBLIOGRAPHY

1. Perel'man, Aleksandr Il'ich, "Geochemistry of Epigenesis," Academy of Sciences, USSR, Nedra, Moscow, 1965. Translated, N.N. Kohanowski, Dept. of Geol, Univ. of N. Dak.; Plenum Press, N.Y., N.Y., 1967.

2. Ridge, John D., Editor, "Ore Deposits of the United States, Vol I and Vol II, AIME, New York, 1968.

3. Brown, J.S., Editor, Monograph 3, "Genesis of Stratiform Lead-Zinc-Barite-Fluorite Deposits," Economic Geology, 1967, Lancaster Press, Lancaster, Penn.

4. James, Clifford J., Editor, "Sedimentary Ores, Ancient and Modern (Revised)," Spec, Pub. #1, Dept. of Geol., Univ. of Leicester, 1969.

5. Nicolini, P. and Lombard, J., Editor, "Stratiform Copper Deposits in Africa," Vol 1 and Vol 2, Lithology, Sedimentology, and tectonics, Symposium, Association of African Geological Surveys, Paris, 1963.

6. Memoir 15, "Geology and Technology of the Grants Uranium Region." State Bureau of Mines and Mineral Resources, 1963, Socorro, New Mexico.

7. Economic Geology, Vol 66, #5, August, 1971, Symposium. "A Paleoaquifer and its Relation to Economic Mineral Deposits. The Lower Ordivician Kingsport Formation and Mascot Dolomite," 1971, Lancaster Press, Lancaster, Penn.

8. Emmons, W.H. "The Principles of Economic Geology," 2nd Edition, McGraw-Hill, New York, 1940, pp. 324-325; 335-342.

9. Bateman, A.M., Editor, "Fiftieth Anniversary Volume, Economic Geology," 1955, Lancaster Press, Lancaster Penn.

   Part I. Anderson, Charles A., "Oxidation of Copper Sulphides and Secondary Sulphide Enrichment," pp. 324-340.

   Krauskopf, Konrad B., "Sedimentary Deposits of Rare Metals," pp. 411-436.

   Part II. Levorsen, A.I., "Time of Petroleum Accumulation," pp. 748-746.

   Ellison, Samuel P. "Economic Applications of Paleoecology."

10. Panel Proceedings, "Uranium Exploration Geology," IAEA, Vienna, 1970.

11. Lindgren, W., and others. "The Ore Deposits of New Mexico," PP 68, 1910.

12. Butler, B.S., and others. "The Ore Deposits of Utah," PP III, 1920.

COMMON FACTORS IN STRATIFORM COPPER BODIES AND THEIR SIGNIFICANCE AS EXPLORATION GUIDES

By Stephen Von Fay

The upper mile of the earth's crust contains about 7×10^9 tons of copper at grades of better than .25% Cu, according to J. David Lowell; as Porphyry Coppers, Magmatic Segregations, Massive Magnetite, and Red Bed and Stratibound deposits, with a little less than half as the "Red Bed and Stratibound" Type. It is probable that the proportions are wrong, and that there is more as "stratibound" copper. For my purposes, "stratibound" means a deposit is confined to a thin stratigraphic unit, bound to it; while "stratiform" means a deposit has the shape of strata, but is not necessarily bound to it. Translations of Russian papers use the terms "sandstone coppers," or "copper sandstones" for the same kind of deposit, but the original Russian word is better translated as "stratiform."

Much of the copper mined to date, from porphyry coppers and from stratiform deposits, is in the form of chalcocite. There is general agreement that chalcocite ore in the porphyry coppers is the product of cold water dissolution of small amounts of copper, then movement of the copper bearing fluid through permeable rocks, and precipitation of copper as chalcocite at and beyond the oxidation-reduction front; in other terms, at the geochemical barrier. In addition to copper, at least sulfur and uranium, probably iron, and other elements migrate in the same manner within this environment. Essential components of this system are a source of copper, water, and permeable rocks; and an oxidation-reduction barrier. This theory, possibly "catechism," has the status of Holy Writ, and has not been challenged for many years.

Many papers, and much conversational speculation, are offered about original amounts of copper in porphyritic rocks, and various chemical equations and combinations are printed purporting to show what happens chemically in the system; thought is often devoted to speculating on why a chalcocite blanket develops in one place and is not present in another place.

The absolutely essential physical property of the rocks is permeability, which can be measured and defined, but does not get much attention. Papers are written on the vertical and lateral migration of supergene copper in igneous rock, but the physical details and parameters which permit this are seldom described.

Most porphyry copper geologists are still unreconstructed hydrothermalists for the primary emplacement of copper. It would seem at least possible that hydrothermal fluids can only pass through permeable rocks, and that further, if such fluids move, they require a fluid input to the system and fluid output, which in turn require a complete hydraulic system within permeable rocks.

In the fall of 1971, it is generally accepted by uranium geologists that uranium ore bodies in clastic rocks are formed by fluid dissolution of small amounts of uranium, then movement of the uranium bearing fluid through permeable rocks, and precipitation of uranium as uraninite and coffinite at and beyond an oxidation-reduction front, or in other terms, at the geochemical barrier. Other metals which are known to migrate and concentrate in these occurrences are molybdenum, copper, silver, selenium, vanadium, chromium, nickel, some iron, silica, calcium, sulfur, occasionally lead and zinc, and there may be many others.

There are no differences (other than position in space) in the critical factors that control ore deposition in the systems of origin for stratiform uranium deposits and supergene porphyry copper chalcocite, that is: dissolution of small amounts of metal, transportation of that metal in a fluid through a permeable media, and deposition at an area of chemical and/or physical change.

In 1910, Lindgren with L.C. Graton, and others, published the classic "Ore Deposits of New Mexico," based on work done in preceeding years. Lindgren, senior author, and premier proponent of hydrothermal origin for ore deposits, was very careful to exclude stratiform copper deposits in New Mexico from any hydrothermal origin. He further states that stratiform copper deposits in adjacent states, and in Permian and Triassic deposits in Europe are a series of very similar deposits, and probably have a similar origin. He briefly states that "the copper deposits in the 'red beds' are believed due to concentration of minute traces of copper in certain strata, or on fissures, by circulating atmospheric waters charged with chloride and sulphate." Lindgren amplifies the statement and explains that copper sulphides are precipitated from water when organic matter or H_2S from organic matter is added to the system. Lindgren thus had three controlling factors in the system: dissolution of small amounts of copper, transportation of copper in a fluid through permeable rocks, and deposition of copper at a reducing or geochemical barrier. These are the same three factors that are invoked to explain porphyry copper chalcocite blanket ore development and uranium ore concentration.

I should point out that Lindgren initially thought that bedded copper deposits in New Mexico were syngenetic. However, after further study he formed the opinion that they are "beyond all doubt epigenetic." The copper was assuredly not deposited with the sediments. Simply, the chalcocite replaces carbonaceous material, or kaolinitic or calcareous material; replaces quartz grains, feldspars in the host, and it also fills voids and fissures in the rock. Lindgren also felt it unreasonable and unnecessary to ascribe such deposits to warm waters rising along faults, although he carefully considered such a possibility. He also noted other significant criteria, primarily that outcropping copper bearing beds are bleached, feldspars are argillized, organic material is commonly present, chalcocite is the characteristic sulphide mineral, and that careful study might show that barite is a consistent accompanying mineral. Russian work now indicates that barite may be depleted in the copper bearing unit.

Butler in "Ore Deposits in Utah," 1920, believed that Lindgren's hypothesis of origin is correct, and also used the same hypothesis to explain silver deposits in sandstones and uranium and vanadium deposits. Butler pointed out the close association of these deposits with major structural features, such as anticlines. He believed that the then very popular syngenetic theory could not explain the association with structure, continental and near shore rocks, replacement phenomena and filling of fissures, which only develop when the rock is strong enough to break, and so on.

Russian literature ascribes an origin for uranium deposits similar to that held by US Geologists, and now ascribes a similar origin to some major stratiform copper deposits. The Zechstein deposits in southwestern Poland contain over a billion tons of 3% copper and occur in sandstones (about 44%), and in shales and marls above the porous sandstones (about 56%).

Stratiform bodies in clastic rocks consist of uranium, uranium-vanadium, uranium-copper, copper with small amounts of uranium, and copper ore types. There are also uranium-molybdenum, and molybdenum ore deposits. Copper ores normally have recoverable amounts of silver. In addition, there are lead-copper and copper-silver-lead occurrences. Clearly, there are a variety of recoverable metal types.

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In the carbonate rock suite, Mississippi Valley deposits show similar relationships to permeable strata.

The southeast Missouri district ores are associated with pinchouts of an underlying sandstone, which is bleached white in the upper portions, and is red at time at depth. Ore is at dolomite-limestone contacts between the sandstone and an overlying impermeable shale.

Illinois-Wisconsin ores directly overlie the Saint Peter sandstone and underlie a thick shale, associated generally with an "oil rock" which has a high hydrocarbon content. In the Tri State district and Tennessee, ore occurs on the walls and within debris of an integrated Karst system in a dolomite which is both an acquifer and host. Fluid inclusions reflect alkaline, saline, warm-water fluids, such as those represented by oil field brines. Such warm saline fluids are common in rocks today. Temperatures and salinities of depths of about a half mile in east Texas oil fields are of the type measured in fluid inclusions. Warmer temperatures, over 200°C, are indicated in deep-well drilling in the Anadarko Basin.

Fluids moving, of course, require basic physical parameters such as water entering the rock system, passing through the system, and water leaving the rock system , or there is no movement and a static system develops. If such fluids are carrying metal ions in soulution, such metal must precipitate as sulphides when sufficient sulfur ion is available to exceed the solubility point.

Flow rates within such a system can be low. Slow rates are significant in fluid flow through so called "impermeable" rock, which actually, in fact are directionally permeable. Such rocks include many shales, with directional permeability along bedding planes.

In uranium deposits, and in descriptions of copper deposits in Africa, etc., up dip, outcropping, clastic rocks normally have no magnetite, although overlying and underlying beds have detrital magnetite grains. Iron is present as limonite, whereas beyond ore, both pyrite and magnetite many be present, and up dip feldspars are commonly kaolinized. In Africa there are small amounts of copper on the up dip side, near the outcrop. Core assays from the literature show variations of .01-.1% Cu throughout so called barren up dip sections of African deposits.

It appears that to find such ore bodies, one should first determine that the desired metal is present in the section and is widespread in small amounts. Sedimentary and structural patterns should indicate that host units are thick enough to contain ore tonnages. In addition, the lenticularity of bedding and anticlinal closures affecting hydraulic flow, in addition to traps for hydrocarbons, are important considerations. Finally, carbon and/or sulfur in quantity is no doubt mandatory.

Copper or uranium ores occur between down dip pyrite and up dip iron oxides in the same horizon, at an oxidation-reduction interface. Garlick strongly emphasizes this important fact, and regards the discovery of down dip pyrite in a drill hole as the first step leading toward discovery of an African copper ore body.

Highest grades of uranium, or of copper in a porphyry copper chalcocite blanket, or of bedded chalcocite at Mufulira, are just beyond the redox interface, on the reduced side.

Precise mineral zoning in uranium is a well-known control of ore. Zoning in many stratiform coppers is just as important, with chalcocite-bornite-chalcopyrite-pyrite the standard metallogenic sequence as penetration into the reduced zone is gained . If lead or zinc is in the system, the system goes chalcocite-bornite-chalcopyrite-pyrite and galena-sphalerite-pyrite.

This characteristic zoning is a function of available sulfur and available copper ions being transported into the barrier, and the solubility products of copper sulfides, the most insoluble precipitating first in a sulfur limited system. Zoning or replacement of other minerals is also common.

In descriptions of African deposits, the old shoreline is defined on the basis of changes in lithology. Zoning of copper minerals is then related to spatial position from the ancient shoreline. Apparently this is another way of saying copper mineral zoning is related to lithology, or lithologic change, and is downdip from the shoreline. In these literature claimed syngenetic deposits,

Garlick states, "Detrital deposition of sulfides, as the major process, must therefore be rejected." Garlick believes that copper precipitates from marine water as some undefined "copper sulphide."

After precipitation of this sulphide, it is then converted "during diagenesis and metamorphism" into "the sulphide minerals now observed in the general arrangement-chalcocite, bornite, chalcopyrite, and pyrite." "Iron sulphide subsequently combined with the copper sulphide, present in the sediments, to form bornite or chalcopyrite."

It seems to me that such mineral combination, and chemical conversion, necessarily requires movement and a chemical system similar to the system operating in the epigenetic deposits. The only significant point of dispute is the source of the copper ion, marine water, or ground water. Even here, Garlick states, "all evidence points to streams in an arid environment transporting--specifically metals in solution to the acqueous repositories." Streams are part of the ground water regimen, and transporting copper in ground water to a reducing zone rather than in surface streams avoids dilution of small amounts of copper with the detrital load also brought to the acqueous repository by the same copper bearing stream. The zoning sequence chalcocite-bornite-chalcopyrite-pyrite is accomplished at the time of copper deposition from ground water, rather than in an undefined manner and time during diagenesis and metamorphism.

Bleaching and leaching of copper bearing strata are pronounced in the US, and commonly occur in Africa. However, this fact is sometimes obscure in literature descriptions, as at White Pine, where chloritization is the more common feature.

Bleaching with characteristic color zoning, pervasive permeability, silicification, etc., can be evident in Mississippi Valley deposits. Thin sulfide tails, the haloes of dispersed metal values, are common features adjacent to Mississippi Valley ore. Metal zoning and position location around reducing centers deep within a basin, however, are difficult to predict and locate, although there is local correlation with upwarp such as domes, anticlines, etc.

Regardless of genetic theory, known stratiform copper ore bodies occur as follows: in sedimentary basins known to contain sub-ore grade copper bearing beds; are in an oscillating (cyclic) sedimentary sequence with copper concentrated at an interface between water lain and continental beds, or beds of two different permeabilities; are in permeable clastic rocks such as arkoses and sandstones; or in less permeable rocks such as shales at the contact with the permeable beds; are associated with disseminated organic material; may show a spatial relationship to uranium, vanadium, molybdenum, zinc, and lead in the same beds; and show many other characteristic similarities.

Regardless of the indirect source of the copper ions (from ocean waters or formation waters), copper mineralogy is exactly controlled by the solubility

of particular metalliferous minerals, and the existing copper minerals can be read to define the oxidation-reduction state of the copper bearing beds.

It follows that to find stratibound copper ore, the exploration geologist should determine that host rocks are known to contain copper and have enough spatial volume to bear ore in sufficient tonnages; determine structural patterns; determine the amount and variation of carbon, permeability, etc.; test by drilling to locate the position of the oxidation-reduction interface, and/or determine location within the reduced zone; and test laterally along or within this zone for the desired favorable mineralized lithology and structure.

If it is feasible to search for laterally limited porphyry coppers (or their characteristic haloes) below post mineral cover, it is also feasible to search for stratiform coppers or (their characteristic alteration haloes) below younger sediments.

BIBLIOGRAPHY

1. Perel'man, Aleksandr Il'ich, "Geochemistry of Epigenesis," Academy of Sciences, USSR, Nedra, Moscow, 1965. Translated, N.N. Kohanowski, Dept. of Geol, Univ. of N. Dak.; Plenum Press, N.Y., N.Y., 1967.

2. Ridge, John D., Editor, "Ore Deposits of the United States, Vol I and Vol II, AIME, New York, 1968.

3. Brown, J.S., Editor, Monograph 3, "Genesis of Stratiform Lead-Zinc-Barite-Fluorite Deposits," Economic Geology, 1967, Lancaster Press, Lancaster, Penn.

4. James, Clifford J., Editor, "Sedimentary Ores, Ancient and Modern (Revised)," Spec, Pub. #1, Dept. of Geol., Univ. of Leicester, 1969.

5. Nicolini, P. and Lombard, J., Editor, "Stratiform Copper Deposits in Africa," Vol 1 and Vol 2, Lithology, Sedimentology, and tectonics, Symposium, Association of African Geological Surveys, Paris, 1963.

6. Memoir 15, "Geology and Technology of the Grants Uranium Region." State Bureau of Mines and Mineral Resources, 1963, Socorro, New Mexico.

7. Economic Geology, Vol 66, #5, August, 1971, Symposium. "A Paleoaquifer and its Relation to Economic Mineral Deposits. The Lower Ordivician Kingsport Formation and Mascot Dolomite," 1971, Lancaster Press, Lancaster, Penn.

8. Emmons, W.H. "The Principles of Economic Geology," 2nd Edition, McGraw-Hill, New York, 1940, pp. 324-325; 335-342.

9. Bateman, A.M., Editor, "Fiftieth Anniversary Volume, Economic Geology," 1955, Lancaster Press, Lancaster Penn.

   Part I. Anderson, Charles A., "Oxidation of Copper Sulphides and Secondary Sulphide Enrichment," pp. 324-340.

   Krauskopf, Konrad B., "Sedimentary Deposits of Rare Metals," pp. 411-436.

   Part II. Levorsen, A.I., "Time of Petroleum Accumulation," pp. 748-746.

   Ellison, Samuel P. "Economic Applications of Paleoecology."

10. Panel Proceedings, "Uranium Exploration Geology," IAEA, Vienna, 1970.

11. Lindgren, W., and others. "The Ore Deposits of New Mexico," PP 68, 1910.

12. Butler, B.S., and others. "The Ore Deposits of Utah," PP III, 1920.

H. J. Countnight

GOSSANS

A paper to be given to the Exploration Department Conference, December 1971, by H.C. Williamson.

Gossan consists of ferric oxide jasper, quartz and manganese dioxide (McKinstry) and in Australia is usually the weathering product of paleoclimates. Extensive areas of the Precambrian rocks exposed in Australia have been under the influence of sub-aerial erosion since the Cambrian. Further, the Phanerozoic rocks have been subjected to the variable climatic conditions of the Tertiary, causing extensive deep supergene weathering and surface silicification of the Tertiary surface. Except for an isolated area around Kosciusko and parts of Tasmania, Australia was not subjected to the glacial conditions of the Pleistocene. Remnants of the deeply-leached Tertiary surface still exist in many parts of the continent, especially where erosional activities were minimal during the Quaternary. Thus a preponderance of weathered, oxidised and bleached rocks and laterites of Fe, Mn, Si and other oxides cover large tracts of Australia.

The field geologist is continually required to identify leached rocks and distinguish between gossans, ironstone scree and laterites. The techniques available to the geologist to discriminate between gossans, ironstone scree and laterites have been rapidly advanced in the last few years by various geologists working in Western Australia.

This paper discusses some of these advances aimed particularly at discriminating between significant gossans (i.e. base metal gossans) and non-significant gossans, and how these techniques can be applied within a geologic framework improving target selection. The methods discussed are applicable to all leached environments.

HISTORICAL

The development of the majority of the base metal mines in Australia was the result of prospectors testing gossans - usually for gold. Often sufficient work was undertaken by the prospectors to reveal the base metal sulphides at and below the water table. Examples: Cobar (Au Cu) 1868, Mt. Morgan (Au) 1882, Broken Hill (Ag Pb) 1884, Mt. Lyell (Au) 1883 and Mt. Isa (Pb) 1923. The prospectors in their long and widespread search for gold dollied and panned any unusual rock outcrop and using the panning dish "loamed" (or soil sampled the surface) for gold.

In the initial stages, the prospectors were drawn to testing gossans because they recognised the following features but often did not recognise the origin of the gossan:

(1) The nature of the gossan and its anomalous mineral content. The usual anomalous mineral was gold - which concentrates by residual leaching (Mt. Morgan).

(2) The outcrop character and colour anomaly of gossans.

SLIDE 1 - Trace Elements in Gossans from some Australian Mines. (Table 1)

SLIDES 2-6 - Slides of outcrop and gossan close-ups of Broken Hill, Peko, Mt. Isa, Iron King.

TABLE 1: TRACE ELEMENTS IN GOSSANS FROM SOME AUSTRALIAN MINES

LOCATION OF GOSSAN	Ni	Cu	Pb	Zn	Ag	Bi	Te
Comstaff, Mt. Lyell	40	1450	2700	2100	15	300	-
Blow, Mt. Lyell	-	1080	2700	7600	47	1500	112
Peko	60	3050	4400	1950	9	300	0.26
Peko	40	1900	2300	330	1	400	-
Nobles Nob	20	150	330	80	1	1300	-
Mt. Isa at -50'	10	180	7000	710	45	300	-
Cobar, C.S.A. Mine	40	4500	6900	530	5	2600	ND
Cobar, C.S.A. Mine	10	9250	3820	300	2	1100	ND
Broken Hill	10	2950	12.5%	1700	650	400	ND
Iron King	100	600	40	200	-	-	6.2

Results in ppm except where specified

ND - not detected

The initial rush of discoveries in Australia ended with Mt. Isa and no major new discoveries of base metal were brought into production until Kambalda in 1968. It is interesting to note that although Australia has enjoyed a mineral boom from the early 1960's, this boom started with the development of the residual and leached deposits - bauxite (Weipa, Jarrahdale, Gove, Mitchell Plateau), iron ore (Hamersley Range), manganese (Groote Eylandt), beach sands - each the product of our distinct weathering pattern.

GOSSAN GEOCHEMISTRY

The search for base metals in Australia was given new stimulus with the recognition that the silicified ironstones at Kambalda were gossans representing nickel-copper sulphides. Bob Gray will be dealing with the normal geochemistry of nickel-copper gossans. At this stage I wish to mention other elements (Te, Se, Pt, Pd, Au) that have been used by geologists in an endeavour to differentiate significant nickel gossans from non-significant gossans, ironstones and laterites. Similar pathfinder elements could be used to discriminate significant gossans and leached caps elsewhere. There is not a great deal of published information on the trace element content of leached caps over porphyry coppers but the following table from some random examples given to me by Dave Fletcher and Burt Devere is of interest as it illustrates that in addition to molybdenum, selenium may be suitable as a pathfinder element. Other elements that may be worthwhile examining are Sn, W, Hg, F. (Climax produce Sn and W, Urad report Sn and W.)

SLIDE 8 - Table 10: Metal Content of Some Leached Caps

TABLE 10: METAL CONTENT OF SOME LEACHED CAPS

LOCATION	DESCRIPTION	Cu	Pb	Zn	As	Te	Se	Mo
Quellaveco	Oxidised capping	410	20	10	ND	ND	6.1	190
Michiquillay	At L-18	335	15	10	ND	ND	6.1	<3
Cuajone	Leached capping	570	15	10	10	.26	2.2	230
Esperanza	Leached capping	1100	15	40	5	.80	7.2	250
La Caridad	Leached capping	80	25	60	60	2.2	5.4	12
Berkley Pit	Leached capping	305	205	70	80	3.1	ND	8
Silver Bell	Leached capping	375	710	15	5	0.96	2.4	135
Pillars	Leached capping	265	400	75	<5	ND	ND	15
Anabama	Leached capping	100	-	-	-	-	-	10
Frances Young	Chalcopyrite texture	1.1%	55	50	200	0.43	15.0	3

Results in ppm except where specified

ND - not detected

Pathfinder ~~T~~race elements in gossans are only of value in discrimination if the method used for their detection is relatively cheap, is sensitive at very low concentrations and is reasonably precise. One company collaborating with the CSIRO developed in the mid-1960's a method of Te determination which satisfied these conditions (sensitive to 0.02 ppm). The intention was to use the method to find if a Te halo existed about the Golden Mile at Kalgoorlie so that a better interpretation could be made of a deep (up to 9,000') drill program for a repetition of the Golden Mile south of Kalgoorlie. The survey was postponed because of the diversion of exploration effort from gold to nickel. However, Te assays were made on some Kambalda gossans before drilling started, helping to confirm that the gossans were derived from base metal sulphides.

Assay information on the tellurium content of some suspected gossans is shown on Table 2. Base metal sulphides have been confirmed below seven of the gossans listed. From this table of results we see that the ratio of the number of gossans representing base metal sulphides to the number of gossans representing iron sulphides increases as the Te content increases:

Range of Te	Ratio of Success
At ND - 0.05 ppm	ZERO
0.05 - 0.20 ppm	ZERO
0.20 - 0.80 ppm	1:2
0.80 - 3.20 ppm	3:4
>3.2	2:3

The Te content of some nickel sulphides is shown in Table 3.

SLIDES 9 & 10 - Tables 2 and 3 respectively.

TABLE 2: Te CONTENT OF SUSPECTED GOSSANS FROM THE EASTERN GOLDFIELDS OF WESTERN AUSTRALIA

ND - 0.05	0.05 - 0.2	0.2 - 0.8	0.8 - 3.2	>3.2
Determination	Linger & Die	Fair Adelaide	Lunnon*	Diemals*
North Black Rabbit	Golden Bounty	Cave Hill	Scotia*	Marshall's Pool*
Wellington	Grossmont	Durkin*	Tramways*	Iron King
Kintore	Kintore	Jan*	1008*	
1631	SH14+			
SM1+	SH14+			
SM2+	SM31+			
SM87+				
SM88+				

\+ Ni laterites with anomalous Cu values

* Gossans after base metal sulphides

ND Not detected

Results in ppm

TABLE 3: Te RESULTS FROM NICKEL SULPHIDE ORES OF WESTERN AUSTRALIA

LOCATION	Te	Ni	Cu
Scotia secondary ore	1.4	2.15%	1550
107 sulphides	4.64	12%	6030
107 sulphides	1.5	2.3%	4300
Kambalda - Lunnon	6.5	7.0%	5100

Results in ppm except where specified

It is well-known that Pt, Pd, ~~etc.~~ group are associated with nickel-copper sulphides in ultrabasics. Methods for the geochemical determination of Pt and Pd have been under active investigation in Australia since the nickel boom started as routine methods for assaying were not available. The laboratories assure us that they have now developed satisfactory methods. A two-day symposium was recently held at the Melbourne University on the subject of "Platinum Metals: Economic Geology and Geochemistry". The information to be shown in the following two slides is edited from a paper delivered by Keays at the symposium entitled "Precious Metal Fractionation and Implication for Ore Genesis and Exploration for Nickel Sulphide Ore". Unfortunately Keays included little information on Pt in his paper as the method of analysis used by Keays - neutron activation - is not sensitive for Pt determination at low levels of concentration. Further, the lack of information on the location of the specimens is disappointing.

SLIDE 11 - Table 4

Comments on table - by Keays:

(1) Relatively very high Au and Pd content in the ccp stringer and the low Ir content. The high Pd and Au content reflects the fact that these two elements remain relatively mobile during differentiation of a sulphide melt.

(2) Erratic pattern of Au distribution and its general low level abundance relative to the Pt group.

(3) The nickel gossans appear to be enriched in Au, Ir and Pd compared to non-significant gossans.

SLIDE 12 - Table 5

TABLE 4: CONCENTRATION OF NOBLE METALS IN SULPHIDE AND GOSSAN SAMPLES FROM WESTERN AUSTRALIA (From Keays)

DEPOSIT	DESCRIPTION	Au (ppb)	Pd (ppb)	Ir (ppb)	Cu (%)	Co (%)
A	Disseminated sulphide	70	717	86	0.11	0.15
A	Massive sulphide	84	1870	89	0.13	0.07
A	Massive sulphide	14	1020	170	0.066	0.075
A	Chalcopyrite stringer	2500	17600	-	15.8	0.01
A	Gossan	130	72.7	130	-	-
B	Massive sulphide	34	1500	170	0.91	0.30
B	Gossan	100	3580	1900	0.82	0.17
C	Massive sulphide	97	2300	1150	0.54	0.33
C	Massive sulphide	160	2400	1030	0.52	0.32
C	Gossan	4.9	112	270	0.096	0.016
D	Disseminated sulphide	300	145	22	1.67	0.067
D	Gossan	1.9	147	1900	2.9	0.094
E	Gossan	44	698	150	-	-
F	Gossan	140	759	160	-	-
F	Gossan	0.92	66	10	-	-
A	Host Rock U.G	7.0	5.	2	—	—

TABLE 5: CONCENTRATION OF NOBLE METALS IN NON-NICKELIFEROUS GOSSANS AND ULTRAMAFIC ROCKS, WESTERN AUSTRALIA (From Keays)

SAMPLE TYPE	Au (ppb)	Pd (ppb)	Ir (ppb)
Gossans			
Massive iron sulphide	240	7.0	1.2
Lateritized Serpentinite	28	46	0.9
Basic and Ultrabasic Rocks			
Peridotite	1.5	-	3.4
Pyroxenite	2.0	-	3.0
Pyroxenite	0.75	-	3.1
Pyroxenite	1.1	-	0.89
Peridotite A.	7.0	5.0	2.0

(4) It is suggested by Keays that Ir would be a more useful discriminator than Pd.

(5) It is stated by Keays that Pd/Pt ratio is relatively constant when compared to Pd/Ir ratios. Let us look at Pd/Pt ratios we have obtained from our work:

LOCATION	DESCRIPTION	Pt	Pd	Pd/Pt
Kambalda	Massive sulphides	0.20	0.10	0.50
Kambalda	Hematitic gossan	0.40	0.51	1.28
Mt. Clifford	Hematitic gossan	0.32	0.12	0.38
Mt. Clifford	Silicified gossan	1.45	2.75	1.89
Widgiemooltha	Gossan	0.57	2.63	4.61
Widgiemooltha	Gossan	1.24	2.03	1.51
Redross	Gossan	1.10	0.21	0.19
Poseidon	Gossan	0.76	0.40	0.53
Springvale	Gossan	0.24	2.53	10.54
Scotia	Gossan	0.36	0.26	0.72

Results in ppm

1 ppm = 0.6 dwt/ton
1 ppm = 0.029 oz/short ton

TEXTURAL FEATURES OF GOSSAN

The macroscopic studies of gossans and leached caps by Locke, Blanchard and others is well-known. Blanchard did not consider gossan geochemistry as an aid to gossan appraisal (Preface - Blanchard) but as we have seen, it is an important indicator available to the exploration geologist to assist him in his interpretation of gossans. Recent work by Guy Travis has shown that microscopic studies of polished sections of gossans can be used to identify textures of original sulphides preserved in the gossan by silica and goethite replacement. Often the textures seen in microscopic studies are replicas of the macro-textures described by Blanchard. Good textural evidence of pre-existing sulphides in a gossan adds confirming evidence to the geochemical results and overcomes problems in interpretation caused by high assays due to scavenging effects of Mn, etc. or

TABLE 6: COMPARISON OF HEMATITIC AND SILICIFIED GOSSANS FROM WESTERN AUSTRALIA

LOCATION	DESCRIPTION	Ni	Cu	Pb	Zn	Co	Mn
Mt. Clifford, 1008	Silicified	130	50	-	40	-	-
Mt. Clifford, 1008	Fe-rich	3400	1150	-	30		
Scotia	Hematitic	8000	880	40	80	160	80
Scotia	Silicified	1800	450	20	35	60	50
Kambalda, Durkin	Silicified	740	300	10	100	25	160
Kambalda, Durkin	Ironstone	1.5%	8800	10	35	620	300
Kambalda, Lunnon	Silicified	390	540	30	20	40	40
Kambalda, Lunnon	Hematitic	3300	3100	150	35	260	60
St. Ives, Jan	Silicified	700	3200	30	10	50	50
St. Ives, Jan	Ironstone	3400	1700	50	30	110	260
St. Ives, Jan	Ironstone	8000	3400	80	410	360	110

Results in ppm except where specified

low assays due to excessive leachings.

SLIDE 13 - Table 6

Petrographers recognise that the very leached silicified gossans have preserved the easiest recognised microtextures.

It should be realised that the gossans can reflect pseudomorphs of both the supergene and primary sulphides. The diagrams from Woodall and Travis' paper illustrate the variation of the mineralogy from primary ore to gossan at Kambalda. The paper discusses and illustrates the changes that occur in the various zones.

SLIDE 14 - Fig. 7 after Woodall and Travis.

With this background, we will study the microtextures of sulphides and gossans from Western Australian nickel deposits.

Travis (personal communication, 1969) illustrated how key textures are preserved in surface gossans with the following photomocrographs:

SLIDES 15A, 15B, 15C, 15D - Examples of Kambalda Gossans.

SLIDES 15-18 - Photomocrographs of Ni Gossans and Sulphides.

Some petrologists prefer to use thin sections of gossans and leached rocks as a means of appraisal. The method is suitable for gossans containing minerals which can be identified in transmitted light, but it is difficult to recognise any relict textural features in goethite and silica under transmitted light. However in the case of some lead-zinc gossans, minerals like cerussite and smithsonite and the "bedded" textural features can be seen under transmitted light.

SLIDE 20 - Example 23021 by H.W. Fander.

Often the characteristic textural features of rocks are preserved even though the rock is highly leached and silicified.

SLIDE 2D - Example 43581 by H.W. Fander.

It is interesting to note that two companies in Western Australia have petrographers working almost exclusively on gossan identification. Several petrological consultants are also using the technique. It is obvious that a group who uses geochemistry and textural studies as aids to gossan interpretation has a distinct advantage in the surface assessment of ground.

THE ELECTRON MICROPROBE AND GOSSAN IDENTIFICATION

The electron microprobe can determine the areal concentration and distribution of elements in a rock specimen and the textural relationship of the minerals present in a defined area. This information can be photographically recorded as scan diagrams of element distributions and the textural features can be illustrated as back scatter diagrams. The electron microprobe with attached optical microscope allows optical examination of identical areas simultaneously with microprobe examination. Thus the two features we have been discussing can be combined in an ideal way.

The Company's instrument at Plainfield was recently used to study secondary sulphides from our Yindi prospect in Western Australia. The study determined:

(a) the minerals present,

(b) the distribution of Ni, Co, Cu, etc., in the minerals present.

The elemental distribution in the minerals under study is shown on the electron microprobe area scans.

Uncorrected random pt qualitative electron microprobe analysis showed the violarite to be a nickel-rich variety with nickel slightly higher in vi from 4282 than in 4283. The nickel-cobalt distribution in the various minerals as estimated by Plainfield is set out below:

Sample No. 4282

Mineral	Estimated % Ni present
Pyrite	1-2%
Chlorite	0.5-2%
Hornblend	MNP
Siderite	ND

	Estimated % Co present
Violarite	1%
Pyrite	ND
ccp	ND
Magnetite	ND

Sample No. 4283

Mineral	Estimated % Ni present
Pyrite	1-2%
Chlorite	MNP
Hornblend	0.1%
Siderite	0.1%

	Estimated % Co present
Violarite	0.5%
Pyrite	ND
ccp	-
Magnetite	-

MNP - mineral not present in specimen
ND - not detected

Sample No.	Hole No.	At	From	To	Ni	Cu
4282	YDD 2	269.3'	269.1	270.0	1.55%	0.23%
4283	YDD 2	273.0'	272.5	273.6	1.55%	0.25%

Photomicrographs and electron microprobe area scans for various elements from the above samples are illustrated on Slides ~~24-1 to 24-7~~. 21 to 27. (See report by Central Research, Plainfield.)

The electron probe is being used by the CSIRO in a confidential study of Western Australian gossans. The work ~~at~~ on Yindi suggests that the method will lead to an improved understanding of element distribution in gossans and identification of remnant textures.

APPLICATION OF METHODS DISCUSSED

(1) W.A. Nickel-Copper Gossans

SLIDES ~~25 - Table 7~~ 28-29 WINDARRA Example

The tables below list all the gossans known to us which have a combination of good geochemical characteristics and microtextures of Ni-Cu sulphides known to be derived from underlying sulphides. The information suggests that if such a gossan is located then there is a fifty-fifty chance that a mineable deposit will be found.

SLIDES ~~26 & 27 - Windarra-Poseidon Gossan~~ 30

On statistical evidence, our Yindi prospect looks exciting and warrants continued effort in this environment.

The following ore positions - Kingston, Mt. Keith, Yackabindie, Boundary and possibly Agnew (history of discovery not known) - were found as the result of intensive pattern drilling of a concealed ultrabasic horizon following the recognition of nickel sulphides in a few percussion holes put down by ranchers (pastoralists) to test ultramafics found in water wells and outlined by a BMR survey.

The history of the discovery of nickel sulphides of the following prospects is not known:

Bamboo Creek, Ruth's Well, Soansville, Ravensthorpe, Boutcher's, Walpole.

TABLE 7: RESULTS OF TESTING NICKEL-COPPER GOSSANS IN WESTERN AUSTRALIA

NAME OF HOST ROCK	GOSSAN CAPPING MINEABLE ORE	NON-OUTCROPPING ORE BODIES WITHIN HOST ROCK	GOSSANS REPRESENTING SQUIB ORE POSITIONS
Widgiemooltha Ultramafic	Widgie 2 Wannaway Redross Widgie 1 Dordie Rocks		Widgie 6
Spargoville Ultramafic	Spargoville 1 Spargoville 2 Spargoville 3		Spargoville 5A Spargoville 5Q
Pioneer Ultramafic			Pioneer 1 Pioneer 3
Windarra Ultramafic	Shirley B Shoot E Shoot	D Shoot C Shoot Union-Hanna-Homestake	Discovery
Ennuin Ultramafic			Trough Well
Mt. Monger Ultramafic			Mt. Monger
Mt. Martin Ultramafic			Mt. Martin
Alice Downs Ultramafic			Springvale
Hannans Lake Serpentinite	Lunnon Durkin Juan McMahon Fisher	Hunt Otter West Juan Gellatly	Area 1
Cooee Ultramafic		Foster	Battery Cooee N.W.
Torquata Ultramafic	Jan		
Tramways Ultramafic	Edwin		John Ham Tramways N.E.
Mt. Clifford Ultramafic	Marriott		107
Marshall Ultramafic			Marriott 2
Wildara Ultramafic			1718
Jimberlana Norite			Bronzite
Broad Arrow Ultramafic	Scotia		

TABLE 8: SUSPECTED GOSSANS IN LATERITE

LOCATION	Ni	Cu	Co	As	Te	Pb	Zn
Cave Hill	1770	185	170	178	<0.08	10	60
Cave Hill	1060	185	130	98	<0.08	20	120
Determination	1.07%	630	4100	2000	<0.05	NA	NA
Wellington	1340	300	NA	NA	<0.05	NA	NA
Fair Adelaide	1540	1760	NA	98	<0.20	NA	NA
Queen Victoria	1080	310	65	95	-	50	330
Queen Victoria	3300	150	180	25	-	40	170
Queen Victoria	8000	670	560	15	-	10	3700
1008	3400	1150	-	ND	>0.80	-	30

Results in ppm except where specified

NA - not assayed

ND - not detected

TABLE 9: METAL CONTENT OF SOME AUSTRALIAN GOSSANS

LOCATION	DESCRIPTION	Cu	Pb	Zn	Te	Se
Two Peaks	Ironstone	1700	120	1.2%	-	-
Two Peaks	Ironstone	3000	2.2%	180	-	-
Ilmars	Vuggy	1040	60	1.0%	-	-
Ilmars	Silicified	55	80	560	-	-
Ilmars	Vuggy hematitic	10	10	9000	-	-
Napier Down	Gossan	3700	7.7%	16.0%	-	-
Napier Down	Gossan	6.0%	10.3%	3.9%	-	-
Copper Gorge	Cellular	70	800	66	0.35	8.0
Andamooka	Limestone	5000	470	140	0.73	3.6
Captain's Flat	Gossan	950	4550	430	-	150
Woodlawn	Gossan	6500	>1.0%	4400	-	200
Woodlawn	Gossan	5300	7050	4700	-	50
Woodlawn	Gossan	8500	>1.0%	2200	-	200
Iron King	Limonite	100	40	200	6.2	-
Metawandy	Banded limonite	1400	80	740	-	-

Results in ppm except where specified

It must be appreciated that our information is incomplete on the occurrence of nickel gossans as often large corporations do not reveal the location of significant gossans which do not cap ore because this may prejudice their future position. Several cases are known of gossans under which no supergene or primary sulphide ore was found after extensive drilling. In some cases the gossan was lateritised with good geochemistry and in such cases textural features are rarely seen. Known significant gossans without nickel sulphide roots are: Mt. Newman, 1008, Hudson, Kurnalpi, Gilgarna Rocks, Fly Bore, Black Rabbit, Black Rabbit North, Linger and Die, Goongarrie and Queen Victoria. The first three are significant gossans with good textural features. The remainder are gossans in a lateritic environment. In all cases the gossans listed were found in ideal geological settings. The geochemistry of some of these gossans is shown on Table 8.

SLIDE ~~28~~ 31 - Table 8

(2) Other Gossans Recently Tested in Australia

It is interesting to review the results of some exploration excluding nickel since the Mt. Isa discovery. In all cases a gossan discovery has played an important role. The best example is the recent Woodlawn discovery. (Details of Woodlawn from DMF notes.) Not all gossans tested have responded like Woodlawn, as the table below illustrates.

SLIDE ~~29~~ 32 - Table 9

SLIDES ~~30 & 31~~ 33-34 - Some Examples of Gossans in Slide 29.

SUMMARY

As Bob Gray will point out, the universal method of gossan appraisal in Western Australia is by the use of metal concentrations and metal ratios. The combination of the use of microscopic textural studies and geochemistry is being used by a small but increasing number of people. The limitations appear to be that if good textures are not preserved in a gossan, then the petrographer has difficulty in relating gossan textures to supergene and primary sulphide texture. As the petrographer gains experience, so also will his interpretative ability improve. The persistance of some petrographers in relying on thin section studies is disappointing as the gossan textures can best be studied in reflected light with a polished section and the textures easily related to textures seen under reflected light from a sulphide. The study of gossans by electron microprobe in combination with the other two methods will improve our ability to identify the type of pre-existing sulphide in a gossan thus discriminating between significant and non-significant gossans.

Asarco, with its electron probe microscope, is in an ideal position to take advantage of the suggested approaches and gain a lead over our competitors.

HCWilliamson

H.C. Williamson

November 22, 1971.

GEOCHEMICAL INDICATORS FOR W.A. NICKEL SULPHIDE DEPOSITS

By R.S. Gray

The abstract which you have all seen contains some "rules of thumb" which we have been using for two years. Credit for developing these rules does not belong to me. Other companies are using similar rules. Much of the original information was obtained by Peter Walker through discussions with field geologists at Widgiemooltha, Scotia and Windarra.

The importance of these geochemical indicators is that an understanding is required in order to follow our nickel search program in W.A.

Perhaps the best place to begin is with the base metal content of fresh rocks, so we have some idea what was present before weathering took place.

(Slide 1: Base Metal Content of Rocks)

Nickel, chromium and cobalt are substantially higher in ultramafic rocks than in any other common rocks. In soil-covered areas, geochemical sampling for Ni and Cr can outline the extent of an ultramafic body very effectively.

Copper and zinc content of ultramafic rocks is low, compared to the most common wall rocks.

The next slide shows base metal content of various subdivisions of ultramafic rocks.

(Slide 2: Base Metal Content - Ultramafic Rocks)

Periodotite and dunite are both quite high in nickel. Pyroxenite is considerably lower in nickel, but still higher than gabbro.

The process of serpentinization does not appear to have any significant effect on total nickel content. The products of serpentinization show a marked variation in the distribution of nickel, with a large percentage of Ni and Co values becoming tied up with magnetite, lower values with serpentine, and very low values with actinolite.

The process of steatization (talc-carbonate alteration) appears to reduce total nickel and cobalt content. Cobalt and nickel leave the system, probably as bicarbonate solutions. What happens to this Ni and Co, I do not know, but it may be available to combine with sulphur from barren sulphides in the wallrocks. Most of the nickel that remains becomes concentrated in the talc minerals. Ni Co content of the carbonate and chlorite is very low.

An unpublished G.S.C. paper by Cameron, Sidley and Durham discusses results of fresh-rock samples collected from 61 ultramafic bodies in Canada. Sulphur was determined by combustion methods, and Cu Co and Ni were determined by atomic absorption following ascorbic acid-hydrogen peroxide leach. This method is designed to extract the metals present as sulphide, without attacking the metals present in the silicate minerals.

(Slide 3: Fresh Rock-Base Metals Present at Sulphide)

Barren ultramafics are those with only minor traces of sulphides. Minore ultramafics contain small deposits or significant showings of Ni-Cu sulphides. Ore ultramafics have moderate to large Ni-Cu sulphide deposits associated with them. In all cases, the material assayed is well removed from the vicinity of sulphide deposits.

Copper and sulphur show much higher concentrations in ultramafics associated with deposits. Statistical studies of the data reveal that Cu and S can be used to separate ore-bearing from unmineralized intrusives, and that no improvement to the statistical accuracy can be made by considering Ni Co Cu and S. This may not be too obvious in the table, because only mean values are shown. The standard deviations for Ni and Co are very large, whereas the standard deviations for Cu and S are relatively low. The authors have selected the following arbitrary values which few barren ultramafics exceed, but which a substantial portion of ore-bearing ultramafics exceed:

Ni	Cu	Co	S(%)
1780	100	158	.178

It would appear that, when dealing with fresh ultramafic rocks, analyses of grab samples for Cu and S would indicate whether the intrusive was favourable for Ni-Cu sulphide deposits. In weathered rocks, sulphur

cannot be used, but copper retains its important role as an indicator.

So far, we have been dealing with geochemistry of fresh ultramafics. Now let us turn to the weathering process.

During the Tertiary, Australia was hot and wet, probably with pronounced rainy and dry seasons. This produced lateritic weathering, with removal of silica, sodium, calcium and magnesium, and residual concentration of aluminium and iron oxides. From Pleistocene to Recent, drier conditions have prevailed, with desert weathering conditions, and some mechanical erosion of the laterite profile.

The behaviour of nickel under lateritic conditions is shown on the following slide:

(Slide 4: Nickel in Lateritic Profile)

The removal of silica and magnesium leaves behind residual concentrations high in iron oxides. Some nickel substitutes for iron in the crystal lattice of the limonites, up to a theoretical maximum of about 2% Ni. A larger part of the nickel is taken into solution and migrates towards the water table, where reaction with magnesia and silica in groundwater precipitates magnesium silicates with varying proportions of nickel. The clay minerals are seldom cleanly leached of nickel, and some soluble nickel ions are adsorbed on the clay, producing a peak about two thirds of the way down the profile.

Basicly there is a net impoverishment in nickel in the upper part of the profile, excluding the limonite caprock, and enrichment in nickel towards the base. The clays formed by weathering of serpentinite or dunite are often fairly impermeable, so that a water table is not well defined. Assays in excess of 1% Ni are not infrequent in the limonite cap rock, and are sometimes found where gaspeite or nickeliferous magnesite are developed in local impermeable zones or are stabilized by reaction with the enclosing wall rocks. Nickeliferous magnesium silicates can cause assays over 1% in percussion drill samples. Thus, values ranging from less than 1000 ppm Ni to over 1% Ni can be expected in the weathered zone, whether or not the parent material contains sulphides.

Cobalt follows a similar pattern to nickel, with one pronounced concentration in the limonite zone, and another peak about two thirds of the way down the profile.

Chromium is relatively insoluble, and shows a similar pattern to iron. The concentration is greatest at surface, and gradually drops off with increasing depth. However, the original chromium content of ultramafic rocks tends to be quite variable, creating erratic concentrations in the weathered zone. Generally, Cr. content will exceed 1000 ppm, with erratic values over 1%. No relationship between chromium and nickel sulphides has been established, so it is useless as an indicator of mineralization.

Copper tends to become stabilized in place, rather than being leached. The weathered zone usually shows some concentration due to shrinkage in volume. Although nickel sulphide gossans seldom contain visible copper oxides or carbonates, assays are generally several times higher than in the protore. Background copper values in weathered ultramafics are usually less than 50 ppm, although some ultramafics containing ore deposits show backgrounds of 100 ppm or more. Analysis of results from several thousand auger drill holes at Windarra is reported to show average values of 125 ppm Cu. Anomalous values which warrant further follow-up are those which exceed 285 ppm Cu, which is the mean plus two standard deviations. Values of this order of magnitude are very significant in ultramafic rocks, but are not substantially higher than those frequently found in weathered gabbro, basalt and shale. We are usually prospecting along ultramafic contacts, and there is frequently mixing of geochemical values from the adjoining rock types. A soil sample may contain nickel derived from underlying ultramafics, along with copper derived from adjoining basic volcanics. Zinc proves very useful in sorting these samples from valid anomalies.

(Slide 5: Base Metal Content of Rocks)

Zinc content of ultramafic rocks is very low, seldom exceeding 100 ppm. Basalt, gabbro, shale and banded iron formation are the most common rock-types found in contact with the W.A. serpentinites. All of these rocks usually show higher Zn values in the weathered zone. Thus a copper anomaly with low zinc is considered much more favourable than a Cu Zn anomaly.

Although I have stated a number of figures in parts per million, it is preferable to avoid absolute quantities, because these vary substantially from area to area. One factor which complicates the picture is the collection properties of manganese. Mn tends to absorb other metal ions such as Ni, Co, Cu and Zn. Manganese

is not often present in significant quantities in ultramafic rocks, but when present, it tends to concentrate in the limonitic iron cap. Co and Zn appear to have the greatest affinity for manganese, and tend to show a higher degree of concentration than Cu or Ni. Field experience suggests that whenever Cu and Co are both anomalous, but Co exceeds Cu, a check for Mn is justified. Manganese values in excess of 1% are regarded as sufficient explanation for Co-Cu concentrations in the order of 400 to 800 ppm.

Another effect which I have not mentioned previously is the transpiration effect. During the winter rainy season, the weathered rocks retain moisture. In the hot dry summer season, this moisture is drawn up to surface by capillary action. Metallic salts in the solution are redeposited in the top two or three feet where the water evaporates. This affects all soluble metal salts, but is particularly noticeable in copper. Values in the top two or three feet are often several times higher than values below ten feet.

The following slides illustrate some typical values to be found in weathered ultramafic rocks and gossans.

(Slide 6: Ultramafic Rocks (Unmineralized)
(Slide 7: Ironstone Capping (Pseudo-Gossan))
(Slide 8: Gossan after nickel sulphides)
(Slide 9: Metal Ratios in Gossans)
(Slide 10: Yindi Drill Results)

Turning our attention now to some of the minor elements which can occasionally be useful as indicators, let us consider selenium. Virtually all high-temperature sulphide deposits contain substantial traces of selenium. It can be used to distinguish possible gossans from laterites. It could also be used over IP anomalies to distinguish graphite or sedimentary sulphides from magmatic sulphides.

Tellurium could be used for the same purpose as selenium, but it is present in smaller quantities, it is more difficult to detect, and assay costs are higher.

Platinum and palladium are also good indicators of nickel sulphide mineralization. Platinum content of ultramafic rocks ranges from 0.001 ppm to 0.05 ppm. Palladium content is usually of the same order of magnitude. Gossans from W.A. nickel sulphide deposits usually exceed 0.1 ppm in both platinum and palladium. Virtually the only other rocks which would assay this

high are chromite seams in some differentiated ultramafic sills. Cay Williamson will have more to say about these elements.

Arsenic, antimony and bismuth have all been suggested as possible indicators. However, results of field work indicate that there is no relation between these three elements and nickel sulphide deposits.

Nov. 1971

BIBLIOGRAPHY

Platinum Metals - Abundance in Common Igneous Rocks
Springer-Verlag., Heidelberg 1969.

Geochemistry of Hydrothermal Ore Deposits
H.L. Barnes, Holt-Reinhardt-Winston 1967.

Distribution of Ore Elements in Ultramafic Rocks.
Cameron, Siddeley and Durham.
G.S.C. Open File, Ottawa, Canada 1970.

Weathering & Geochemical Behaviour of the Elements of Ultramafic Rocks in New Caledonia.
J.J. Trescases, 12th Pacific Science Congress, 1971.

SLIDE 1

BASE METAL CONTENT OF ROCKS

(after Vinogradov, 1964)

	P.P.M.				
	Ni	Co	Cr	Cu	Zn
ULTRAMAFIC	2000	150	1600	10	50
MAFIC	130	48	170	87	105
INTERMEDIATE	15	7	22	30	60
GRANITIC	4.5	1	4.1	10	39
SYENITIC	8	1	2	5	130
SHALE	20-100	10-50	100-500	30-150	50-300
SANDSTONE	10	10	10-100	40	20

SLIDE 2

BASE METAL CONTENT-ULTRAMAFIC ROCKS

Joplin "Chemical Analyses of Australian Rocks"

	Ni	Co	S
DUNITE	2600	270	320
PERIDOTITE	2160	185	?
PYROXENITE	900	?	?
HORNBLENDITE	500	?	550
ALTERED ROCKS			
SERPENTINITE	2315	210	350
TALC-CARBONATE	940	?	325
TREMOLITE-ACTINOLITE	500	?	?

SLIDE 3

FRESH ROCK-BASE METALS

PRESENT AS SULPHIDES

	No. of Samples	Ni	Cu	Co	S(%)
BARREN ULTRAMAFIC	616	579	26	44	.059
MINORE ULTRAMAFIC	91	842	52	44	.177
ORE ULTRAMAFIC	372	1875	439	84	.582
FAVOURABILITY THRESHOLD		1780	100	158	.178

WEATHERED ULTRAMAFIC ROCKS

(UNMINERALIZED)

AREA	NO. OF SAMPLES	(PPM) Ni	Cu	Co	Zn	Cr
LATHAM	6	2360	15	104	75	
BLACK HILLS	9	1840	98	87	174	
NORTH IRONCAP	15	1090	58	78	58	
YALBRA	23	905	59	51	108	
WIDGIEMOOLTHA	6	2310	57	80	72	
HIGHLY LEACHED SERPENTINITE		55	15	25	135	9800
FRESH SERPENTINITE FROM SAME AREA		2700	75	105	135	770

SILICEOUS IRONSTONE "PSEUDOGOSSAN"

	NO. OF SAMPLES	Ni	Cu	Co	Zn
PINNACLES STA	7	3600	86	388	436
YINDI	6	5160	67	360	358
QUEEN VICTORIA ROCKS	3	11,430	120	-	362
MAZZA-LEONORA	1	60,000	10	-	35
EDWARDS FIND	1	11,000	45	580	75

GOSSAN ASSAYS

	NO. OF SAMPLES	Ni	Cu	Co	Zn
KAMBALDA					
DURKIN SHOOT	2	565	420	70	23
LUNNON SHOOT	2	9,150	5950	440	35
McMAHON SHOOT	1	12,000	960	250	60
ST IVES AREA	6	8,100	2600	312	102
WINDARRA	2	4,200	5680	220	65
SCOTIA	2	5,150	665	110	58
AGNEW (SELTRUST)	8	5,570	925	227	175
MT. KEITH	1	5,200	340	160	45
YINDI	1	2,000	940	40	170
MANGAROON	4	5,960	4525	226	81
SPRINGVALE	6	8,600	1170	464	97
QUEEN VICTORIA ROCKS	4	5,080	414	298	1850

METAL RATIOS-GOSSAN SAMPLES

	Cu/Ni	Cu/Co	Cu/Zn
KAMBALDA			
DURKIN SHOOT	0.74	6.00	18.3
LUNNON SHOOT	0.65	13.50	170.0
McMAHON SHOOT	0.08	3.84	16.0
ST. IVES AREA	0.32	8.33	25.5
WINDARRA	1.35	25.80	87.1
SCOTIA	0.13	6.05	11.5
AGNEW (SELTRUST)	0.17	4.06	5.3
MT. KEITH	0.07	2.12	7.5
YINDI	0.47	23.50	5.5
MANGAROON	0.76	20.00	55.8
SPRINGVALE	0.14	2.52	12.1
QUEEN VICTORIA ROCKS	0.08	1.39	0.2
	>0.1	>1.0	>5.0

Selection of Areas Favourable for McArthur-type Sedimentary Base Metal Deposits

By R.S. Gray

The McArthur River deposit is a type example of a very important group of sedimentary base metal deposits, which include Mt. Isa, Broken Hill, Sullivan, Balmat and Edwards, and possibly the Zambian and Katangan copper belts. Because McArthur is unmetamorphosed and unrelatively undisturbed, it is easier to sort out the features required for its formation.

McArthur, Broken Hill, Sullivan and Balmat - Edwards are all Lower to Middle Proterozoic in age. The Zambian copper belt is also Proterozoic, but I do not have any information on age dating. There may be a reason why these deposits scattered over three continents are all of similar age. The ~~middle~~ early Proterozoic has certain unique features such as the first signs of shallow marine life, the first significant deposition of carbonate beds, and an atmospheric environment which has not been duplicated before or since.

(Slide 1 Atmospheric History of O_2 and CO_2)

Photo-dissociation of water ceases when the oxygen content reaches 0.1% of Present Atmospheric Level. This is known as the Urey Level. The earth's atmosphere remained at this level until organic production of oxygen began in Lower Proterozoic times. The amount of oxygen in the atmosphere then increased until it reached 1.0% of Present Atmosphere Level. At this point, known as the Pasteur Level, microbes change their metabolism

from fermentation to respiration. This level would be maintained for considerable time, because any excess of oxygen would have been immediately consumed by contemporaneous microbes changing from fermentation to respiration. The Pasteur Level was finally broken about the end of Middle Proterozoic, and oxygen content has continued to increase since that time.

The Pasteur Level corresponds with a dividing point between anoxygenic reducing conditions and oxydizing conditions. Up to the end of Middle Proterozoic times, pyritic sands and banded iron formations are common. From Late Proterozoic times, redbeds and hematitic iron formations began to form, and pyritic sediments become restricted to local environments.

Another feature unique to early Proterozoic is the emergence of shallow marine life. The first evidence of algal structures occurs in the Lower Proterozoic. The significance of this is not certain, but perhaps it would provide a mechanism for precipitation in near-shore environments for metals which previously tended to concentrate in seawater.

Limestones are absent in Archean rocks, and are scarce in Lower Proterozoic sediments. The first major limestone deposits were laid down in Middle Proterozoic times. This indicates that a new environment had been created which did not exist previously.

The environment of deposition at McArthur is shallow marine with obvious near-shore features. Pyritic and dolomitic shales have been deposited in lagoonal basins. Algal reefs and reef detreitus occur along the fault scarp and on paleo topographic highs. At Mt. Isa, there is a suggestion that part of the silica-dolomite may be related to algal reefs. This is illustrated in the following two slides taken from E.M. Bennett's paper presented in 1970.

(Slide 2 Mt. Isa-Reconstruction of Geological History)

(Slide 3 " " " " " ")

Algal reefs are considered evidence for shallow water deposition.

In both the Mt. Isa and McArthur areas, the sediments are dominantly chemical precipitates with pelitic material but very little arenaceous material. Dolomitic shales and black shales are present in both areas. Algal dolomite is definitely present at McArthur and probably present at Mt. Isa. Disseminated pyrite is widespread in both areas, much more so than base metal sulphides.

(Slide 4 Cross Section of HYC Basin, McArthur River)

(Slide 5 " " " " " " ")

Strong regional faulting is present in both the Mt. Isa and McArthur areas. In both areas, there is a tendency for depositional features to differ on either side of certain faults. This indicates penecontemporaneous faulting. Criteria for identification of penecontemporaneous faults are as follows:

(1) Certain units well developed on one side of a fault are absent or reduced on the other side, the full sequence suggesting relatively uninterrupted deposition, and the short sequence exhibiting conventional evidence of disconformity or even angular unconformity.

(2) The apparent shifts on the fault are consistently greater for the lowest stratigraphic units affected, and progressively less in the younger horizons. The final up-sequence termination of the faults may be blind.

(3) Certain faults exhibit conspicuous evidence of having been folded.

At McArthur, algal reefs growing along the Emu fault scarp were probably dislodged by tremors associated with movement along the fault. The resulting slump breccias are interbedded with the sediments, and in places have scoured out part of the ore beds. This is also evidence that the mineralization was already in existance before the beds were consolidated, and while the sediments were still being deposited. It rules out any form of origin depending on migrating groundwater.

At Mt. Isa, the Mt. Isa Group shales are underlain by basic volcanics. At McArthur, the

McArthur Group sediments are underlain by basic tuffs. Both areas contain acidic tuffs interbedded with the sediments. This evidence of igneous activity is believed to be important, since the most likely source of the base metals is from fumaroles associated with volcanic activity along the faults.

In the McArthur area, the only evidence of intrusive activity along the Emu fault is confined to the area within five miles of the HYC deposit.

Aragonite and halite casts are definitely present at McArthur. This indicates hypersalinity in the basin waters. If similar evidence existed at Mt. Isa, it has been destroyed by metamorphism.

The McArthur area contains numerous lead-zinc occurrences and a few copper occurrences. Several small highgrade deposits are known, but most of the occurrences apart from HYC are low-grade disseminations. Disseminated pyrite is also widely spread through the shaly units. The Mt. Isa area also contains a number of base metal occurrences in addition to the major deposit. All units of the Mt. Isa group contain disseminated pyrite, often in large quantities.

I have been comparing features that are similar at both Mt. Isa and McArthur River. Features which occur only at Mt. Isa and not at McArthur River are not regarded

as essential features of this type of deposit. They are probably a product of the higher degree of metamorphism. For the same reason, comparisons with Broken Hill have not been made because the high degree of metamorphism obscures the original nature of the rocks. I might quote a paragraph from a classic paper by C.L. Knight, whose application of similar concepts led to the discovery of the McArthur deposits.

"So many factors could be suspected of affecting ore localization of any individual ore deposit that fundamental problems of ore genesis could not be solved by work, no matter how detailed, or any one of them, and a better approach would be to examine the essential features of a large number of them to find out which features were common factors".

We have established a number of common factors. Even without developing a theory of ore genesis, these common factors can be applied to exploration.

The first step is to examine areas of Middle Proterozoic sediments looking for sequences of carbonaceous shales, pyritic shales and algal dolomites. In Western Australia, these requirements are met by at least six stratigraphic units within an area of about 40,000 square miles. (Slide 6 Geology of W.A.)

Next we can look for evidence of strong faulting and acid volcanic activity. This is most pronounced along

the hinge line dividing the lower Proterozoic Hammersley basin from the middle Proterozoic Ashburton geosyncline.

Now we start more detailed studies looking for evidence of shallow marine lagoonal and reef-type sedimentation, penecontemporaneous faulting, and widespread disseminated pyrite.

During the past year, we have completed four regional reconnaissance programs on favourable areas within the Ashburton geosyncline. In the Palgrave area sediments consist of carbonates, carbonaceous shales, and pyritic shales, with strong faulting, and abundant pyrite mineralization, but evidence of volcanic activity is lacking. Widespread low grade copper occurrences were discovered, but none with sufficient grade and tonnage. In the Mt. Price area the same sequence of rocks are present, together with evidence of penecontemporaneous faulting. No significant mineralization was detected. The Duck Creek dolomite was followed through the Wyloo and Turee Creek map sheets, and numerous lead, zinc and copper occurrences were located. Several geochemical anomalies remain to be tested. Anomalous base metal values were detected in shaly interbeds in basic volcanics, and these are currently being drilled. One small lead-silver gossan has been located.

The reconnaissance program will continue next year with work to be done further southeast along the hinge line, and in the Mt. McLarty area.

Within a few years, all of the areas which fit the criteria can be examined in reconnaissance fashion. The chances for discovery appear to be relatively good.

The same criteria could be applied to Middle Proterozoic areas in North America. Perhaps we could zero in fairly quickly on another Sullivan or Balmat-Edwards.

R.S. Gray

REFERENCES

1. Sedimentary Ores, Ancient and Modern "Sedimentary ores of the early and middle Precambrian and the history of atmospheric oxygen" by M.G. Rutten. Spec. Publ. No. 1. Dept. of Geology, Univ. of Leicester, 1969.

2. "History, Geology and Planned Expansion of Mt. Isa Mines Properties" by E.M. Bennett, 1970.

3. "Penecontemporaneous Faulting and its Likely Significance in Relation to Mt. Isa Ore Deposition" by W.D. Smith, Geol. Soc. Aust., Spec. Publ. No. 2, 1969.

4. "Regional Environment of H.Y.C. Lead-Zinc Deposit, N.T." by W.J. Murray Unpublished paper, ANZAAS Conference, 1971.

5. "Ore Genesis - The Source Bed Concept" by C.L. Knight, Economic Geology 1958.

THE ROLE OF GYPSUM IN THE FORMATION OF BASE METAL DEPOSITS

By R.S. Gray

When I first checked with an analytical chemist to find out whether the chemical reaction $CaSO_4 + CH_4 \rightarrow CaCO_3 + H_2S + H_2O$ was feasible, I was thinking mainly of solving two problems - first, the creation of a reducing agent to precipitate sulphides, and second, creating a porous channelway to permit migration of groundwater or connate water solutions. Further research suggests an even closer relation between evaporites and stratiform base metal deposits. Two very important papers which have influenced my thinking are "Origin of Marine Evaporites by Diagenesis" by D.J. Shearman, and "Chloride-rich Brines from Sabkha Sediments and their Possible Role in Ore Formation" by P.R. Bush. The suggestion now is that the metal-bearing brines themselves are derived from a special kind of evaporite sediment, and that a reaction between these brines and organic material results in precipitation of sulphides in fluid traps of stratigraphic or structural origin.

To get back to my original point, the reaction of hydrocarbons with anhydrite or gypsum is not only feasible, but is highly exothermic, producing between 30 and 40 kilo-calories per gram molecule of hydrocarbon. Incidentally, this added heat could explain why fluid inclusion studies of Mississippi ores indicate higher temperatures of formation than can be explained by the probable depth of burial and normal thermal gradient.

Conversion of gypsum to calcium carbonate would create a volume reduction of 51%. In the wake of the reaction, the destruction of gypsum would leave a collapse breccia as the rocks adjusted to the reduced volume. This breccia would provide a permeable channelway for migration of groundwater or connate water solutions. The hydrogen sulphide produced would probably escape upward until it reached a structural or stratigraphic trap. Metal-bearing solutions migrating along the permeable channelway would precipitate sulphides when they reached the same trap.

As an example of the destruction of gypsum, I offer the following quotation: "The Edward's Limestone of central Texas provides a very interesting example of the nearly complete solution of a 20 foot thick gypsum layer. A few square miles of gypsum remain, and are exploited commercially in the vicinity of Kirschberg. Quite apart from exploitation, in a very few years, geologically speaking, the bedded gypsum would have dissolved away entirely. However, porous collapse breccias at the stratigraphic horizon of the Kirschberg evaporites occur over an area of hundreds of square miles. Where similar breccias occur within a limestone-dolostone sequence, the previous existence of an evaporite layer may commonly be suspected".

If the theory is correct, we should be looking for stratiform base metal deposits in areas of carbonate sequences favourable for evaporite deposition. This usually brings to mind restricted basins, periodically cut off from access to the ocean. However, studies of recent sediments in the Persian Gulf suggest that marine evaporites may be largely formed by diagenesis in the intertidal and supratidal areas of arid regions. Evaporites formed

in this manner are known as sabkha sediments. Textures established as diagnostic of sabkha sediments in the Persian Gulf have been found in the lower Carboniferous of Great Britain, the Permian evaporites of the German Zechstein, and gypsum and anhydrite deposits of the Upper Mississippi Valley. It is too much of a coincidence that each of these areas contains major deposits of stratiform base metal ores.

P.R. Bush, in his paper which I mentioned earlier establishes that the chemical reactions which take place in the tidal flats of an arid area produce a remnant groundwater brine which is extremely similar to the inclusion brines of Mississippi Valley ores. The similarity is much closer than for brines of hydrothermal origin, oil-field brines or mixed hydrothermal-groundwater brines such as the Salton Sea.

The suggestion is that connate brines squeezed out of sabkha sediments by the weight of overlying rocks migrate up-dip along channelways formed by the reaction of anhydrite with organic material until they reach structural traps, where they react with hydrogen sulphide produced during the formation of the channelways. The source of the metals may be from the evaporites themselves, or from leaching of the wallrocks by the chloride-rich brines.

The papers by Shearman and Bush not only explain the development of sabkha sediments, but also provide some insight into why dolomitization can be expected to accompany the process, and also why the composition of evaporite deposits found in nature differ from the composition of salts contained in sea water.

If time permits, I believe it would be worthwhile for me to read the papers by Shearman and Bush.

R.S. Gray

References:

(1) "Origins of Marine Evaporites by Diagenesis"
D.J. Shearman, IMM Transactions, Section B, August 1966.

(2) "Chloride-rich Brines from Sabkha Sediments and their Possible Role in Ore Formation"
P.R. Bush, IMM Transactions, Section B, ~~February 1971.~~ August 1970

(3) "Guidebook, Lower Cretaceous Shallow Shelf Carbonate Sequence, West-central Texas"
C.H. Moore, Jr., Dallas Geological Society, 1969.

(4) "Stratigraphic Habitat of Mississippi Valley-type Orebodies"
J.J. Dozy (and particularly the discussion following the paper), IMM Transactions, Section B, August 1971.

(5) "Appalachian-type Stratiform Deposits in the U.S.A."
A.D. Hoagland. Unpublished paper, ANZAAS Congress, Brisbane, Australia, 1971.

(6) "Lower Carboniferous Evaporites and Mineralization in Eastern and Central Midlands of Britain"
P.G. Llewellyn and R. Stabbins, IMM Transactions, Section B, November 1968.

November 26, 1971.

ASBESTOS EXPLORATION BY OPTICAL AND CHEMICAL ANALYSIS OF STREAM SILT AND SOIL SAMPLE

S.A. Anzalone

Asarco's asbestos exploration efforts have accelerated during the past few years. This has been particularly evident in the Northwest Cordillera. This region, with its extensive belts of ultramafic rocks, has been, and continues to be, a prime target area for asbestos exploration. (Figure 1.)

Two producing mines, Cassiar and Clinton Creek, plus the blocked-out orebody at Kutcho Creek, attest to the region's productivity and future potential. Asbestos prospects are known over an area extending from Alaska (Eagle Prospect) to California (Adams Prospect and Colinga Mine).

The Canadian portion of the Cordillera has received considerable attention over the past 15 years, primarily during exploration for asbestos, although a good deal of effort has gone into nickel exploration during the past 5 years. The Giant Mascot nickel mine, north of Hope, is currently the only producing nickel mine in B.C.

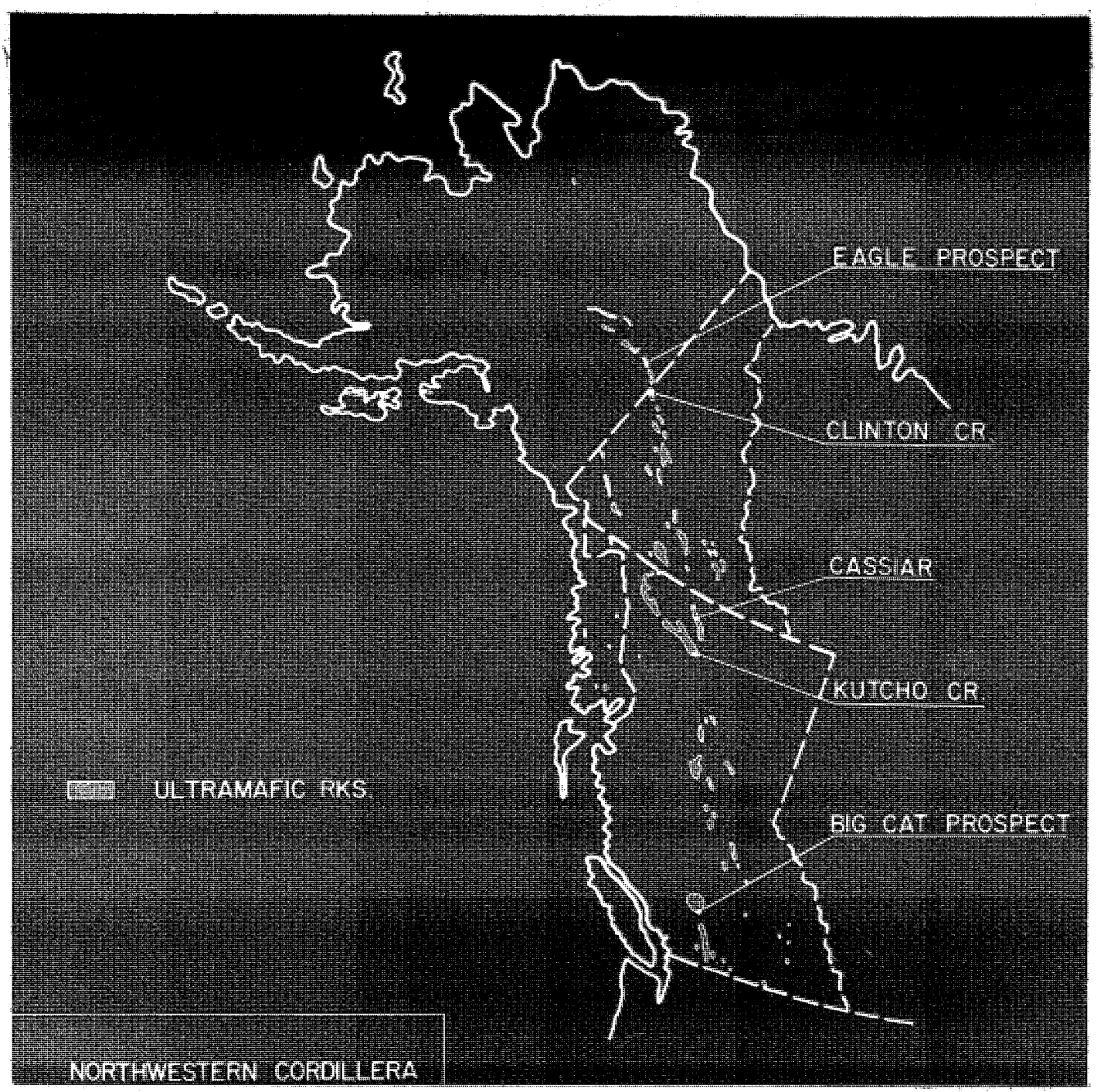
The bulk of the area encompassed within the ultramafic belts has been flown by airmag, and the obvious serpentine outcrops were recognized at an early stage due to their color anomalies. All of the producing mines, and most of the presently known prospects, have conspicuous outcrops. They are, for the most part, located in regions of negligible or thin cover, within Alpine Ultramafic Belts. Figure 2 provides some idea of the terrain and topographic expression found in the northern part of B.C. and the Yukon. This particular photo is a view taken from the Kutcho Creek Prospect. In much of the remainder of B.C. and Alaska, the ultramafic belts are covered to a considerably greater extent with forest and/or tundra. Most of the belts have been outlined by airmag; however, that still leaves a good deal of ground to cover, and one does not know whether the anomaly is caused by barren peridotite, serpentine, or if the feature causing the anomaly contains asbestos fiber.

Exploration for these obscure asbestos deposits has been hampered by difficult access (few roads), poor outcrop exposure, plus the absence of an effective geochemical exploration technique. For example, nickel, cobalt, chrome and iron have long been known to be associated with serpentine. Unfortunately, their presence in stream silt or soil samples does not indicate whether asbestos is present in the serpentine.

While attempting to formulate an exploration program and put together geological data aimed at overcoming these problems, inquiries were made among individual geologists and various companies engaged in exploration for asbestos. They were

FIGURE 1

NORTHWESTERN CORDILLERA - ULTRAMAFIC BELTS



questioned about any geochem techniques they may have used, and how effective they had been. It developed that little practical work had been done with stream silts or soils. In addition, microscopic analysis of stream silts has been essentially ignored. Most geologists assumed that the fiber would break up and not be observed very far from the source. This has proven not to be the case, as will be illustrated later in this discussion.

Most companies continue to rely on prospectors, or concentrate on their own helicopter reconnaissance.

I believe the utilization of optical and chemical analysis of stream silt and soil samples can assist in the location of new asbestos deposits. The following data, derived from three recently completed studies, is offered in support of this thesis.

(1) The first is a report on the microscopic examination of stream silt samples derived from drainages known to cross areas of asbestos bearing serpentine. These were compared with silt samples derived from drainages, cutting ultramafics believed not to contain asbestos in any readily recognizable form.

(2) Second is a brief comment on soil studies and analysis, by Charles Beverly of Asarco's Denver Office staff, in conjunction with M.E. McCallum of the University of Colorado.

(3) Third, a review of X-ray and petrographic work on serpentine mineral textures by Mr. M.F. Wicks, Assistant Curator of Mineralogy, Royal Ontario Museum.

STREAM SILTS - MICROSCOPIC EXAMINATION

Stream silts from a number of different ultramafic belts were collected and studied under a binocular microscope. The most thorough test work was conducted on stream silts collected near the Big Cat Asbestos Prospect, Lillooet, B.C. For the sake of brevity, I will restrict my comments to this area, although the results from the Prince George and Letain Lake regions were also encouraging.

Figure 3 illustrates the type of limited outcrop that might be detected through stream silt analysis.

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FIGURE 2

TYPICAL TOPOGRAPHIC EXPRESSION OF ALPINE ULTRAMAFIC BELTS
IN
NORTHERN CORDILLERA, KUTCHO CREEK ASBESTOS PROSPECT

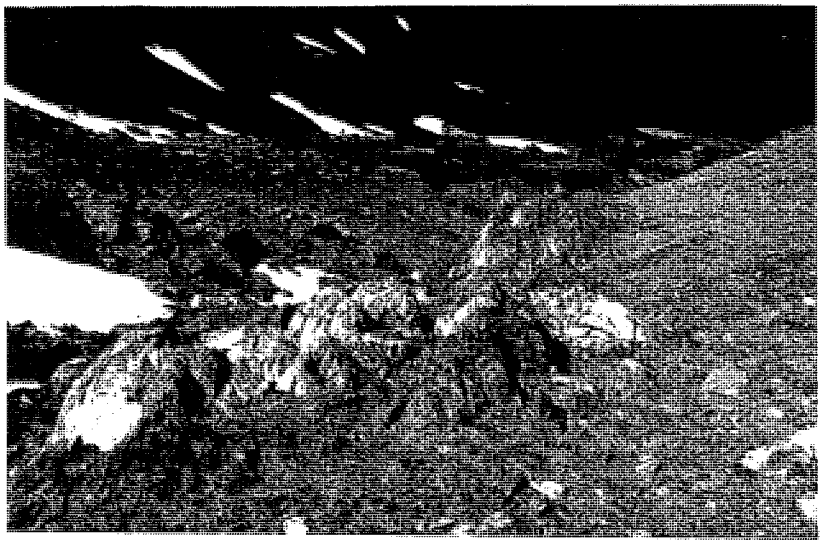


FIGURE 3
TYPICAL LIMITED OUTCROP
OF
FIBER BEARING SERPENTINIZED ULTRABASIC
IN
NORTHERN B.C., LETAIN LAKE ASBESTOS PROSPECT

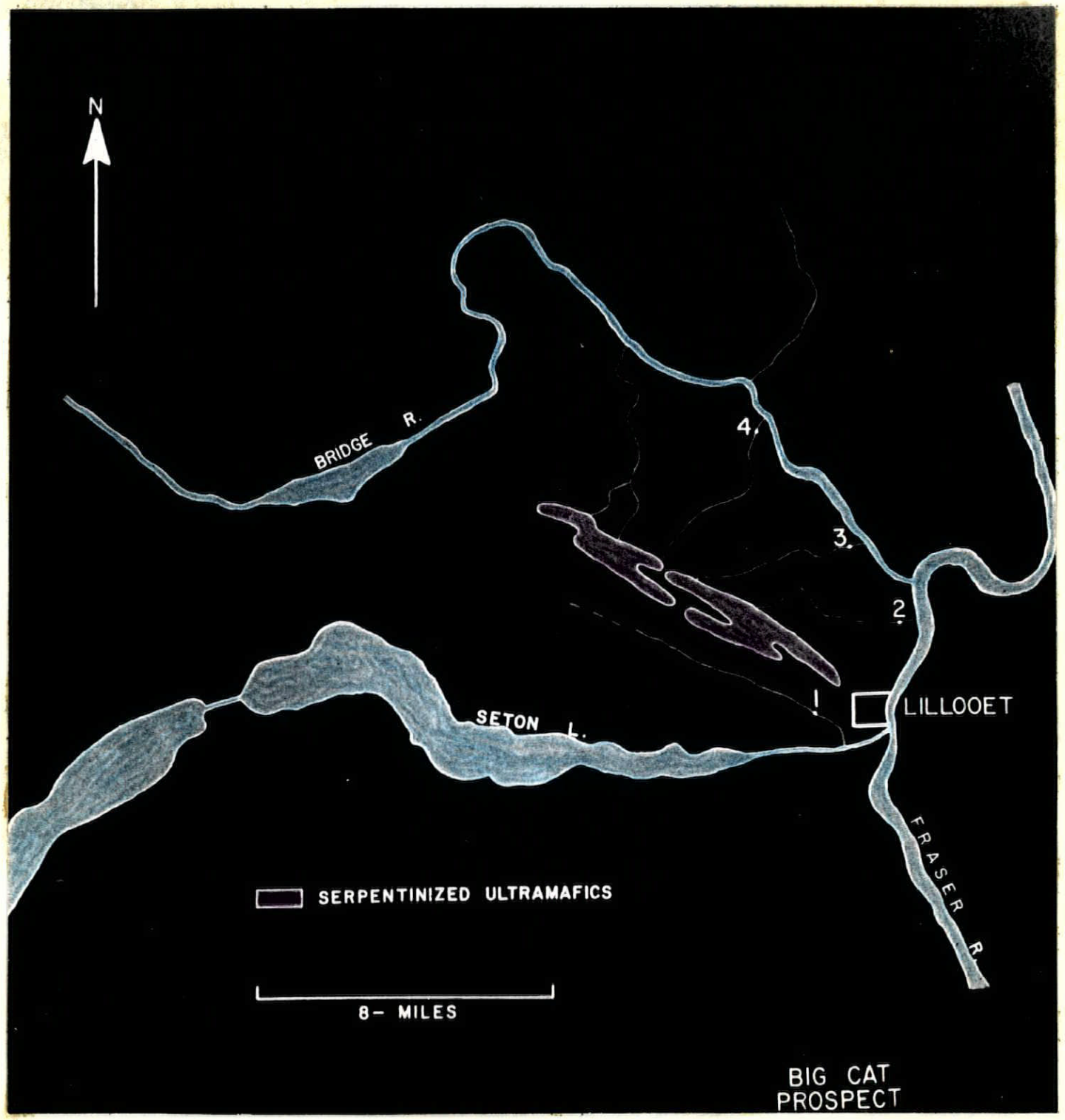
FIGURE 2

TYPICAL TOPOGRAPHIC EXPRESSION OF ALPINE ULTRAMAFIC BELTS
IN
NORTHERN CORDILLERA, KUTCHO CREEK ASBESTOS PROSPECT

FIGURE 3
TYPICAL LIMITED OUTCROP
OF
FIBER BEARING SERPENTINIZED ULTRABASIC
IN
NORTHERN B.C., LETAIN LAKE ASBESTOS PROSPECT

FIGURE 4

BIG CAT ASBESTOS PROSPECT - LILLOOET, BRITISH COLUMBIA



The general geology of the Big Cat Prospect is illustrated on Figure 4. The number shown on the streams indicate the various sample sites.

The geology is simple, consisting of a NW striking band of serpentinized peridotite intruding a series of Mesozoic argillites and greywackes. The topography of the prospect area is such that the drainages in the region only encounter the above-mentioned rock type.

Samples were collected and simply dried. The coarse fraction was examined under a binocular microscope (Nicon 77906). Following this preliminary examination, the samples were run through 20, 40, and 80 mesh screens. Each fraction was then examined in detail.

Recognizable asbestos was observed in each of the samples collected. Some of the asbestos fragments must have travelled in excess of 5 miles down drainage to the sample collection site.

The majority of observable asbestos occurs in the form of short "bundles" approximately .033 inches wide (20-40 mesh), and approximately 1/16th of an inch long. Why the preponderance of asbestos fragments were in this size range has not been established. The bulk of the fiber in most deposits is in the form of "shorts". Longer fibers appear to break into 1/16th inch small bundles as they travel down drainage. It appears that once the 1/16th inch bundles begin to break down (Figures 5 & 7), the fibers become so fine that they are difficult to recognize except under very high powered petrographic or electron microscopes.

The figures illustrated and described below portray a number of the asbestos fiber bundles collected at various locations as shown on the Big Cat Prospect Map.

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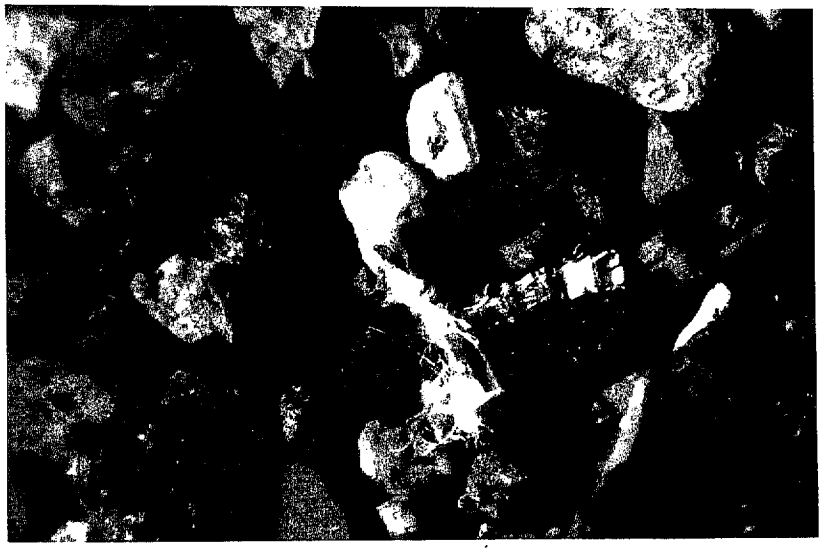
FIGURE 5



BIG CAT ASBESTOS SAMPLE SITE NO. 1
Coarse Fraction (unscreened)
Note: Crenulative Nature of Fiber Bundle (30X)

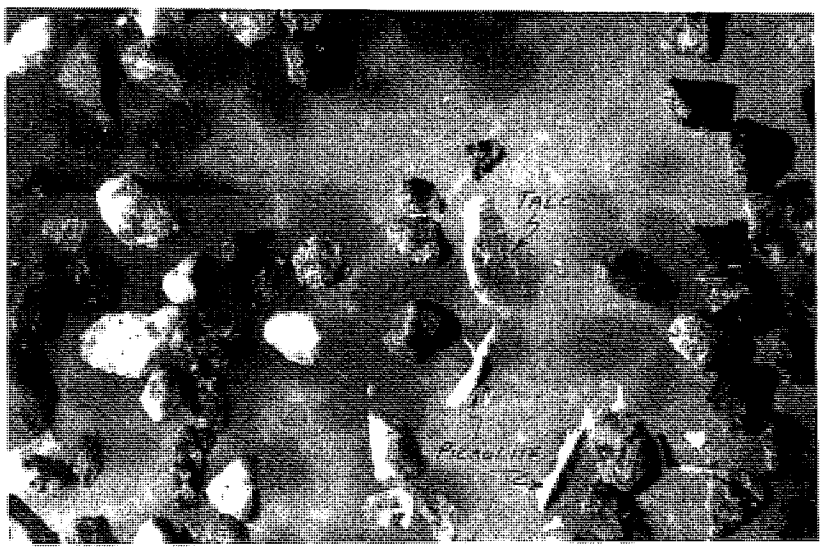
FIGURE 6

BIG CAT ASBESTOS SAMPLE SITE NO. 1
20-40 Mesh
Note: Asbestos remains as compact fiber bundle after screening (20X)

FIGURE 7

BIG CAT ASBESTOS SAMPLE SITE NO. 4
Coarse Fraction
Note: Fiber bundle beginning to break up due to impact of gravel (30X)

FIGURE 8



BIG CAT ASBESTOS SAMPLE SITE NO. 2
Talc and Picrolite readily distinguishable from asbestos fiber (20X)

A number of drainages from areas known to contain serpentinized rocks with little or no asbestos fiber were also examined. In the areas studied, admittedly too new to establish any firm statistical data, no fiber bundles were noted.

No rocks containing veins of asbestos fiber were observed at or near the sample sites. The asbestos veined areas are normally the weakest part of any fiber-bearing serpentinized rock. Consequently, one would not expect to find asbestos-veined rocks in streams very far down drainage.

On the basis of the tests mentioned above, it appears possible, at least, that the microscopic examination of stream gravels and silts for asbestos fiber, may be of some assistance in locating obscure asbestos prospects in the Western Cordillera.

SOIL INVESTIGATIONS

The soil investigation by Beverly and McCallum is essentially a study of contrasting residual weathering products as observed over an area of kimberlitic diatrems penetrating a granitic stock or sill. The region studied lies along the Wyoming-Colorado border directly south of Laramie, Wyoming (comment - Kimberlite). Rather than discuss the entire paper, I will restrict my comments to two Tables that summarize their work. Table 1 portrays the Ph and $CaCO_3$-$CaMg(CO_3)_2$ ratios detected in soils over serpentine and granite basement rocks.

TABLE 1

The enrichment in carbonate and magnesia noted in soils derived from the weathering of serpentinized rocks has also been observed by members of the Spokane Office staff during their recent asbestos investigations.

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TABLE 1.

pH and $CaCO_3$ - $CaMg(CO_3)_2$ equivalent data

	Sample depth (inches)	pH	% $CaCO_3$ equiv.	% $CaMg(CO_3)_2$ equiv.
Granite	2.0	6.5	0.18	0.16
	3.5	7.1	0.05	0.05
	6.0	7.1	0.30	0.28
	8.0	7.0	0.05	0.05
Kimberlite	3.0	8.1	7.45	6.85
	9.0	8.1	4.05	3.73
	54.0	8.2	12.70	11.68
	60.0	8.2	7.15	6.58
	84.0	8.2	4.78	4.40
	108.0	7.7	1.73	1.59

Determinations by W. Morkil, Soil Testing Lab, Dept. of Agronomy, Colorado State University.

Mineralogy of the soils varies considerably as a function of parent material. This difference is reflected equally well in residual and weathering product fractions (Table 2.). X-ray diffraction studies indicate a striking mineral variation in soils over Kimberlite versus Granite, and also show mineralogical trends and differences controlled by grain size depth and inherent chemical stability. Please refer to Table 2 for mineralogical details.

Those interested in the details of this study, should contact Chuck Beverly at the Denver office.

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TABLE 2.

Principal residual and weathering product minerals

Residual minerals kimberlite	Residual minerals granite	Weathering products kimberlite	Weathering products granite
serpentine	quartz	montmorillonite	kaolinite
lizardite	K-feldspar	illite	quartz (finely x-talline)
chrysotile	sodic plagioclase	mixed layer clays	
antigorite	muscovite	mont.-illite	sericite
Al-serpentine	biotite	mont.-chlorite	saussurite
serpophite	hornblende	chlorite	chlorite
Mg-ilmenite	magnetite	Mg-vermiculite	hematite
pyrope garnet	sphene	laumontite	limonite
perovskite	zircon	calcite	
chrome diopside		hematite	
phlogopite		limonite	
chromite			
picotite			
magnetite			
calcite			
dolomite			
talc			
chlorite			

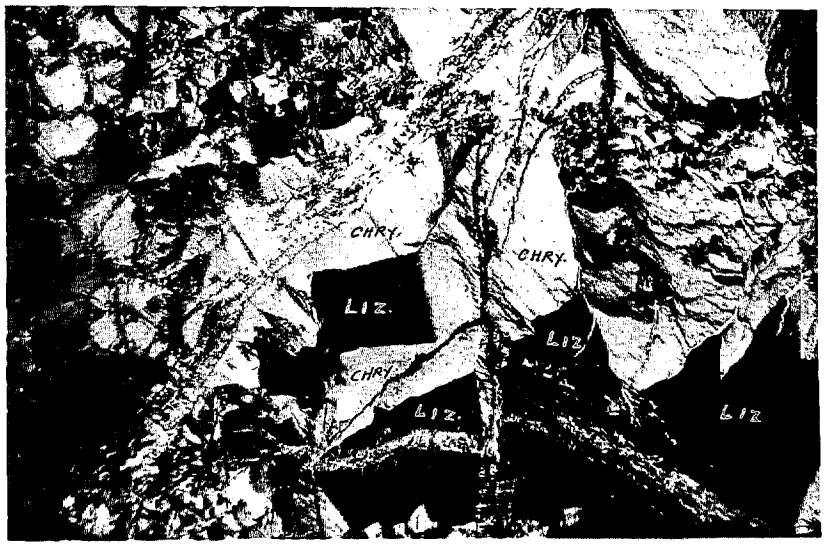
MICROSCOPIC AND X-RAY ANALYSIS OF SERPENTINE MINERAL TEXTURES

The study of serpentine mineral growth textures by F.J. Wicks displays some interesting exploration potential. Wicks combines an X-ray microbeam camera and a petrographic microscope in his work, although for our application in exploration for asbestos, we need only utilize the petrographic microscope. The X-ray microprobe was required to enable him to identify, in situ, the various minerals making up the serpentine textures visible in thin sections.

Mineralogists have long been interested in the unusual optic phenomenon known as "hour glass" configuration, displayed by some serpentines. In this condition, serpentine behaves like an isotropic, or nearly isotropic mineral. Due to the fine grained nature of serpentine, and the isotropic character of this variety of the mineral, identification of the various constituent was nearly impossible. Wicks and J. Zussman, of the University of Oxford, utilizing the X-ray microprobe, eventually identified the isotropic mineral making up the "hour glass" configuration as lizardite. In the course of further studies, Wicks observed that in many serpentines containing economic amounts of chrysotile asbestos, a marked difference in textural assemblage was noted. Lizardite "hour glass" textures (Figure 9) dominate lizardite mesh textures (Figure 10). Secondary textures of chrysotile and lizardite are abundant and begin to replace the lizardite "hour glass" texture (Figure 11).

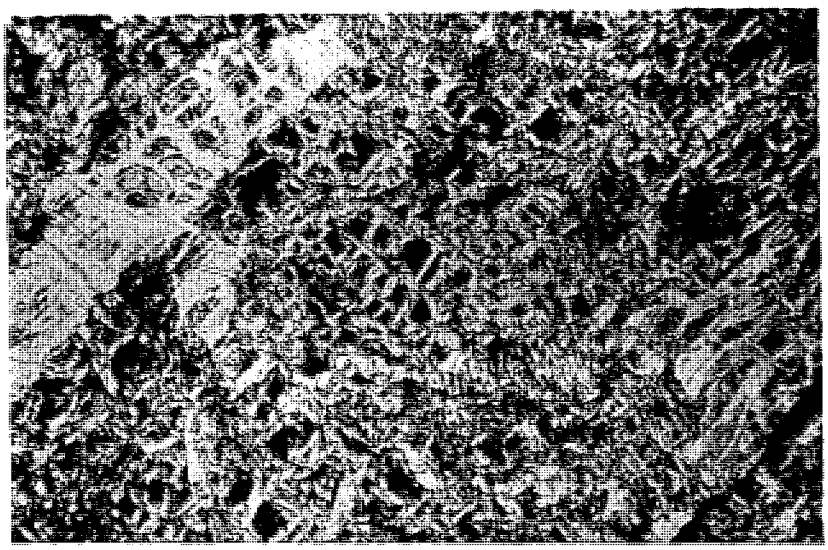
Specimens from about 20 chrysotile asbestos deposits - Eastern Townships, Quebec; Northern Quebec, Ontario, Manitoba, British Columbia, California, Rhodesia and South Africa - have been examined. All display a similar development of secondary textures. Quoting from Wicks, "the recognition of this unique assemblage of textures could be of importance in the exploration for asbestos deposits since it presents a further criterion for evaluating promising deposits". One obvious use would be as a tool to aid in the interpretation of zonal relationships in an area of asbestos potential. Further studies, of course, are required to evaluate these possibilities. Quoting further from Wicks, "to date, the progression from the normal primary textures to the chrysotile asbestos type secondary textures, have been traced over a few inches in the British Canadian and Normandy Mines in the Eastern Townships, Quebec, and over tens of miles in the Setting Lake-Moak Lake ultramafic belt in the Northern Manitoba area. This latter case is an interesting example of the possible usefulness of the secondary textures in

FIGURE 9



LIZARDITE "HOUR GLASS" TEXTURE AFTER OLIVENE

FIGURE 10



LIZARDITE "MESH" TEXTURE AFTER OLIVENE

FIGURE 11

"SECONDARY" CHRYSOTILE TEXTURE REPLACING LIZARDITE "MESH"

FIGURE 12

CHRYSOTILE MESH FORMED AFTER LIZARDITE MESH

the exploration for asbestos. The ultramafic intrusions at the southwest end of the belt are composed of lizardite mesh textures. However, 10-15 miles toward the NE, secondary lizardite interlocking textures associated with lizardite interlocking veins, have developed. Twenty to 30 miles further to the NE, lizardite "hour glass" textures have developed; and 5 miles further to the NE, lizardite mesh textures have been replaced by lizardite - chrysotile interlocking textures, which in turn have been replaced by chrysotile for form chrysotile mesh textures (Figure 12). This last location, the Pipe Lake Mine, is a nickel mine, not an asbestos mine; but chrysotile asbestos veins are quite plentiful and probably will be recovered as a by-product of the nickel mining."

In conclusion, the utilization of the exploration techniques discussed herein, are recommended as a procedure that may assist in Asarco's exploration efforts designed to locate potentially important asbestos deposits.

S.A. Anzalone.

SAA:sm

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

May 11, 1972

Mr. J. H. Courtright
Chief Geologist
Tucson, Arizona

Geologic Information Drill

The subject of my presentation at the 1971 Exploration Conference at Palm Springs, California, was "The Geologic Information Drill". Though no formal text was written for the meeting, I have finally recorded pertinent remarks for distribution as requested at the end of the meeting.

First, I should like to make it clear that my remarks and recommendations for the use of a Geologic Drill are directed solely at the Southwestern U.S. porphyry copper province. A brief review of a few pertinent geologic features, exploration over the past ten years, and results of that exploration are necessary to appreciate the proposal for the use of a Geologic Information Drill.

Geologic Features. The area under discussion is part of the Basin and Range province with its discrete mountains and large, broad intervening valleys. With the exception of Bisbee, the porphyry copper deposits of the Southwest are Laramide in age and associated with a Laramide intrusive that has intruded, altered, and mineralized all the pre-Laramide rocks. Of importance is the fact that the effects of alteration are recognizable for at least 2500' from the outer margin of the ore zone, which is elliptical and averages 3500 x 6000 feet (Lowell & Guilbert, 1970). Thus, the overall size of the average ore zone plus alteration is at least 6000 x 9500 feet. "Copper-in-Biotite" (discussed at this meeting) holds promise of giving clues to the existence of major porphyry copper deposits at even greater distances.

Another important fact is that premineral rocks crop out in only 30% of the surface area, leaving vast amounts of prime exploration ground covered by post-mineral rocks and alluvium.

Past Exploration. The past ten years have seen an unprecedented exploration effort directed at the discovery of porphyry copper in the Southwest. This effort has utilized the disciplines of geology, geophysics, and geochemistry.

The geologic work has been intense with much of it directed towards discovery of small, pervasively altered outcrops (Sacaton, Poston Butte types) and the propylitic fringe alteration zone. In this search many, many hours have been logged in small aircraft and helicopters and geochemical surveys have covered all the mountain fronts.

As intensity of exploration continued all the "old outcropping dogs" were redrilled in hopes of finding "new pups". It is generally agreed upon by Southwest geologists that no major porphyry copper deposits, amenable for open pitting, remain within the premineral outcrops.

Geophysical techniques, mainly I.P., have been applied. Most areas with 50' to +1500' of cover have been "saturated" with I.P., with many areas having been resurveyed several times as instrumentation changed.

Results of Exploration. Over the past ten years, 13 major discoveries have been made and, of these, eight represent truly new discoveries not associated with extensions or faulted portions of existing mines. These eight are: Sacaton (open pit and underground, ASARCO); Poston Butte (open pit, Conoco; in-place leach (?), ASARCO); Rosemont (open pit, Anaconda); Vekol (open pit, Newmont); Copper Creek (underground, Newmont); Lakeshore (underground, El Paso); Sanchez (open pit, Inspiration); Red Mountain (underground, Kerr-McGee). This is a very commendable discovery record and will be difficult to duplicate in the next decade. Of the 13 discoveries, only one (Vekol) represents a partial geophysical discovery (magnetic, I.P.); there was no geochemical discovery. Of the 13 discoveries, 6.5 will be underground mines (the half is for the deep portion of ASARCO's Sacaton deposit).

Faced with a strongly competitive exploration climate; 70% of the area being post-mineral cover; little likelihood for open pit discoveries within pre-mineral outcrop; and, to date, the ineffectiveness of geophysical and geochemical techniques to locate specific targets, what course of exploration should ASARCO take in the Southwest?

To me, the answer is simple: thorough geology and geologic thinking. The geology and geologic thinking would concentrate in the "so-called permissive areas" -- variously known as porphyry copper lineaments, productive trends, crossroads, magnetic gradients, etc. Stated another way, exploration would take the form of intense regional studies making use of all information (published, unpublished, original field work). Critical study of this information, in light of the ever increasing knowledge of porphyry coppers, should develop prime exploration targets. Obviously, such a program calls for high caliber porphyry copper exploration geologists which, fortunately, we have within our Division. An excellent example of this type of "thinking exploration" is our Superior East project initiated by Mr. Sell.

The one single thing that can most aid this type of geologic exploration is the procuring of a rock sample in the third dimension -- ENTER THE GEOLOGIC INFORMATION DRILL. With the ability to obtain concrete, irrefutable, third dimensional information in the simplest and most basic geologic form -- a rock sample -- the geologist will be able to confirm, modify, or change his conclusions concerning the porphyry copper potential of a concealed area.

The procuring of this most basic geologic fact -- a rock -- will allow a number of physical studies (if feasible to the problem) to be made. These include magnetic susceptibility, specific gravity, trace element geochemistry, alteration studies (including fluid inclusions), age dating, in-hole geophysical methods, etc. Further, the drill hole will allow water samples to be collected and analyzed.

Earlier you heard two papers concerned with porphyry copper exploration -- "Copper-in-Biotite as a Guide to Porphyry Copper Deposits" and "Relative Position of Porphyry Copper Deposits to Barren Laramide Stocks". I believe both have considerable merit but both meet with a major problem -- information ends at the edge of cover. The Geologic Drill is a natural to provide the additional and necessary information beneath cover.

The Geologic Drill will be used as a tool to extend our information out from the known. It will create new, concrete, useable information that will stimulate geologic thinking and lead to a better, more coherent understanding of the geology along the "porphyry copper lineaments". This is the way we in the Southwest are going to find new porphyry coppers for ASARCO.

The type of drill considered for this work is a rotary drill equipped for both air and mud drilling and capable of taking spot cores. The drill would be in the Failing 1500 class, giving a depth penetration to 2,000 feet. Most drill holes would most likely be in the 500 to 1200 foot range.

Total costs, direct and indirect, to contract such a drill on a yearly basis are estimated at $12,000 per month. This should give an overall footage price in the 3 to 4 dollar range.

W. L. Kurtz

W. L. Kurtz

WLK:lad

EXPLORATION SERVICES DIVISION
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RECEIVED
DEC 13 1971
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December 7, 1971

MEMORANDUM to J. H. Courtright:

"GEOCHEMISTRY AND THE EXPLORATION DEPARTMENT" - Talk given at the Asarco Exploration Meeting, Palm Springs, California, November 1971.

Geochemical techniques constitute an important part of many of the programs undertaken by the Exploration Department. Presumably the relative importance of these techniques will tend to further increase in the future as we become more and more concerned with the search for buried deposits. Therefore, I think this is an opportune time to discuss possible ways in which we can attempt to ensure maximum benefit from these techniques. I would like first to give briefly some of my ideas on the subject and then hear of your reactions to them as well as any alternative suggestions.

In my opinion the most important need is for adequate, locally available geochemical service in each major region. As I mentioned in my preliminary abstract I think that this can be best provided by a qualified geologist/geochemist located in each major regional office and reporting to the supervisor of that office. Only through long term exposure to the geochemical problems of a region can an exploration geochemist be expected to achieve sufficient familiarity with local problems and develop specific techniques to combat them. He would be expected to participate in the preliminary planning stages of all programs in that region to help ensure sufficient regard was given to possible geochemical approaches. If geochemical procedures are amongst those selected for the project he should continue to participate in it, at least in an advisory role, through to completion. Obviously he could also carry out or direct any essential orientation studies before the first field phases of the program proper begin.

Apart from this project aid and advisory role the regional geochemist should be actively encouraged to undertake practical research projects designed to develop new and improve pre-existing techniques of potential value in his region. As his experience of a region increased it would be likely that he develop general exploration ideas of his own which he would be expected to formulate into proposals for his supervisor. In certain circumstances, if such proposals were accepted he would be encouraged to actively participate in the resultant field program. This would help avoid undue restriction to his specialist field and ensure he did not develop too narrow an exploration perspective.

As regards the background and training of the proposed regional geochemists, I think it is essential that they be basically in the field of exploration geology. These men should also have at least a few years experience in exploration geology. Their geochemical background will likely have been received through post-graduate training and research experience in some practical aspects of exploration geochemistry. They should be of sufficiently high caliber that they might be considered as potential candidates for more senior general exploration positions as their careers progress.

Although I think the highest priority requirement is for regional geochemists, there is also a need for improved general geochemical research capability. Obviously financial considerations limit involvement in this type of activity but a good case can be made initially for one well qualified research geochemist to work on the development of new techniques as well as specific problems encountered by regional geologists and geochemists.

However, not all essential research need be carried out within the company. In certain cases I think we might make greater use than previously of outside facilities. This is particularly true in the case of specific fields in which commercial or university research groups have built up a commanding expertise. In some cases we might make use of these groups as consultants. In others we might wish to actually sponsor a project.

Another way to achieve progress on specific major problems is to sponsor graduate research projects in university departments preeminent in the field of interest. Obviously much of the knowledge thereby gained becomes public knowledge in the long term but a sponsor does have a useful time lead. In some cases support of geologists from within the company working in such graduate programs might be considered.

I think there will continue to be a need for a centralized geochemical laboratory able to provide a range of routine and research analytical services. However, both the range of the quality of this service can be improved. We have been involved in staff changes designed to achieve this aim. Additional instrumentation would greatly improve our multi-element capability. We would then be able to carry out considerably more cheap semi-quantitative multi-element analysis of both geologic and geochemical samples for the department as a whole.

These then are some of my ideas as to how geochemical techniques might be better utilized with the exploration department. They have been made in the hope of promoting discussion. Obviously the proposed changes could not be achieved overnight but if the general policy were accepted we could at least begin to implement them. In view of the general state of the mining industry the present might be a particularly opportune time to start any recruiting. In conclusion I believe that what I have said regarding regional geochemists is equally true in the case of geophysics. Availability of these specialists in each region would help ensure an optimum balance was attained between the two approaches.

L. D. James.

LDJ:db

L. D. JAMES

RECEIVED 15
DEC 13 1971
EXPLORATION DEPT.

GEOPHYSICAL NEEDS IN ASARCO'S EXPLORATION DEPARTMENT

(Talk given by C. K. Moss at Asarco Exploration Conference, Palm Springs, California, December 1971.)

The theme for this conference as you all know is "New Ideas for Exploration". Actually, I did not submit a formal new idea for geophysics for the conference. However, since I had been harassing John Collins with complaints about the lack of effect that geophysics has been having in Company exploration, John instructed me to treat this as a subject for discussion here.

Perhaps the title for my remarks could be "Why the Dearth of New Geophysical Ideas in This Conference".

In this conference there have been many ideas contributed by the geologists for new approaches to the problems which they face in exploration. Each geologist is keenly aware of needs for new solutions to old problems, and he obviously spends appreciable time searching for new ideas within the framework of his specialty.

New ideas for geophysics are conspicuously absent in this conference. Certainly this is not because all geophysical approaches have been exhausted. Quite the contrary, there are many different methods and techniques waiting to be applied in the proper place and time in exploration, and new advances in instrumentation and interpretation are continually being made.

The needs in Asarco's Exploration Department are two-fold, in my opinion. First, we do not presently have geophysicists spread widely enough throughout divisional offices that the numerous and varied problems encountered in the regional offices can be given adequate individual geophysical consideration.

Secondly, I believe that the image and function of a divisional geophysicist should be changed from that commonly visualized by members of this Department. The geophysicist should be concerned not only with providing assistance in the implementation and interpretation of geophysical surveys over prospects located by the geologist, (which is the role normally pictured for him); his job should also include the responsibility of viewing geophysics on an independent and often broader basis in the interest of finding criteria that might result in more effective utilization of geologic mapping, geochemical surveys, and provide targets for later more specific geophysical surveys.

On past occasions when I have asked one of our Supervisors whether a

geophysicist would not be valuable on his divisional staff, I have commonly gotten the answer that he did not feel that the geologists could keep a geophysicist busy on a full time basis.

I contend that a properly qualified geophysicist would largely keep himself busy, and could in some cases help the geologists to better direct their own field efforts.

To play such a role fully, a geophysicist would need to be a man with experience, imagination and judgment so as to rate an influential position within the staff.

Geophysical personnel of the Salt Lake Office try to fill the same dual capacity which I suggest should be that of a divisional geophysicist. First, we are concerned with consultation with geologists on geophysical applications and interpretation; and we have secondly been searching for new ways to assist in exploration. As an example of new approaches to exploration with which we have been concerned, we have, I believe, found in recent years new relevance in magnetics as related to copper mineralization in Arizona. We have also in recent months found promise in computer treatments of magnetic data in Southeast Missouri which should assist in locating potential areas for stratiform mineralization; and from an instrumental standpoint we have made progress in devising special electromagnetic equipment for direct detection of the sulfide mineralization in Southeast Missouri. I believe that these developments could well have an important impact on future exploration in these respective areas.

The special attention we in Salt Lake have given to Arizona and Missouri has been an outgrowth of the many years of our geophysical involvement in these particular districts. This involvement provided us with a comparatively intimate familiarity with local geology and mineral controls. I believe that similar new geophysical approaches could be found in most, if not all of the Company's divisions, if sufficient time and effort were directed in this line.

Unfortunately, from our position, the widespread location and diverse character of Company projects throughout the world precludes the possibility of adequate geophysical study programs from a single office, such as Salt Lake, hence there is the requirement for geophysicists at divisional locations, to handle such important work.

To summarize my feelings for personnel needs in Asarco:

I believe that the possibilities for new applications and innovations in geophysics are as great as they are in geology. I believe fullest realization of these possibilities can best come through the employment of competent geophysicists at divisional levels. These men would work directly with

geologists to gain the greatest possible familiarity with local geology.

Such geophysicists should be employed on the premise that they could expect in time to become senior members of the exploration staff where their experience and knowledge would be used in conceiving, planning, and implementating new exploration projects.

I would point to Bill Saegart as an example of a man who at least briefly held an influential geophysical position in a divisional office. Most of you know Saegart although perhaps some do not know he was a geophysicist.

During the brief period of time he worked directly as a geophysicist, Bill gave geophysics of his division a strong shot in the arm.

EXPLORATION SERVICES DIVISION
3422 SOUTH 700 WEST
SALT LAKE CITY, UTAH 84119

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J. H. C. DEC 23 1971
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December 20, 1971

Mr. J. H. Courtright
Tucson Office

ASARCO EXPLORATION CONFERENCE
RECORD OF PROCEEDINGS
DECEMBER, 1971

Dear Harold:

Enclosed is a summary of my remarks made at the subject conference concerning ASARCO Exploration Record Sheets.

As I understood Mr. Collins' instructions, each speaker was to send a copy of his talk to you for compilation into a general proceedings booklet which in turn will be circulated to each of the regional offices for a permanent record of the conference.

Most of my talk was off-the-cuff and the discussion went to great lengths so this is, at best, a poor record of my part of the proceedings. Perhaps copies of the two proposed newly revised Record Sheets can be included within the proceedings even though they were unavailable at the conference.

Good Luck!

M. P. Barnes

M. P. BARNES

MPB/mb
Enc.

Summary of Remarks Concerning
Recording of Geologic Data on ASARCO
Exploration Record Sheets Made at the
Exploration Conference in December, 1971

by M. P. Barnes

Introduction

Nearly all of those present have had some experience now with the ASARCO Exploration Record Sheet for computer index and storage. Most of these sheets are for literature search, but a few have been filled out for field examinations. After some experience a few people from the various offices have made comments and suggestions concerning the formats of the sheet. We were hoping we would get more feed-back from people who have had experience using the sheets, but I believe now we have learned enough to proceed from the pilot stage to the finalized plan for the Exploration Record Sheets.

General

One major concept that needs to be emphasized here - from this time on we are going to talk about two types of Exploration Record Sheets. Please note that we are not emphasizing computer record sheets. The finalized sheets with formats somewhat similar to the pilot model will be the only records made for literature and file search and for field examinations that are not followed up by more comprehensive reports. Even the more comprehensive reports will be summarized on the field examination summary record format. Again I emphasize, forget the computer aspect of this system for the time being. Think of these record sheets as a check list for noting pertinent data whether in the field or during literature study. The original sheets will be retained in the regional office in a notebook file just as Mr. Courtright has requested that the original reconnaissance exploration file sheets be kept in the past.

The intent is to use the exploration record sheet as a check list while making literature search for recording pertinent information about a property, prospect, mine, mining district or favorable geologic area. The only reason such information is recorded is because the data may be useful at some later date. Again let me emphasize that the literature summary sheet is to be filled out only when searching literature with reference to geological and mineralogical features of specific geographical location or boundaries. Researching of generalized topics or subjects will not be referenced on this sheet. Total negative data or very generalized regional literature studies should not be recorded on this record sheet.

The intent of the field examination sheet is somewhat different from that of the literature search record sheet. An examination resulting in negative findings or a reject by the geologist should still be recorded as fully as possible because, of course, such information will be of value to future geologists and may prevent further examination in the future.

In the pilot program we have attempted to use a single sheet format to record all information whether literature, file, or field examination. I am now convinced that two separate type sheets will be more convenient even though they contain much the same kind of information. For instance, more space can be provided for references of literature and the space can be arranged more efficiently for each of the two purposes. The files will be kept separately so there is no need for their being on the same sheet.

To this point nothing has been said concerning computer storage and retrieval. Properly so. These records are for your use in each of the field offices. At this point in time it is only incidental that the format arrangement is convenient for storage through the computer to magnetic tape. In other words, each of the records kept must be of sufficient merit to stand alone regardless of the intent to store them and retrieve them by a computer in the future. Just how long it may be before we can really begin storing these data at our own computer center for access by the regional offices is still a good question - probably two or three years at least. However, this factor should in no way diminish the necessity of keeping good records now.

A copy of each ASARCO Exploration Record Sheet will be forwarded to J. H. Courtright, the chief geologist and a second copy to myself, M. Barnes, as chief computer geologist. Figure 1 illustrates how these record sheet data will be used for storage through the computer onto mag tape. Magnetic tapes are system dependent, so tape storage will await the finalized computer system to be used by ASARCO.

Updating of the computer file will be done by simply adding to the record file a new sheet properly dated containing the new information.

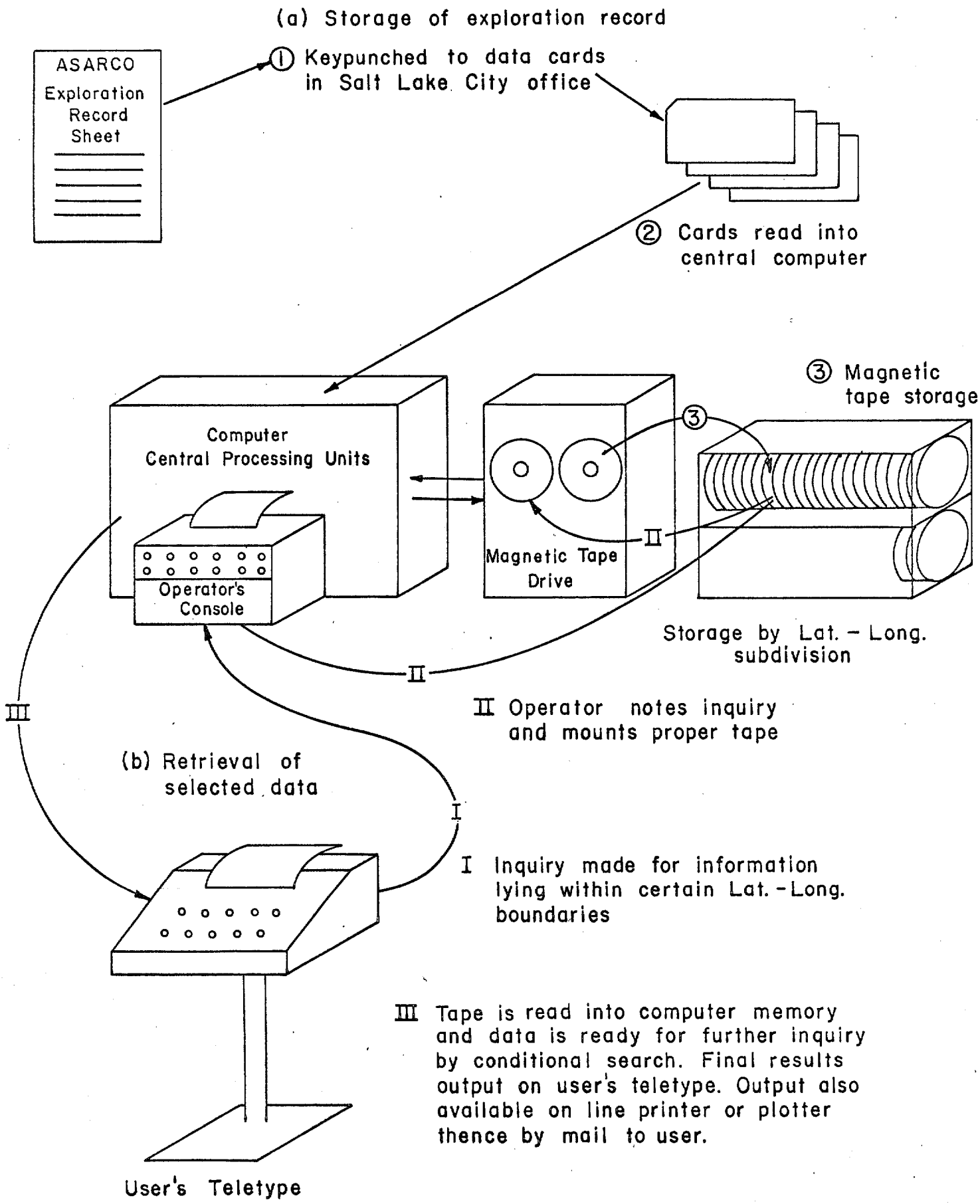
The lower part of Figure 1 demonstrates how retrieval may be made through the computer. Storage within the system will be dependent upon location as recorded by latitude and longitude coordinates. However, search within the system can be conditioned upon any area of information that is available within the stored formats. For example, within any specified area we may be looking for a geological area of some future interest classification, or perhaps a specific metal or commodity, or a deposit related to a particular structural environment. The request may be conditioned upon any of the other parimeters that are recorded with the format of the record.

Summary

To summarize, two ASARCO Exploration Record Sheets will be kept in the future 1) a literature or file search record or 2) a field examination record summary sheet. The information contained within each of these sheets is of sufficient merit to justify keeping it for the regional office information only. A copy of these records will be forwarded to the chief geologist and the chief computer geologist. At some future

time the records will be transcribed to magnetic tape for permanent storage and there will be accessible for selected retrieval through the computer. The ultimate use of such information cannot be fully comprehended at this time, but hopefully these records will be more helpful to the geologists of the ensuing generations than are the records of those who preceded us.

FIGURE I


(a) Storage of exploration record
ASARCO
Exploration
Record
Sheet
① Keypunched to data cards in Salt Lake City office
② Cards read into central computer
③ Magnetic tape storage
Computer
Central Processing Units
Operator's
Console
Magnetic Tape
Drive
Storage by Lat. - Long. subdivision
II Operator notes inquiry and mounts proper tape
(b) Retrieval of selected data
I Inquiry made for information lying within certain Lat. - Long. boundaries
III Tape is read into computer memory and data is ready for further inquiry by conditional search. Final results output on user's teletype. Output also available on line printer or plotter thence by mail to user.
User's Teletype

PALM SPRINGS MEETING - DECEMBER 1971

HOT BRINES OF THE SALTON SEA BASIN

J.H. COURTRIGHT

Back in 1966, the Ore-Purchasing Department of the Southwest received a package of black, brittle material from Los Angeles with a letter requesting an estimate of net smelter return on this "ore". The substance had accumulated in the discharge pipe of a 5200 ft. well near Niland at the southeast end of the Salton Sea. Returns from a Tucson assay lab showed 9.65% Cu and 435 oz. Ag.

Geothermal power was the objective in the Salton Sea Basin drilling. High temperatures (plus 300° C) with considerable power potential were encountered, but the high content of various salts (35%) and corrosive nature of the brine (ph-2) presented real problems. We made some very preliminary investigations and endeavored (without success) to interest ASARCO in "solution mining" of metals. My letter of March 3, 1967 (Att. A) contains a brief review of essential data and an estimate of theoretical metal and non-metal production per month from 10 wells at 1000 gpm each, as follows:

		Short Tons	PPM (in brine)
KCl	-----	72,000	40,000
Li	-----	540	300*
Sr	-----	1,080	600
Zn	-----	1,530	850
Pb	-----	160	90
Cu	-----	16	9
Ag	-----	1.8 (52,400 oz.)	1

*Lithium content from White's March 8, 1963 paper

The Salton Sea Basin contains 20,000 ft. (seismic and gravity surveys) of Pleistocene to Recent sediments with interbedded evaporites (see block diagram, Att. B). The upper 4000 to 5000 ft. are relatively impermeable, and the hot saline brines were not encountered in the shallower wells drilled at first. The brine field lies within a northeast trending line of Recent volcanic domes, mud volcanoes and hot springs, and within 5 miles of the northwest trending San Andreas fault.

Reporting on the first well to penetrate the hot brines, Donald E. White (Att. C) stated "...evidence favors the geologically fascinating possibility that this brine is man's first sample of an active ore solution of the type that probably formed many of the world's economic concentrations of ore metals..." This concept did not long survive "in depth" scientific investigations. Within three years, writers, including White (Att. B), agreed that (1) the brine water was almost entirely of meteoric origin, (2) the salts were derived from the evaporites, and (3) the metals were derived by leaching of the interbedded sediments (with non-anomalous metal contents).

The Quarternary volcanic rocks at Niland are regarded by some as evidence of a magma chamber below which supplied the heat; however, Koenig (Att. B, p. 78) considers the abnormal upward heat flow to be due to the relatively thin crust of the Salton Sea - Gulf of California trough ----- a probable extension of the East Pacific Rise.

Although the brines are now trapped beneath impermeable beds, they may in some future geologic time (if not depleted by man) escape to the surface, or sea floor, and form ore deposits. The Boleo copper deposits of Pliocene age in Baja California probably originated in this manner. Other occurrences no doubt exist along the "trough", but are concealed beneath the sea, or, if on land, have not yet been exposed by erosion.

J. H. Courtright

J.H. Courtright

Attachment A

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona
March 3, 1967

Mr. K. E. Richard, Chief Geologist
American Smelting and Refining Company
120 Broadway
New York, N. Y. 10005

HYDROTHERMAL BRINES
SALTON SEA, CALIFORNIA

Dear Sir:

Reference is made to my letters to you of January 24 and February 14 transmitting data on metal-bearing hydrothermal brine wells controlled by Magma Power and Earth Energy Inc., the latter a subsidiary of Union Oil.

During the recent AIME meeting in Los Angeles, Mr. Saegart, Mr. Watson and I talked with Mr. McCabe of Magma Power and Dr. Carel Ott of Earth Energy. We also attended a lecture on the hydrothermal brines of the Salton Sea Basin by Donald E. White, author of the paper dated March 8, 1963, on the first deep well drilled near the Salton Sea.

Earth Energy later drilled 3 wells ranging from 5000' to 8000' in depth over a distance of 3 miles and conducted extensive tests to determine the power potential of the Basin. One of the 3 was allowed to discharge over a period of 12 months, producing brine at the rate of 500,000 pounds per hour and steam equivalent to 12,000 kilowatts of power. No drop in pressure (300 lbs. per square inch at well head) was noted, nor was there any effect observed on adjacent wells, indicating a reliable reserve of steam for power production.

Due to the corrosive nature of the brine (pH 2) and other problems involved in the production of the contained salts and metals, Earth Energy decided to defer development of the Salton Sea Basin in favor of other areas with essentially pure water accompanying the steam, such as the big geysers 80 miles north of San Francisco, California. McCabe of Magma is not satisfied with this delay and has been attempting to interest other companies, including ASARCO, in making a deal with Earth Energy and Magma Power to invest in research and development of processes to recover salts and other marketable elements, including metals, from the Salton Sea Basin.

The major constituents of the deep well brines of the Salton Sea are NaCl, CaCl, and KCl, totalling 35 per cent. Water makes up 60 per cent and the remaining 5 per cent is composed of numerous metallic and non-metallic elements --- Fe, Cu, Pb, Zn, Ag, Mn, Li, Ba, Sr, S, etc.

McCabe stated that for production of power, 10 wells (at $150,000 each) would be required for a 120,000 kw plant. Cost of a plant for production of salts was estimated at $15 million; no estimate was given as to the cost of the power plant. From 10 wells, the total brine production would amount

to 5 million pounds per hour, or 1,800,000 tons per month. According to the latest analyses given by Dr. White, a month's brine production would contain approximately:

		Short Tons	PPM (in brine)
KCl	----	72,000	40,000
Li	----	540	300*
Sr	----	1,080	600
Zn	----	1,530	850
Pb	----	160	90
Cu	----	16	9
Ag	----	1.8	1 (52,400 ounces)

* Lithium content from White's March 8, 1963 paper

Obviously, these brines are a potentially important source of both metals and salts, providing economic recovery processes can be developed. Dr. White estimated that the Salton Sea Basin contains at least 5 cubic kilometers of brine.

Dr. Ott stated that the salts (NaCl, CaCl, KCl) were recoverable by solar evaporation, but the sodium chloride contained too much Pb to be marketable except for certain industrial uses. According to news reports, Morton Salt (holding adjacent ground) is proceeding with plans to spend up to $30 million on plants to produce sodium and calcium chloride, also potash and anhydrous ammonia.

So far the only reported metal recovery from the brines is that which was precipitated on crushed glass in discharge pipes. A sample of this material sent to Mr. Reed Welch assayed 435 ounces of silver and 9.6% copper.

The brine also may become an important source of lithium, as the demand for this metal could increase greatly if development of the lithium chloride battery is successful. Several companies are engaged in research and one reported during the past year the development of a lithium battery which produces 230 watt-hours per pound --- over 11 times the lead-acid battery (see attachments).

Dr. Ott implied that they did have some research going which might produce important results within 3 or 4 months, but in the meantime they would be willing to listen to any major company's proposal for participation.

Other saline basins may contain metal-bearing brines at depths so far not reached in drill exploration. The Salton Sea Basin contains 20,000' (seismic and gravity data) of Pleistocene, or Recent alluvium interbedded with evaporities. The upper 4000' to 5000' is relatively impermeable, and

the hot saline brines were not encountered in early shallow wells. Of note is the fact that the brine field encompasses an area of hot springs directly over a projection of the San Andreas Fault.

We believe the possibilities of metal and non-metal production from brines merits serious consideration and recommend that a consultant be engaged to assess the risk involved in financing research and development to acquire an interest in the Earth Energy-Magma Power leases in the Salton Sea Basin.

Ralph Parsons, Los Angeles, and Jacobs, Pasadena, are consulting firms specializing in brine production and processing. Stearns Rogers also provides services in this field, but reportedly is now working for Morton in the Salton Sea area.

Yours very truly,

J. H. Courtright

J. H. COURTRIGHT

Attachments
JHC/kw
cc: KERichard, 1x
RFWelch
WESaegart - All w/atts.
SIBowditch
BNWatson

Mineral Information Service
July 1967
Attachment B

THE SALTON-MEXICALI GEOTHERMAL PROVINCE

By James B. Koenig

"HOW TO FIND ASBESTOS"

Prepared for Presentation at the Asarco
Exploration Conference, November 30-December 3, 1971

The subject "How to Find Asbestos" is a large order since the term asbestos, used broadly, covers any fibrous mineral regardless of its composition, physical characteristics or industrial uses. In view of this, I will not attempt to cover the whole field and will confine my remarks to the serpentine variety of asbestos, chrysotile, as my experience has been restricted to that variety and since that variety has the most important industrial applications and serves about 90% of the market. Furthermore, I will only discuss the setting of the most important deposits in North America.

Genesis

As the genesis of chrysotile provides some definite guides for exploration, a brief review of the genesis of the mineral is appropriate.

Asbestos is the product of transformation of other minerals or rocks. The rocks from which the most important chrysotile deposits have been derived are peridotite (pyroxene and olivene), Dunite (olivene only), pyroxenite (pyroxene only), and their near relatives. Chrysotile is a form of serpentine, thus it follows that the original rocks must have been serpentinized in order for chrysotile to be formed. Serpentinization is due to the reaction of the rock

minerals with siliceous solutions under proper conditions. Some authorities believe that these solutions are hydrothermal and were derived from nearby acidic intrusives, others believe that the solutions are a late stage liquid fraction derived from the parent ultramafic rocks, and still others hold that the water and silica are derived from adjacent country rocks during the tectonic ascent of ultramafic masses through the sialic crust. Regardless of the source of the silica and water, our hope is that in this transformation process conditions were such that chrysotile was formed in mineable quantities.

The formation of chrysotile must have been a slow and complicated process, which was related to varied and probably extremely local, tectonic, temperature and pressure conditions. The actual mechanics involved in the development of this fibrous mineral are difficult to explain. P. H. Riordan, an authority on the Thetford Mines District, provides a logical theory which pertains to that district. His theory is presented in his paper ECONOMIC GEOLOGY (1955), "The Genesis of Asbestos in Ultrabasic Rocks". Hans Berger presents a condensation of theories, which he believes to be reasonable, in his book "Asbestos Fundamentals" (Chemical Publishing Co., Inc., 212 Fifth Avenue, N.Y., N.Y.). Berger also discusses the chemistry involved in the formation of serpentine. I recommend both references.

From the above brief statements on genesis it is reasonable to expect that chrysotile deposits will be highly irregular in shape, size, fiber content and fiber quality. Likewise, it is obvious that we should confine our search for major chrysotile deposits to ultramafic rock masses that have been subjected to tectonic activity and have been, at least partially, serpentinized. Beyond this, if we believe that the silica bearing solutions necessary for serpentinization are hydrothermal and were derived from younger acidic intrusives, it follows that we would consider the presence of these younger intrusive rocks as a favorable criteria to be used in selecting ultramafic areas for exploration.

It should be noted that the size and shape of the ultramafic masses, in which important chrysotile deposits occur, vary greatly. They may be dike or sill-like a few hundred feet in width or they may be large plutonic complexes. In addition, it should be noted that the serpentinization with which the chrysotile is associated can vary in degree from moderate to intense.

Exploration

Now that we know that important chrysotile deposits are most likely to occur in serpentinized ultramafic rocks we move on to the subject of the discussion, "How to Find Asbestos". To begin with, I believe I can safely say that most, if not all, important deposits that have been found to date

either had some showings of asbestos at surface or were found as a result of drilling along belts of ultramafic rock in which asbestos deposits were known to be present.

In our recent investigations in the Mt. Shasta area in California we have used what we consider to be conventional exploration techniques. However, as these techniques should have universal application, I believe these techniques and also their limitations should be described.

(1) Choice of Area

If we are starting out with no background knowledge of where to look for asbestos, the first step would obviously be literature research to determine where the favorable host rocks are located and whether serpentinization and/or asbestos occurrences have been reported in these rocks.

As an example, the literature contains numerous references pertaining to the asbestos occurrences in the Shasta area. In all, about 30 occurrences had been tabulated in different publications.

(2) Reconnaissance

Having chosen an area of interest, the most direct approach is to check out the known or reported asbestos showings to determine their importance and their habits and to make a general reconnaissance to determine whether conditions appear favorable and a more detailed reconnaissance is justified. If so, the detailed reconnaissance should be directed toward finding

(a) outcropping asbestos, or (b) fiber weathered from buried outcrops which, combined with soil, forms a cardboard-like mat, or (c) asbestos bearing float in streams. Obviously, along with this, the geology should be mapped to determine significant relationships.

At the Shasta area we have noted, in one instance, that fair sized asbestos bearing boulders have traveled over three miles from their source, but in other instances we do not find float where we would expect it to be. Furthermore, we rarely see asbestos-soil matting. This lack of matting may be a function of rapid weathering and erosion. In any event, it is evident here that the absence of float or soil-asbestos matting does not necessarily mean that there is no asbestos present.

In appraising outcrop and float one must keep in mind that the longest and most fragile fiber usually occurs along the stronger joints and fractures which are the weakest part of the rock. Consequently, when the rock has been broken by weathering processes or by trenching or by blasting it is likely that the best fiber has broken loose from the boulders and will not be readily seen as it will be obscured by the fines or soil. Lionel Piuze of Lake Asbestos tells us that when the rock is broken in mining at Black Lake that the fines may contain about half of the values. Keeping this in mind, if all we see is float and boulders, we can use a plus factor in our appraisal of the grade of the occurrence.

I should mention here that at Shasta the ultrabasic complex has an area of about 750 square miles. The topography is rugged, elevations range from 3000 to 9000 feet and access, in part, is difficult. After our initial evaluation of the 30 scattered showings which had been mentioned in the literature, it was apparent to us that we could not investigate the entire area during the 1971 season. Consequently, we were faced with selecting what we hoped would be the best portion of the area for careful reconnaissance this season before we had developed useful criteria to guide us. However, after grading the 36 occurrences seen earlier on a good, fair and poor basis we noted that the better deposits were within broad belts which followed trends shown on the State geological map. Thus, on this somewhat nebulous reasoning we selected an area of about 320 square miles for fairly detailed reconnaissance on line spacing of about 1/2 to 3/4 miles. In this reconnaissance 41 new showings were found. Broader reconnaissance next year will tell us whether our premise was correct. In fact, our reconnaissance data suggests that the better asbestos showings are near diorite intrusives, hence the diorite may be the key to further search. The air photos, both color and black and white, are now being reviewed to determine the possible significance of numerous linears seen in the photos to the asbestos occurrences. Thus far, it is noted that only four or five of the 77 occurrences are on or at intersections of linears.

(3) Picrolite

At Shasta we see considerable picrolite, a green columnar variety of serpentine. From its observed field relationship with chrysotile we concluded that it is an intermediate stage between serpentine rock and chrysotile. In other words, had the transformation process proceeded farther, the picrolite would have become chrysotile. (Riordan, we find, also subscribes to this theory.) Because of this, we believe that in the Shasta area the presence of numerous picrolite filled veinlets may mean that nearby or at depth conditions favorable for the formation of chrysotile may have prevailed. Picrolite then may well be an indicator mineral. (Note: R. B. Sprague has pointed out that, based on his experience, there is no close relationship between picrolite and chrysotile.)

(4) Color Photos

Color air photos have been of help in the recent reconnaissance at Shasta. Prior to starting the reconnaissance we could read very little geology from the photos, due to the masking effect of the heavy timber and manzanita cover. However, in the field it was found that the subtle color differences seen on the photos became interpretable in that serpentine zones and some rock types could be recognized, but only where vegetation was not dense and where road cuts provided exposures.

It should be noted here that a "color anomaly" seen by Rod Sprague from the air was responsible for his discovery, in 1957, of what is now Asbestos Corp.'s Asbestos Hill deposit in Ungava.

(5) Magnetics

Magnetics, as we all know, can delineate areas of ultrabasic rocks. At Shasta an Asarco air mag. survey flown at 12,000' MSL elevation reflects the ultramafic complex as mapped and shows that the ultramafic rocks extend under older rocks to the south.

As magnetite is often a by-product in the formation of asbestos and it occurs in and along the asbestos veinlets, ground magnetics may be useful in indicating or delineating asbestos deposits. I emphasize may because a relationship between magnetic response and asbestos may not always exist.

(a) At Black Lake a mag. survey was made on the ice covering the lake during the exploration stage. Recently Richard Van Blaricom compared this survey with the ore bodies as presently known and found that the correllation between the magnetics and ore at Black Lake is uncertain.

(b) At the deposit now known as Asbestos Hill in Ungava, Rod Sprague and I observed that proceeding westerly from the asbestos bearing area the veinlets contained more magnetite and less asbestos and finally the veinlets contained only magnetite. In this case, it is probable that a magnetic low, rather than a high, would reflect the asbestos area.

(c) On the other hand, to illustrate that magnetics can be helpful I will describe the results of a survey on the Mt. Eddy deposit in the Shasta area. At Mt. Eddy a small part of the northern portion of the deposit is fairly well exposed in outcrop and in dozer cuts, and after detailed mapping we could tie down boundaries of the deposit fairly accurately. To begin with, a ground mag. test was made by Mr. Van Blaricom over this section of the deposit to determine whether the magnetics would reflect the asbestos zone. As an excellent correllation was obtained over this northern section, the survey was expanded southerly along the trend of the deposit where exposures were sparse and scattered. In this area the magnetics are less definitive. However, the anomalies follow along the trend of the asbestos bearing outcrops and they suggest that the zone may be broader than we can infer from outcrop and float distribution. Although the results in the southern section are more difficult to interpret they do permit us to be fairly confident that the asbestos zone persists southerly and that it has good width. The survey was run on 200' line spacing and 10' station spacing. A Scintrex vertical field fluxgate magnetometer was used.

It should be emphasized that without the closely spaced readings it is doubtful that a meaningful correllation would have been obtained because the average susceptibility of the asbestos zone is not much different than the susceptibility of the barren rocks on either side. The readings over

the asbestos zone were highly erratic in contrast to relatively constant readings over the enclosing rocks. In other words, the highly erratic values are the anomalies. This condition may be due to either remobilization of magnetite into veinlets or reversed polarization of the magnetite in the individual veinlets. Furthermore, it should be pointed out that if the deposit had been covered by perhaps 20 feet or so of overburden or drift it is quite possible that the erratic readings over at least part of the deposit may have averaged out, hence the anomaly may not have been apparent.

(6) Reading Asbestos

Since the chemical composition of asbestos is virtually the same as the host rock and both the physical characteristics and the length of the fiber have considerable bearing on the value of asbestos, we cannot use chemical assays to determine either the amount of asbestos present or its dollar value. As you probably know, there are methods whereby one can make an accurate appraisal of the fiber content and value by measuring and counting the veinlets. These methods are accurate only when continuous clean exposures, such as drill core and walls of underground openings, are available.

As asbestos deposits are erratic by habit one cannot average out a few surface exposures to arrive at a value figure. Nevertheless anyone engaged in looking for asbestos must familiarize himself with the method and use it on large boulders or outcrops so that he can obtain a rough idea of the amount of fiber he is seeing.

It should be noted, too, that weathering tends to make asbestos fiber more brittle, thus if samples are taken to test the quality of the fiber, the samples should be of fresh, unweathered material with no vegetable matter included. Furthermore, to make a proper test using the Quebec test technique the sample must contain enough material to produce one pound of fiber.

Research

Soil Sampling

As you may know, we have done some experimental work to determine whether soil sampling might be applicable to asbestos search. Bill Salisbury, on his initiative, obtained a suite of soil samples, taken below the humus horizon across the Trinity deposit in the Shasta area. The results showed that there was a marked increase in Magnesium and a significant decrease in Zinc and Vanadium over the asbestos bearing serpentine zone. The correllation was really amazing and we thought that perhaps we might have come upon a useful exploration tool, but results from Mt. Eddy failed to confirm the Trinity picture. We are now pursuing the matter further.

Three other lines of research come to my mind; they all involve geophysics:

(1) I.P., as I recall, has delineated serpentinization on at least one occasion in the course of copper exploration, hence I.P. may be an applicable tool to outline serpentine zones.

(2) Resistivity may be able to outline zones of fracturing associated with asbestos as there should be some contrast between fractured asbestos bearing zones and normal country rock.

(3) E.M. will detect shear zones and magnetite in veins, thus E.M. may provide useful information.

If the geophysicists agree that these may be proper applications, I suggest that we try them out over several varieties of known occurrences to determine what correllations may be obtained.

Coalinga Occurrence

I must call your attention to a little publicized, unusual deposit of short fiber chrysotile because the deposit has a huge reserve potential, and because it is possible that similar large deposits containing better quality fiber may exist elsewhere.

About 100 miles S.E. of San Francisco near Coalinga, on the west side of the San Joaquin Valley, a serpentine mass (about 12 x 3 Mi. in area) intrudes Mesozoic sediments. This mass is believed to have been injected when it was cold or nearly cold. The southeastern one-third of this intrusive contains a reserve estimated at "several billion tons" of material reported to average 50% fiber.

The ore deposits are irregular in size and consist of incompetent masses of sheared and rounded serpentine fragments with randomly oriented

flexible, white, matted, plates of fiber which are up to several inches in diameter. The end product of milling is a product comparable to Canadian Group 7 (the shortest category). The fiber is very weak but is very white. The market is very limited.

These deposits were first recognized in 1957. There are three operators, Union Carbide, Coalinga Asbestos (J.M.) and Atlas Minerals. Reference - "New Idria Mining District" by Robert K. Linn in Vol. 2, ORE DEPOSITS OF THE U.S. (Graton Sales)

Closing Statement

I am sure you will have noted from what I have had to say that, primarily, one must look for evidences of asbestos at surface and that there is no substitute for hiking, but there are tools available which can be helpful in this search. I am sure that you have also noted that there is much room for research aimed at developing new techniques that will enable us to find hidden and buried deposits.

In closing, let me say that although the ground rules are somewhat different, exploration for asbestos can be and is just as exciting as exploration for metals.

Keith Whiting

Keith Whiting

ORGANIC MATTER, BLACK SHALES, AND STRATIFORM ORE DEPOSITS

By W.G. Hoskins - December, 1971

Organic matter is the most important constituent in accumulating metals in black shales and may be equally important in the accumulation of metal in economic stratiform deposits.

Over 32,000 rock samples of limestones, dolomites, sandstones, and shales of many geologic ages from throughout the United States were analyzed for organic content. The results confirm that organic matter is widely distributed in all these rocks and the greater the content the darker the rock.

Analysis of sedimentary rocks from seventeen states show a strong positive correlation between the presence of organic matter and the metals copper, nickel, silver, cobalt, chromium, molybdenum, and vanadium, and a positive correlation of these metals to shelf or near shore environments.

A strong positive correlation exists between economic stratiform deposits and organic matter in the form of hydrocarbons or solid debris. Ore districts and deposits showing positive correlations are Mississippi-Valley type ores of the midwest, White Pine, Michigan, Pine Point, Canada, Boleo, Mexico, Zechstein of Poland, the Angouran, Masserat and Lake deposits of Mesozoic Age in Iran, and the Roan series of Africa.

The Chemistry of organic matter meets all requirements for the precipitation of metals in stratiform ore deposits regardless of origin of waters carrying metals.

A careful study of types of organic matter and relationships to stratigraphy and structure in a sedimentary rock known to contain geochemical quantities of metals is most useful in the search for stratiform ore deposits.

ORGANIC MATTER, BLACK SHALES, AND STRATIFORM DEPOSITS

A literature study of organic matter was undertaken to determine the relative abundance of organic matter in sedimentary rocks, its relationship to metals, and if a positive correlation exists between it and stratiform metal deposits.

The most extensive work on the quantity of organic matter in buried sediments was done by Trask and Patnode. They examined approximately 32,000 rock samples from wells in most of the oil producing regions of the United States and found that the average organic matter content of all sedimentary rocks was approximately 1.5%. Carbon was found in every sample analyzed, but limestones generally had a lower content than clastic sediments of corresponding age and geographical position.

Extensive studies of organic content of sediments was also made by Russell. He carried out closed-tube tests on over 700 samples of shales, limestones, and dolomites obtained from 17 states, in rocks of many Geologic Ages. He found bituminous matter to be widely distributed in both limestones and shales, the darker rocks containing the larger amounts.

Organic matter and its role in the accumulation of fossil fuels has been thoroughly studied, but not as applied to metal accumulation.

We can easily visualize the abundance of organic matter necessary to fullfill the requirements for the vast coal and oil fields of the world, but tend to disregard the amount that is not used in making fossil fuels. Estimates of organic matter based on amounts in sediments and waters that are not used in making fossil fuels show approximately 1000 times more than the matter needed for the known fossil fuels of the world.

Organic matter plays a never ending role in its association with metals, from biogenic accumulations of mineral salts during life, adsorption of metal ions from solutions through the period of decay and drifting to final burial, and after burial to the eventual evolution of hydrocarbons as food for bacteria liberating sulphur as H_2S for metal precipitation occurring in other sediments at distances from initial burial.

A summary of the presence of metals in sedimentary rocks was made by Krauskopf, and specific studies of black shales were later made by Vine and Tourtelot.

Krauskopf's study consisted of determining the average content of metals in the crust versus content in shales, sandstones, limestones, and dolomites, and these rocks compared with metal abundance in black shales.

A total of 31 metals were compared; however, only seven of the more economically important were selected for discussion. The seven metals were silver,

copper, molybdenum, nickel, lead, vanadium, and zinc. Comparison shows that average shales are somewhat enriched in these metals and more enriched than sandstones, limestones, and dolomites, but black shales show a much greater enrichment. In black shales silver is 50 to 500 times greater than crustal abundance, copper 3 to 4, molybdenum 10 to 300, nickel 2 to 4, lead 1.2 to 25, vanadium 3 to 13, and zinc 2.8 to 8 times.

Organic matter was divided into three groups, coal, asphaltite and petroleum, and the metal content determined. Coal was not considered to be enriched in these metals, but asphaltite and petroleum were determined to be as enriched as black shales and possibly more.

Krauskopf concludes that all types of carbonaceous sediments show marked enrichment in silver, molybdenum, and nickel. Organic matter in black shales is more similar to petroleum and asphaltite than coal. Petroleum and black shales are characterized by high vanadium and possibly lead, chromium, and zinc. High copper and cobalt were found in ash from asphaltite and petroleum.

The study made by Vine and Tourtelot was to determine if higher concentrations of metals exist in shelf or in eugeosynclinal environments, positive or negative correlations between metals and the relationship of metals to organic matter.

Samples were selected from black shales of ages ranging from Precambrian to Eocene, considered to be from both shelf and eugeosynclinal environments. The samples were broken into fractions of detrital, organic matter, and chemically and biogenically precipitated minerals. Each fraction in each group was assayed for vanadium, chronium, zinc, silver, nickel, copper, molybdenum, cobalt, silicon, aluminum, magnesium, iron, sodium, potassium, titianium, manganese, barium, gallium, lead, zircon, and strontium.

Based on this data it was found that elements primarily associated with the detrital mineral fraction of black shales are silicon, aluminum, magneium, iron, sodium, potassium, titanium, manganese, barium, gallium, lead, strontium, and zircon.

Elements associated with the organic matter fraction were silver, boron, cobalt, chromium, copper, molybdenum, nickel, and vanadium.

Elements associated primarily with the chemical and biogenetically precipitated mineral fraction include iron, calcium, boron, strontium, and zinc, thus elements in this group include constituents of silicious and calcareous shells.

Summarizing from both studies, the following may be concluded:

1. There is a strong positive correlation between organic matter and many metals contained in black shales, and organic matter is responsible for most of this enrichment.

2. Copper, molybdenum, nickel, and vanadium show the most positive correlation with organic matter; however, silver, cobalt, and zinc are positive with copper, molybdenum, nickel, and vanadium.

3. Some samples of both shelf and eugeosynclinal environments have high contents of vanadium, chronium, zinc, and silver, and moderately high copper and nickel.

4. High molybdenum and nickel are characteristic of shelf environments and high barium of eugeosynclinal environments.

5. Molybdenum from shelf environments has 3 to 10 times higher enrichment than eugeosynclinal environments.

6. Eugeosynclinal environments have local concentrations of silver as high as a single bed of metal-rich shale from the shelf.

7. Asphaltite and petroleum ash contain higher contents of metals than coals (which indicated that concentrations of these two hydrocarbons are very capable of precipitating economic deposits of metals).

8. Enrichment in phosphatic rocks is due to organic matter.

9. Metal precipitation as a simple chemical union of two kinds of ions probably plays a less important role than adsorption and biologic processes.

10. Black shales are enriched by metal adsorption on clay particles, but the most important process is by adsorption and bacterial action on organic matter.

Many metals are present in black shales as ions adsorbed on organic matter rather than in different compounds or minerals. Careful work by Wedepohl on zinc in German Black shales, states that only one third to one half of total metal is as sulphides. Perel'man also suggests that in certain reducing environments, metals remain as ions.

All stratiform ore deposits suggest positive correlation with organic matter.

The sandstone uranium deposits in the United States are probably the most thoroughly studied metal deposits containing organic matter. The opinion held by the vast majority of geologists is that organic matter must be present for uranium ore deposition.

The White Pine copper deposit in Michigan certainly contains organic matter, both as hydrocarbons and debris in the Nonesuch Shale and the Copper Harbor Conglomerate.

The following statements are by Hamilton and Ohle, taken from papers given on the Copper Harbon Conglomerate.

Hamilton states, "Native copper occurs mostly as rims around interstitial carbonaceous material, and the carbonaceous material controls the distribution of native copper."

Ohle states, "A positive correlation to which every observer agrees is that native copper in sandstone occurs almost exclusively where there are grains of hydrocarbons."

The Zechstein deposits of Poland and the Kupfershiefer in Germany contain abundant (15%) organic matter. Hydrocarbons as gases are working hazards in the Zechstein deposits.

Touwaide after studing the Boleo Copper Deposit in Mexico states that he believes the ore to be deposited by ground waters of an unknown source that leached copper from flows and tuffs, and the copper was then precipitated by organic matter in the clay.

The following are brief comments on the ore host rocks in some African deposits:

Mufulira Mine - ore is in and around black carbonaceous feldspathic sandstones.

Chibuluma Mine - carbonaceous material in ore body.

Nyanga Mine - copper present in carbonaceous beds.

Roan Antelope - no truly organic matter recognized.

Katanga Deposits - amorphous carbon

Belgain Congo (Lake Moero Zone) - copper in feldspathic carbonaceous sandstones.

The lead-zinc deposits at Pine Point, Canada, are believed by Neil Campbell to be precipitated by organic matter. He states that "Petroleum exploration throughout the western plains of Canada has shown that sulphur and its compounds are widespread in the Devonian and hydrocarbons are not uncommon and in the Pine Point area, solutions containing lead and zinc are believed to have precipitated galena and sphaletite upon coming in contact with these reducing agents entrapped in reef or other reservoirs."

Paul Barton, Jr. states in his paper on "Possible role of organic matter in the precipitation of Mississippi-Valley ores," that, "Small amounts of hydrocarbons are very common as coatings on ore and wall rocks and as immiscible droplets trapped along with the mineralizing aqueous fluid in inclusions."

On, "Precipitation of Mississippi-Valley type ores," Brian Skinner states that organic matter still remains in the sediments and oil accumulations are common in and close to mineralized regions.

In the upper Mississippi Valley district, (Wisconsin, Illinois, and Iowa) the deposits are described as ore occurring in the Galena and Plattevile formations which are brittle limestones, carbonaceous shales, and oil rock and clay.

Alan Hoagland states in a paper on Appalachian stratibound deposits that, "Solid hydrocarbons are found widely, though sparsely distributed in minute cracks in the uppermost 100 feet of the Knox formation. He also states that, "The classic examples are the Mississippi-Valley type deposits of the Tri-State and Wisconsin-Illinois-Iowa Districts which both have abundant hydrocarbons closely associated with ore."

In the southeast Missouri Lead District, many of the deposits lie near the crests of gentle anticlines and reefs. Locally galena lies against biuminous shale. Fresh oil droplets are present in core drilled by ASARCO near Emminence, Missouri, which indicates that within the vicinity, peripheral to the fresh oil, ore may be present. Dan Stewart of American Zinc (oral communication) stated that the "secret" to finding ore was to find a dead oil field.

J. Pereira describes stratiform deposits in Iran and Ireland as being closely associated with organic matter.

The Angouran, Masserat and Kalan deposits of Mesozoic Age in Iran are described as follows:

> The Angouran ore deposit occurs in thin limestone with local bituminous horizons and sand beds.
>
> The Masserat ore deposit is in thin limestone with bitumin.
>
> The Lakan ore deposit is in black and brown shale with graphite.

In Ireland the lower carboniferous deposits of Tynagh, Long Ford and Silver Mines are described as ore occurring in limestones, carbonaceous beds, shales, sandstones, and black muds.

It can be concluded that:

1. Organic matter is present in sedimentary rocks ranging in age from Precambrian to Recent.

2. Black shales are geochemically enriched in metals.

3. Organic matter fractions from black shales contain the highest enrichments of silver, copper, molybdenum, nickel, cobalt, and vanadium.

4. Organic matter is important in the adsorption of metal ions, and in the production of free sulphur for metals through bacterial action.

5. Some percent of contained metals in black shales is present as ions.

6. A positive correlation exists between organic matter and stratiform metal depostis.

7. Petrified and coalified organic matter are unfavorable environments for metal accumulations.

Areas containing sequences of thin bedded black shales in permeable sedimentary rocks may be either of economic importance of secondary sources for ore bodies in the adjacent permeable rocks.

The search for uranium, copper, and silver in sandstone formations can be greatly narrowed by predictions of organic matter accumulations in Paleo-stream channels.

Organic matter as reefs, asphaltite and peripheral zones to petroleum fields, in sedimentary rocks known to contain metals are environments most suited for ore deposits.

A study of organic matter and its relationship to stratigraphy and structure in a sedimentary rock known to contain geochemical quantities of metals is a useful approach in the search for stratiform ore deposits.

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BIBLIOGRAPHY

Baibulatov, E.B. and Sartbaev, M.K. "Characteristics of the Distribution of Copper Mineralization in the Cretaceous Deposits of the Southern Slope of the Alaiskii Range." Geol. Institute, Academy of Sciences USSR. Translated September-October 1966.

Barton, R.B., Jr. "Possible Role of Organic Matter in the Precipitation of the Mississippi-Valley Ores." Econ. Geol. Monog. #3, 1968, pp. 371-377.

Boyle, R.W. and Garrett, R.G. "Geochemical Prospecting - A Review of its Status and Future." Earth Science Reviews, 1970, pp. 51-75.

Campbell, N. "Genesis of Strata Form Lead-Zinc-Barite-Fluorite Deposits." Econ. Geol. Monog. #3, 1967, pp. 65.

Emmons, W.H. "The Principles of Economic Geology." McGraw-Hill, 1940, Chapter 28.

Hamilton, S.K. "Copper Harbor Conglomerate." Econ. Geol. Vol. 62, No. 7, November, 1967.

Hoagland, A.D. "Appalachian Stratabound Deposits." Econ. Geol. Vol. 66, 1971, pp. 805-810.

Krauskopf, K.B. "Organic Material in Sediments." Introduction to Geochemistry, McGraw-Hill, 1967, Chapter 11.

Krauskopf, K.B. "Sedimentary Deposits of Rare Metals." Econ. Geol. 50th Anniversary Volume, 1905-1955, Part 1, pp. 411-463.

LeVorsen, A.I. "Geology of Petroleum." 1958, pp. 475-517.

Malouf, E.E. "The Role of Microorganisms in Chemical Mining." Mining Engineering, November, 1971.

Malyuga, V.I., Proskuryakov, M.I. and Sokolova, T.N. "Distribution of Exogenic Copper Concentrations in the Ural Region." Institute of the Academy of Sciences of the USSR, Moscow. Translated November and December 1966.

Narkelyun, L.F. and Bezrodnykh, Y.P. "Ore Mineralization in the Lenian Cupriferous Sandstones." Geol. Institute, Academy of Sciences of the USSR. Translated November-December 1967.

Ohle, E.L. "Copper Mineralization in Upper Part of Copper Harbor Conglomerate." Econ. Geol. Vol. 63, No. 2, March-April, 1968.

Perel'man, A.I. "Geochemistry of Epigenesis." Depart. of Geochem., Institute of Ore Deposits, Petrography, and Mineralogy. Academy of Sciences of the USSR, Moscow, Plenum Press, New York, 1967.

Pereira, J. "Stratabound Lead-Zinc Deposits in Ireland and Iran." Econ. Geol. Monograph #3, 1968, pp. 192-199.

Russell, W.L. "Some Characteristics of Organic Content of Rocks." Bull. Amer. Assoc. Petrol. Geol., Vol. 18, 1934, pp. 1103-1125.

Skinner, J.B. "Precipitation of Mississippi-Valley Type Ores." Econ. Geol. Monog. #3, 1968, pp. 363-370.

Vine, J.D. and Tourtelot. "Geochemistry of Black Shales Deposits." U.S.G.S. Bull. 1214-E.

White, Donald E. "Outline of Thermal and Mineral Waters are Related to Orgin of Mississippi-Valley Ore Deposits." Econ. Geol. Monog. #3, 1967, pp. 379-382.

Whyte, R.J. and Green. "Geol. and Paleogeography of Chibuluma West Ore Body, Zambian, Copper Belt." Econ. Geol. Vol.66, 1971, pp. 400-424.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

June 6, 1972

To: Division Supervisors

Enclosed are Papers given at the December, 1971, Exploration Meeting in Palm Springs, as listed below:

1. R.L. Brown - Metallogeny - A Little Used Technique in ASARCO.

2. R.E. Gale - Zonal Interpretation as an Exploration Tool.

3. J.C. Balla - Relative Position of Porphyry Copper Deposits to Barren Laramide Stocks.

4. F.T. Graybeal - Copper in Biotite as a Guide to Porphyry Copper Deposits.

5. B.J. Devere - Resurgent Volcanic Centres and Their Role in Porphyry Copper Localization.

6. A. Giesecke - The Application of Nappe-Tectonics to the Arizona-Sonora Copper Province.

7.* R.B. Sprague - An Exploration Project in North America Based on European Ideas of Ore Genesis.

8. P.N. Walker - Localization of Major Stratiform Ore Bodies.

9. S. Von Fay - Common Factors in Stratiform Copper Bodies and Their Significance as Exploration Guides.

10. H.C. Williamson - Gossans (Recent Advances in the Identification of Leached Outcrops).

11. R.S. Gray - (A) Geochemical Indicators for W.A. Nickel Sulphide Deposits; (B) Selection of Areas Favorable for McArthur-Type Sedimentary Base Metal Deposits; (C) Role of Gypsum in the Formation of Base Metal Deposits.

12. S.A. Anzalone - Asbestos Exploration by Optical and Chemical Analysis of Stream Silt and Soil Sample.

13. W.L. Kurtz - Geological Information - Drill.

14. L.D. James - Geochemistry and the Exploration Department.

15. C.K. Moss - Geophysical Needs in ASARCO'S Exploration Department.

16. M.P. Barnes - Recording of Geologic Data on Exploration Record Sheets.

17. J.H. Courtright - Hot Brines of the Salton Sea Basin.

18. K. Whiting - "How to Find Asbestos".

19. W.G. Hoskins - Organic Matter, Black Shales, and Stratiform Ore Deposits.

*Paper will be distributed at some later date.

J. H. Courtright

J.H. Courtright

Encls: as noted

cc: J.J. Collins w/encls.

METALLOGENY, A LITTLE USED TECHNIQUE IN ASARCO

In the following paper, the technique of metallogeny is defined and described. The opinion is expressed that the technique can be useful as a preliminary study which may be profitably carried out prior to the commencement of exploration in new areas. A study of the metallogenic patterns in the Northern Appalachian System of North America is given in an effort to demonstrate how these techniques can be employed.

The first metallogenic studies were made by the Russians, who were faced by vast areas of unexplored, unmapped territories, and who also had severe commodity requirements. As a result of these factors, the Russians engaged in large conceptual studies in which various metallogenic ideas were defined. Early papers by Bilibin, Semenove and Labazin, all written in the 30's and 40's formed a basis for later workers both in Europe and in North America. Potter and McCartney have metallogenic papers in various Canadian journals.

Unesco and the French Department of Geological and Mining Research are putting out a set of metallogenic maps which will cover Europe on a scale of 1:2,500,000. Metallogenic maps on a similar scale for North American are being compiled jointly by the Geological Survey of Canada and by the United States Geological Survey. The European maps, at least, are superior and it will be possible for workers in the field of metallogeny in Europe to confine their efforts to second or third order studies on larger map scales after the complete map set is published.

Metallogeny is a system of classification of mineral deposits which attempts to show how various types of deposits are individually located in terms of geological space, time, and history. Metallogeny is not merely an exercise which results in the plotting of the location of deposits containing various metals. It is rather a study which results in the production of maps which display the basic characteristics of each deposit, including the size of the deposit, the valuable minerals contained in the deposit, the nature of the gangue minerals, the wall rocks, and the generally accepted genesis of the ore. Needless to say

the mere mechanics of showing all this information on a small scale map is a difficult chore in itself. Since one aim of metallogenic maps is to point out the relative economic importance of the various areas shown on the map, the mere question of how many unimportant showings should be plotted becomes important. One can recall one effort at a metallogenic study of the Appalachians which would lead one to believe that the State of New Hampshire, where production has been trivial, is in fact a more important copper producer than the Island of Newfoundland, where production has been important. The reason for this error was of course that the copper showings in New Hampshire are well documented, whereas there is little published information regarding the mineral deposits of Newfoundland.

No decent metallogenic map can be constructed if the detailed geological history and structure of the area involved is not considered. Therefore an important phase of a metallogenic work involves simple study of the geological development of districts. This study involves construction of Paleo-geological cross sections, which show the development of the district from the very earliest geological time through post-mineral times. After this type of geological picture is built up, the development of the various mineral deposits is fitted into this picture.

The bedrock history of the Northern Appalachian System started in the late Precambrian and essentially ended in the Triassic Period. The basics of the structure and rock types of the area are better known in the Northern Appalachian than perhaps any rocks in the world, as they have been exhaustively studied and interpreted by Schuchert, Kay, Billings and Cady. In addition, analyses of Appalachian geology in terms of plate tectonics have recently been published by Bird and Dewey.

Bird and Dewey's concepts of plate tectonics, combined with Marshal Kay's well known descriptions of the geosynclinal structures in the Appalachians were shown on a number of plates.

The oldest rocks in the north-eastern Appalachian System are Proterozoic, and these old rocks are exposed in the Adirondack Mountains,

the south Labrador Coast, in the northern arm of Newfoundland, in Nova Scotia, and in south-eastern New Brunswick. The Grenville of the Adirondacks and of the Labrador Coast is considered to have been stable, but some writers feel that the Precambrian of the Maritime Provinces in Nova Scotia and in New Brunswick was refolded during the Taconic and Acadian epochs. All the Precambrian rocks however were more or less resistant to structural change, and they formed the foundation on which the Paleozoic geosynclines were formed.

The first of these geosynclines was the mio-geosynclinal belt of the Champlain Valley, the Gaspe Coast of Quebec, and of Western Newfoundland. This geosyncline was characterized by the deposition of carbonate rocks, of gentle depositional conditions presumably of lagoonal beds, all of which conditions lasted throughout the Cambrian and Ordovician Ages. The depositional history of the Champlain geosyncline was completed in the late Ordovician.

A eugeosyncline, marked by violent volcanic conditions, and located in the belt running through Eastern Massachusetts, New Hampshire, Northern Maine, Central New Brunswick and Central Newfoundland was formed during late Ordovician, Silurian and Devonian times. Depositional conditions in the eugeosynclinal belt were far more violent than in the mio-geosyncline of the Champlain Valley and the Gaspe.

While there is some on-lap between the two parallel geosynclines, it is thought that they were mainly divided by a Precambrian highland which is still seen in the backbone of the Green Mountains of Vermont. At any rate there is a clear division between the two belts of present day rocks, and there is in fact a further subdivision in the volcanic rocks of the eugeosyncline which will be commented upon later. The late Ordovician was the occassion of the first great era of folding and of thrust faulting. It was during this period that the Taconic over-thrusts (gravity slides ?)occurred, and it was during the Taconic that the greatest amount of folding and of faulting occurred in the Appalachian System.

The Acadian Revolution, which was confined more to eastern New Brunswick and eastern Newfoundland is thought to have occurred in the late Devonian and also was the occassion of more localized folding and faulting, as well as igneous intrusion.

I have seen papers which have speculated that the Taconic Revolution was caused by an uplift along a belt running through eastern Massachusetts, the New Hampshire-Maine border and thence northerly through New Brunswick and Central Newfoundland, which elevated the core of the eugeosyncline and that the western directed compression and of flat faulting (Logan's Line and others) was due to the "drainage" of rocks off the western side of this uplift. This theory is offered as an alternative to the classic ideas of the compressional forces originating in the mid-Atlantic.

Carboniferous sedimentation was wide spread but not ubiquitous. Carboniferous rocks are known in Nova Scotia, Central New Brunswick, and in Rhode Island. These depositional centres are isolated, but the biggest area of Carboniferous deposition was the Moncton Basin which is some hundreds of miles in diameter and in which an accumulation of red sandstones, coal, and red silt rocks took place.

The last depositional event in the Appalachian System took place during the Triasic, when red beds were deposited in taphrogeosynclines in Connecticut, and in central Newfoundland. The Cabot fault, the subject of a number of papers by Tuzo Wilson, including one with the interesting title "Did The Atlantic Close And Then Reopen?" , is without doubt the most important structural feature in the Appalachian System. It extends from eastern Massachusetts through the Bay of Fundy through Cabot Straight and through West Central Newfoundland. It is the site of a number of ophiolites and has contributed to a wide variety of interesting questions now being studied by Williams, Smitheringale, Neale and others.

Wilson originally proposed this fault on the basis of gravity

information and also on the basis of the fact that European type fauna are found in Newfoundland and in Nova Scotia to the east of the fault and North American type fauna are found to the west of it. He takes the view that the Cabot Fault could be an extension of the Glen Cove Fault of the northern British Isles.

The implication is that under-thrusting of a continental plate occurred in early Paleozoic times, the Beniof zone lying approximately in the same position as the Cabot Fault. The theory would go on to propose that during late Paleozoic and Metazoic times under-thrusting of this plate ceased and in fact that the under-thrust plate retreated and great rift zones in approximately the same position opened up.

Unresolved questions, such as what was happening at the mid-Atlantic ridge are still open questions but presumably answers will be coming which will fill in these gaps.

In any case, it is easy to draw a set of convincing sections based on Marshall Kay's older work and on the newer sections of Bird and Dewey. The distribution of mineral deposits in the Appalachians becomes easily explainable and predictable on the basis of these sections. The oldest deposits of any interests to us are the lead-zinc deposits of the early paleozoic. Occurrences of this type are present in the west coast of Newfoundland, on the north shore of the Gaspe Penninsula, and in Western Vermont. These deposits are all marked by limestone-dolomitic interfaces, by collaspe breccias, and they are apparently very small, but typical examples of Mississippi Valley type mineralization. The area in which they may be found is marked and is confined to the western half of the Champlain Valley-St. Lawrence Valley- Western Newfoundland Areas. This zone is a definite and well marked metallogenic province, as the exact same depositional conditions and environment existed throughout the entire belt. For some reason the deposits are characteristically smaller than those in the main body of the Mid-continent lead-zinc province of the United States, and presumably this can be accounted for.

The eugeosynclinal volcanic rocks have been the great ore producers of the Appalachian System, and they probably constitute not one but two metallogenic provinces. There are clearly two mineral assemblages in the Appalachians, the most common being the pyrite-chalcopyrite assemblage which constitutes the ore in the majority of the mines in the region. The other association, sphalerite-galena-chalcopyrite-pyrite is of course much more important, and this assemblage is found at Buchans, at Bathurst and in the Blue Hill Area in Maine.

The serpentinites which form the host rock of the important and famous asbestos deposits of Eastern Quebec and Northern Vermont are to some degree an embarrassing feature, as I cannot explain their location in terms of the constructions I have made. As is well known, the serpentinites in the Eastern Townships of Quebec are part of a chain of ultra-basic rocks, or ophiolites which extend along the backbone of the Appalachian System from Alabama to Newfoundland. In Quebec these serpentinites are large enough and close enough spaced so that the asbestos deposits they contain constitute a metallogenic province. The province extends southward into Vermont, and eastward into Gaspe. The deposits are nowhere as important as they are in Southern Quebec. Most people consider that these deposits are also late Ordovician or Taconic in age.

One way of explaining the two mineral assemblages is that the former are associated with mafic rocks which are connected with the Cabot Fault, whereas the sphalerite-galena-chalcopyrite-pyrite assemblage is connected with the more felsic volcanics which had their source some distance from this fault. The obvious indication is that only those rocks in the felsic volcanic assemblage should be prospected.

Another hypothesis is that the complex poly-metallic ores such as Buchans and Bathurst were deposited close to the volcanic cores by the now commonly accepted volcanic exhalative mechanism, whereas the simpler pyrite-chalcopyrite ores were deposited in basins by bio-genetic or some other process in lagoonal basins. A number of problems, having chiefly to do with the spacial location of various deposits of the two types remain to be solved. I prefer this explanation of the two types

of deposits, and would assign only the copper-nickel deposits of such as those of St. Stephen, New Brunswick, and Mt. Katahdin,Maine to the ophiolites of the Cabot Fault System.

Devonian intrusion took place in a wide belt parallel with the trend of the Appalachians, but the belt was sufficiently broad as to intrude both the miogeosynclinal and eugeosynclinal rocks. Where Devonian granitoid rocks were intruded into the miogeosynclinal carbonates, copper deposits were formed and where they intruded the pelitic sediments of the eugeosynclinal zone tin and tungsten deposits were formed. Of these two areas the copper zone is the most important, but it is disappointingly small since it extends only from the Gaspe through the extreme northern New Brunswick and thence into western Maine. This Devonian Copper province is important economically, since it contains Gaspe copper but its exploration significance is limited since it is small and since most of it lies in the State of Maine where mineral rights are practically unobtainable.

Quite obviously, some metallogenic provinces are easier to find than others. The mid-continent zinc-lead province for an example, in which all the deposits lie in lower Ordovician limestones is easy to sketch out on a map. However, I think I have demonstrated that it is extremely difficult to sketch out the various base metal provinces in the Maritime Provinces and in Newfoundland. I think that there is practical necessity of engaging in this type of work in areas which are new to Asarco, and which reconnaissance programs are being initiated. I think that this type of preliminary work could in some cases sharpen the exploration technique required and could also better define the areas to be explored.

R. L. Brown

Toronto, Ontario
May, 1972

ZONAL INTERPRETATION AS AN EXPLORATION TOOL

R.E. GALE

ZONAL INTERPRETATION AS AN EXPLORATION TOOL

There are three different types of zonation of ores which can be discussed.

(1) Zoning in mineral belts or provinces

(2) Zoning in mining districts.

(3) Ore body zoning, or zoning within an individual orebody.

The distinction between the first two classes, mineral belts and mining districts is quite arbitrary and the implied difference, if any, is one of size. A mineral belt may include a number of mining districts which produce similar ores and it may stretch for tens, or even hundreds of miles, commonly there is a suggestion that the many deposits are of a relatively similar age in origin.

A mining district on the other hand is composed of a group of mines which may cover a few square miles in area. The mines produce similar ores which are believed to have a similar time of origin and the mines may all be related to a geological feature such as an intrusive stock or major fault zone, etc.

An example of a well known mineral belt in B.C., as shown in figure 1, is the copper belt which borders the eastern side of the Coast Range Batholith. An example of a mining district within this belt is the Highland Valley area with its several deposits associated with the contact of the Bethsaida quartz diorite porphyry and the older Guichon quartz diorite batholith.

The importance of recognizing and using concepts of regional zoning is:

(1) Recognition of the existence of a mineral belt will allow projections of known areas of mineralization to point out areas of possible extensions in heretofore unknown target areas.

(2) Presence of unexplored gaps in a mineral belt indicate areas which should be explored.

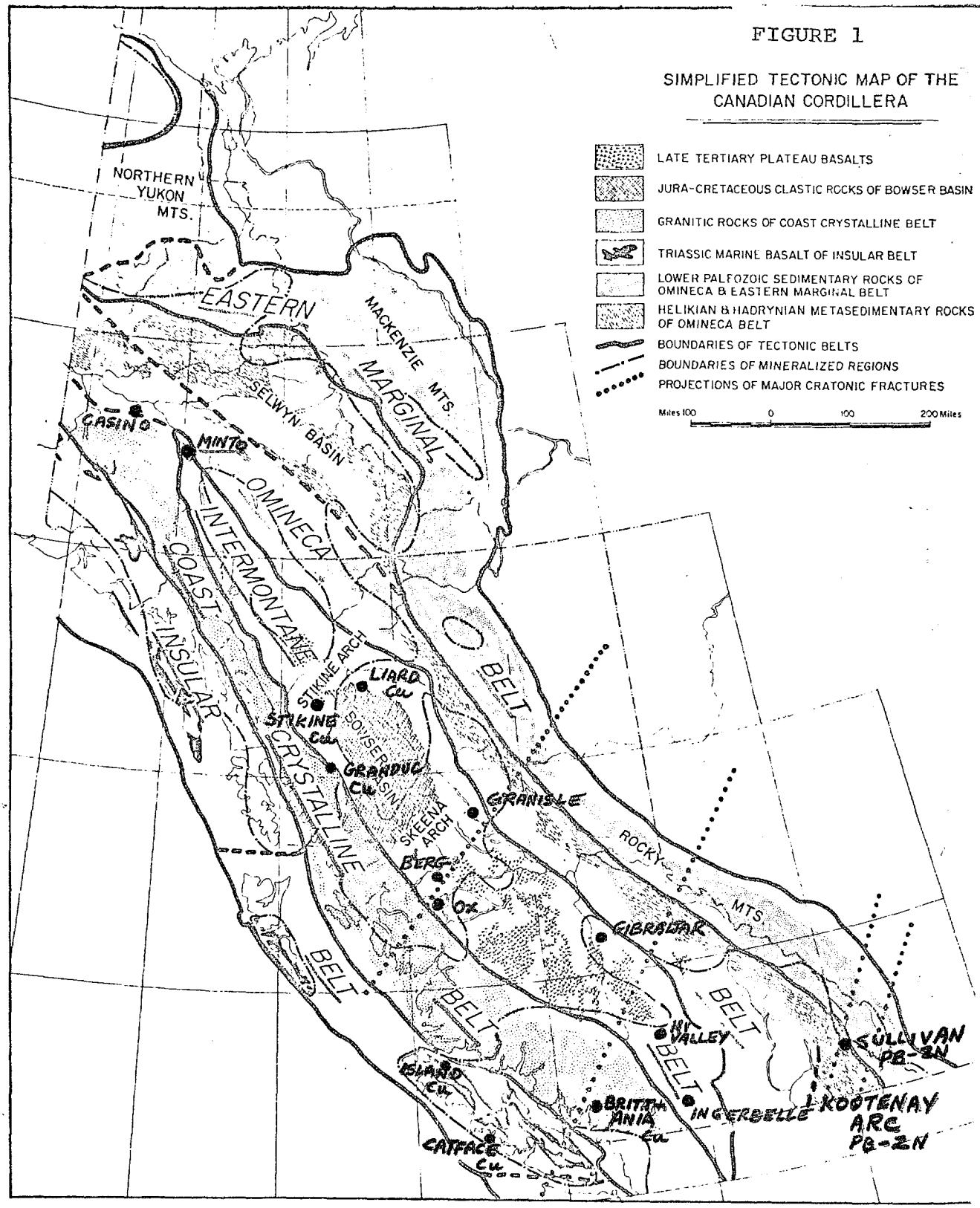


FIGURE 1
SIMPLIFIED TECTONIC MAP OF THE CANADIAN CORDILLERA
LATE TERTIARY PLATEAU BASALTS
JURA-CRETACEOUS CLASTIC ROCKS OF BOWSER BASIN
GRANITIC ROCKS OF COAST CRYSTALLINE BELT
TRIASSIC MARINE BASALT OF INSULAR BELT
LOWER PALEOZOIC SEDIMENTARY ROCKS OF OMINECA & EASTERN MARGINAL BELT
HELIKIAN & HADRYNIAN METASEDIMENTARY ROCKS OF OMINECA BELT
BOUNDARIES OF TECTONIC BELTS
BOUNDARIES OF MINERALIZED REGIONS
PROJECTIONS OF MAJOR CRATONIC FRACTURES
Miles 100 0 100 200 Miles
NORTHERN YUKON MTS.
EASTERN MARGINAL
MACKENZIE MTS.
SELWYN BASIN
CASINO
MINTO
OMINECA
INTERMONTANE
COAST
INSULAR
CRYSTALLINE
BELT
STIKINE ARCH
LIARD Cu
STIKINE Cu
BOWSER BASIN
GRANDUC Cu
SKEENA ARCH
GRANISLE
BERG
OX
ROCKY MTS.
GIBRALTAR
HI VALLEY
SULLIVAN PB-ZN
ISLAND Cu
BRITISH ANIA Cu
INGERBELLE
KOOTENAY ARC PB-ZN
CATFACE Cu

(3) Study of adjacent areas may turn up parallel belts with somewhat different geology and ore types.

(4) Study of known mineral belts throughout the world will yield data which can then be used by analogy to find similar belts of geology in little explored areas. The preparation of metallogenetic maps on a worldwide basis is underway at the present time, under the auspices of the United Nations, and such maps should prove very useful in comparing similar belts around the world.

Ore Body Zonation

My main subject of interest concerns the third type of ore zonation, ore body zonation. The most direct and fruitful use of zonal studies is derived with reference to this third category of mineral zoning.

In many types of ore deposits, but especially in those where the host rocks are relatively uniform in composition, zonal features of alteration and mineralization become apparent. Porphyry copper ore zones show numerous examples of zoning and much data is now being brought together on zonal features in these deposits, which can be put to good use in exploration.

Porphyry Copper Alteration Zones

Recent papers, including Lowell's 1970 work on San Manuel and Kalamazoo ore bodies and Rose's 1970 summary work on several different porphyry coppers has added to our knowledge of zoning in the porphyry deposits.

Figure two is from Lowell's paper on San Manuel. As shown in Lowell's paper, the major features of alteration zoning of porphyries are a "Potassic Zone" of potash feldspar and biotite alteration at the core of the mineralized zone which gives way laterally to a quartz-sericite "Phyllic" alteration and in turn to a chlorite-albite-epidote "Propyltic" alteration at the outer edge of the alteration aureole. In some ore bodies, as in part of the Kalamazoo orebody, an "Argillic zone" containing kaolinite appears as part of the Phyllic zone.

Rose brings up the interesting question as to how much of the sericite alteration seen in porphyry deposits may be due to supergene weathering effects rather than hypogene

FIGURE 2

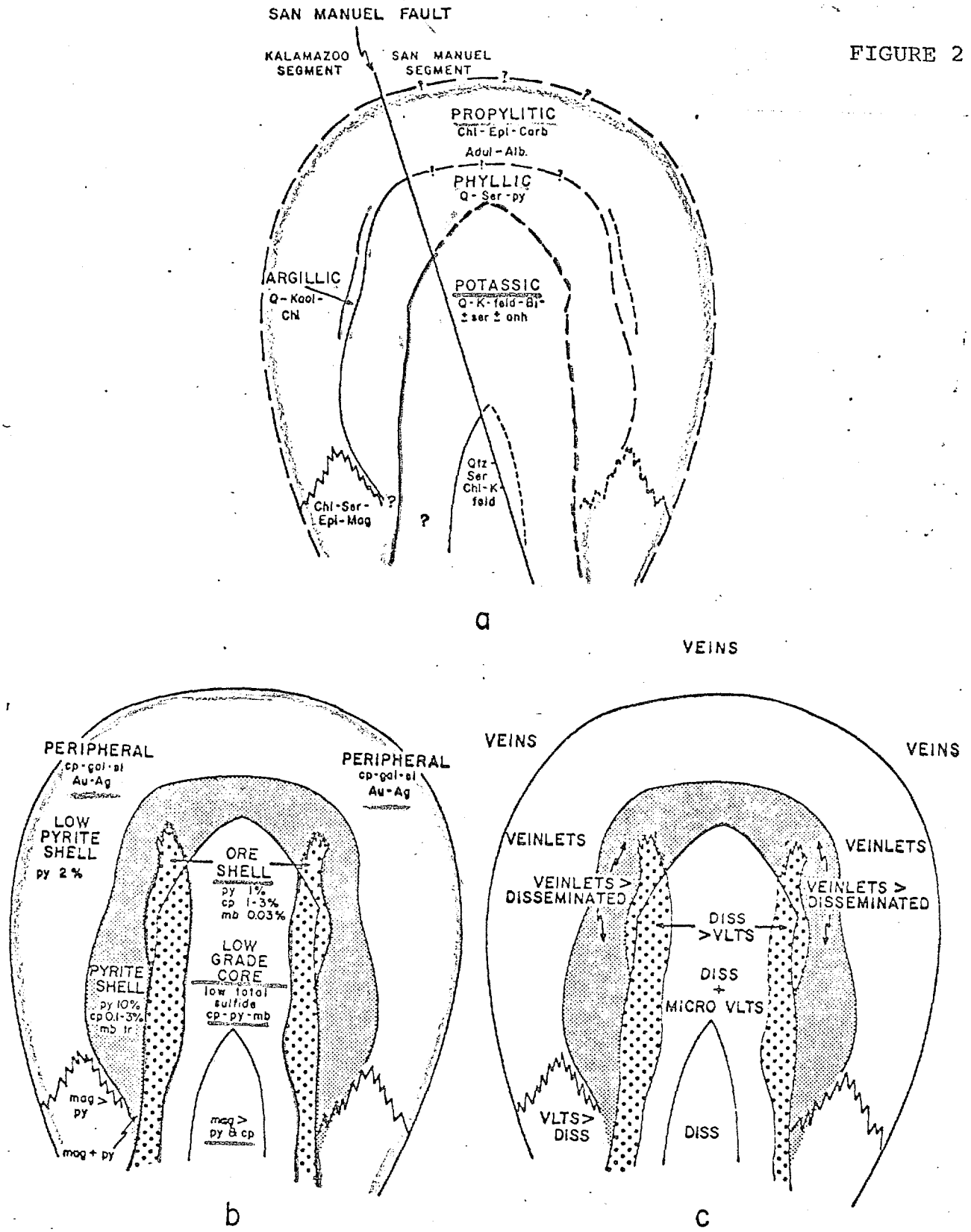


FIG. 3. Concentric alteration-mineralization zones at San Manuel–Kalamazoo. (a) schematic drawing of alteration zones. Broken lines on Kalamazoo side indicate uncertain continuity or location and on San Manuel side extrapolation from Kalamazoo. (b) schematic drawing of mineralization zones. (c) schematic drawing of the occurrence of sulfides.

alteration, with supergene effects superimposed on and obscuring hypogene alteration. Lowell's Phyllic zone disappears and is absent at depth at Kalamazoo. Lowell doesn't comment much about this feature and his data at depth apparently are not too complete. Absence of sericite may be due to vertical zoning at San Manuel.

Under weathering conditions, abundant pyrite in the intrusive forms acid solutions which drastically alter the rock. Often the strongest pyrite is associated with strongly sericitised rocks. Published descriptions of alteration at Ajo suggest that sericitic alteration is relatively weakly developed with essentially only a Potassic and Propyltic zone of alteration present. Apparently pyrite is also not abundantly present at Ajo and the general setting may be more akin to that seen in the Highland Valley deposits in B.C. Sericitic alteration in the latter deposits is not dominant and coincidentally or otherwise, pyrite is also scarce. It is interesting to speculate, therefore, that sericitic alteration may in some cases be more of a supergene than a hydrothermal effect.

Metal Zoning

To return to Lowell's diagram, the most interesting aspect of zoning of porphyry deposits is the zoning of the metallic constituents. The characteristic zoning of sulfides and oxides is known in several porphyrys. It commonly consists of weak chalcopyrite-bornite-molybdenite-pyrite and sometimes chalcocite, deposited near a central low grade core passing outward into a zone of better chalcopyrite-molybdenite-pyrite forming the ore which then gives way to strong pyrite and finally an aureole with galena, sphalerite, gold and silver mineralization.

Vertical zoning is not so well known or described as the lateral effects. The main feature of vertical zoning is that in the core area at depth magnetite and bornite become noteable and pyrite very scarce or absent.

Oxidation - Reduction Processes

The zoning of the metallic constituents of porphyry ore zones indicates that going from the start to the close of the mineralization period a change from the relatively early oxidizing conditions of magnetite-bornite deposition through to later reducing conditions of deposition of chalcopyrite-pyrite and simple pyrite is represented.

The change from oxidizing to reducing conditions as seen in deposition of sulfides, as deposition proceeded, should also be reflected in a changing composition of alteration minerals in their paragenesis. Alteration and mineralization are two phases in one continuing process and the transition from earlier alteration to the later mineralization should take place with no significant break. Any explanation of zonal effects seen in silicate minerals should conform to the general concept of a change toward relatively more reducing conditions as alteration proceeds.

Lowell and Rose discuss only briefly the relative age and sequence of formation of the different alteration zones in porphyryies. Rose believes that in some deposits biotite-orthoclase alteration is contemporaneous with sulfide deposition. Creasy, in his 1959 work on phase relations in porphyry alteration, indicates that the Potassic alteration is superimposed on the earlier Propylitic zone.

Lacking any real idea of the trend or significance of the paragenesis of alteration minerals in porphyry deposits I would like to consider such trends instead in the Mission deposit skarn-ore.

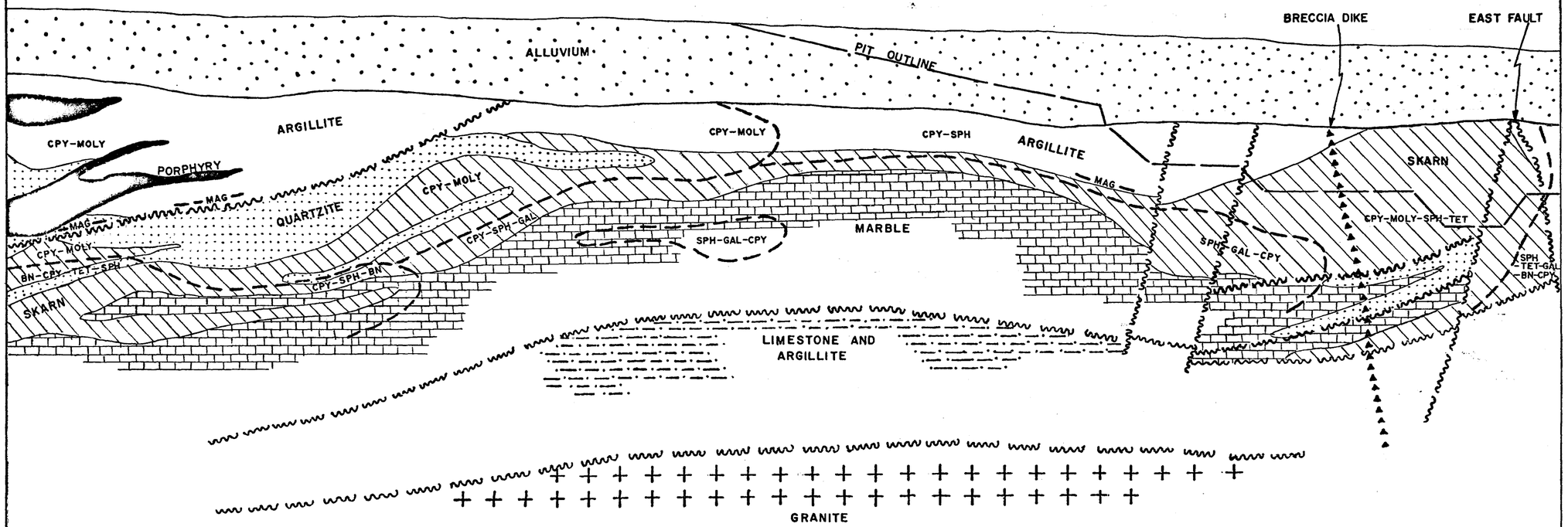
Zoning in the Mission Orebody

In the Mission skarn ores there is evidence of zoning in both the garnet skarn and the ore minerals. This zoning is roughly symmetrical with respect to the quartz monzonite porphyry intruding the western end of the orebody.

Figure three illustrates, in section, important aspects of Mission zoning. The picture is similar to that seen in many other deposits. Bornite-chalcopyrite-magnetite deposited at depth close to porphyry gives way to chalcopyrite-hematite and chalcopyrite-pyrite at greater distance from porphyry. Galena-sphalerite mineralization is prominent toward the eastern end of the orebody. In Figure four, zoning of bornite is emphasized.

In the calc-silicate alteration to garnet and other skarn minerals which preceded mineralization, there is also evidence of zoning with anisotropic yellow and greenish yellow garnets in the eastern and central part of the mine changing to an isotropic red garnet at the western end around the porphyry. Chemically, the change in color is a reflection of an increase in the andradite molecule in the garnet, meaning an increased iron content in garnet at the west end of the orebody.

FIGURE 3 — EAST-WEST SECTION
MISSION ORE ZONE
SCALE 1"=200'



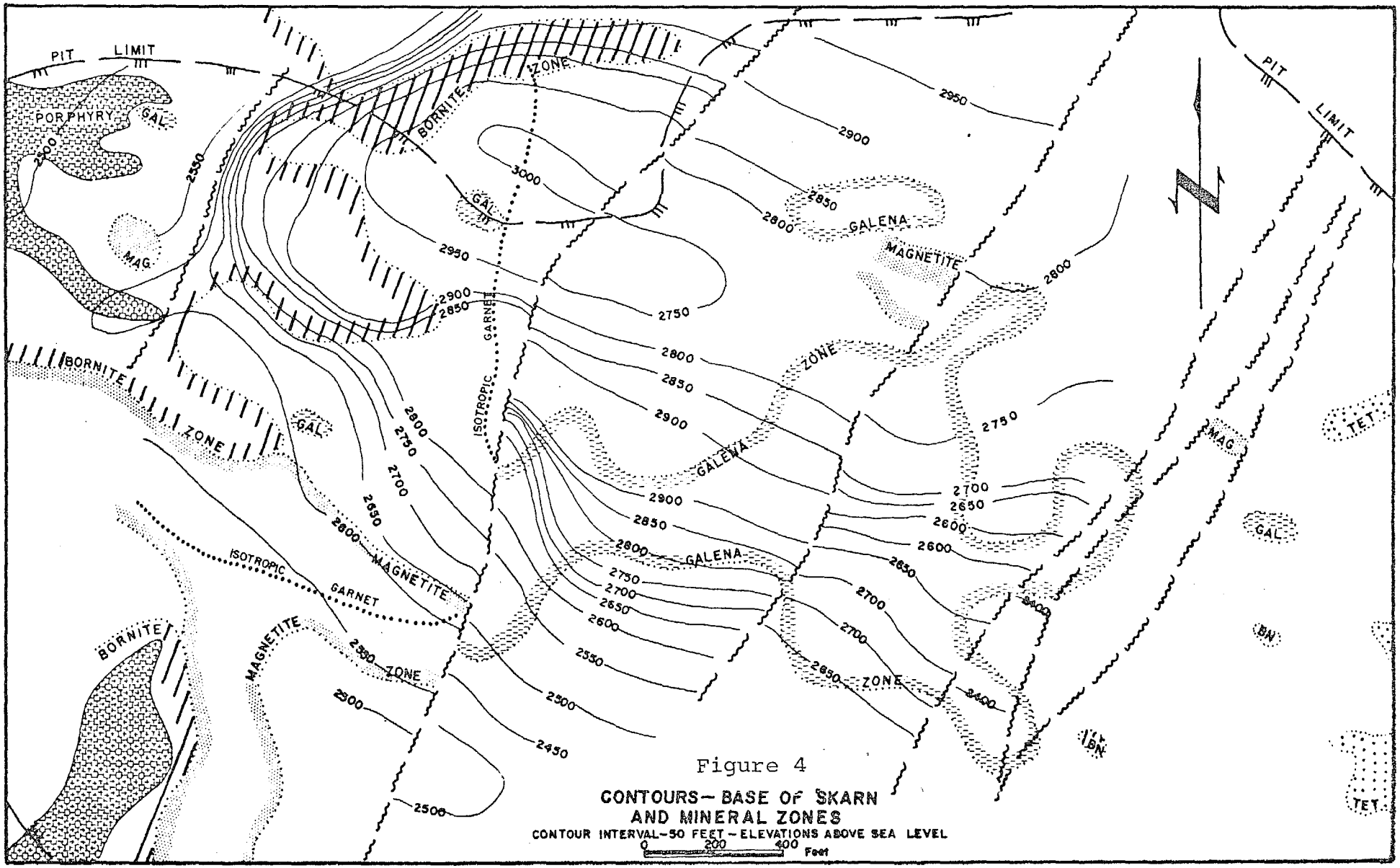


Figure 4

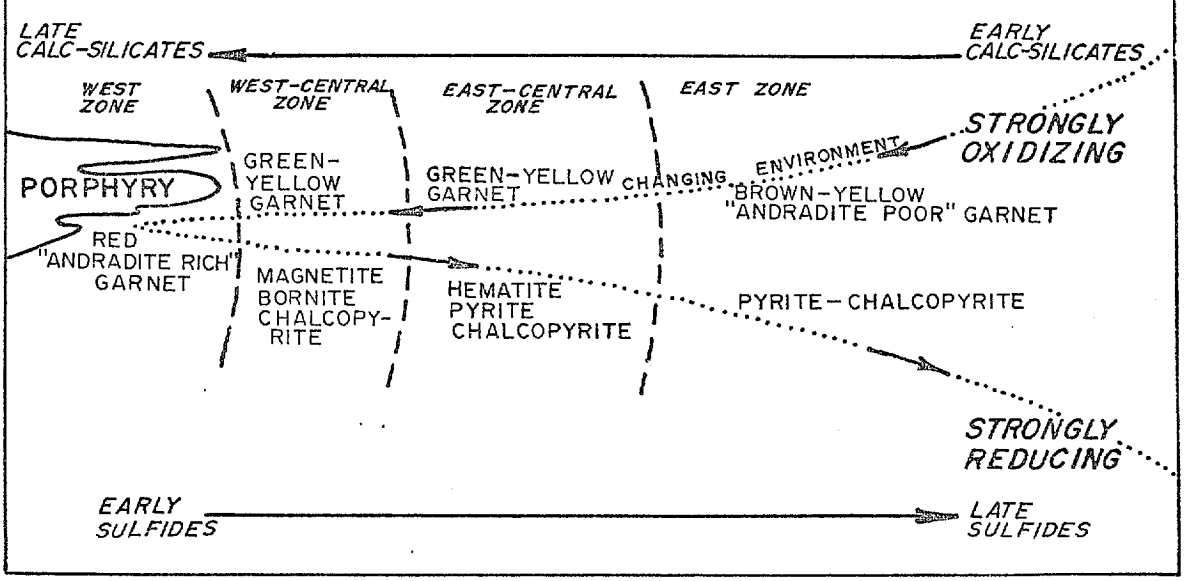
CONTOURS— BASE OF SKARN AND MINERAL ZONES

CONTOUR INTERVAL-50 FEET - ELEVATIONS ABOVE SEA LEVEL

0 200 400 Feet

Figure five summarizes and interprets zonal features to indicate that the earliest alteration phase of the eastern end of the orebody was a relatively iron-poor garnet and at a later stage and closer to the intrusive, the garnets formed were progressively enriched in Fe culminating in the appearance of andradite. The earliest metal deposition saw Fe deposited as magnetite in an oxidizing environment and early accompanying sulfide was a relatively sulfer-poor sulfide, bornite. As deposition proceeded, with falling temperature, a trend to higher sulfer concentration and a more strongly reducing environment resulted in deposition of chalcopyrite and pyrite. The net end result of the Mission alteration - mineralization cycle would seem to have been, among other things, a steady trend toward a more reducing environment coupled with an increase in iron.

Figure 5
ZONAL RELATIONSHIPS AND CHANGING ENVIRONMENT



There is not enough data to attempt to see if the same trend toward enrichment of Fe takes place in the alteration zones of porphyry copper deposits but I would consider it a good possibility. However, Creasy has pointed out that in chemical analyses of fresh and ore rocks from several porphyry mines there is usually a loss rather than a gain of iron indicated.

Use of Zoning in Exploration

Having recognized the existence of zonal features in many porphyry copper deposits, it should be practical to use zoning in detailed exploration of potential ore deposits, especially where one is seeking a relatively small target within a large altered area and even more so where overburden is extensive and interpretation must be made from a few outcrops.

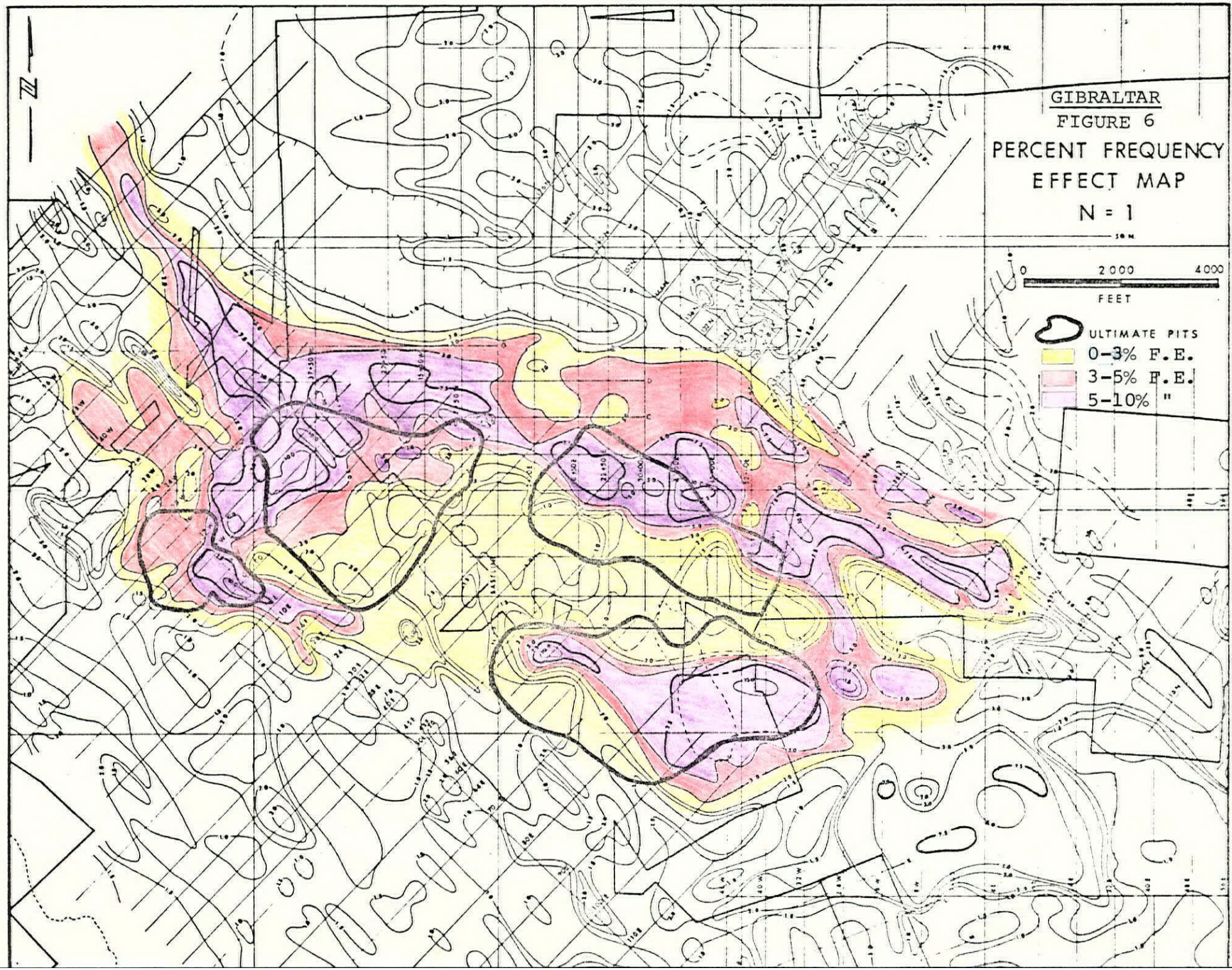
Discovery of The Gibraltar Porphyry Copper Deposit

A case in point in B.C. was the discovery of the Gibraltar copper-molybdenum orebody. This discovery featured the successful interpretation of zoning within a mineralized halo indicated partly in outcrop but mainly by a concentric I.P. Anomaly, which was successfully studied to find the copper-bearing portion of the alteration zone.

Gibraltar is located in the porphyry copper belt of B.C. - close to the midway point between the Highland Valley area and the Granisle Mine. It has reserves of 350 million tons of 0.4% Cu.equivalent with a 1:1 stripping ratio, and is scheduled to go into production in mid 1972 at a capacity of 30,000 TPD.

The Gibraltar ore occurs in a 2-mile long X 1 mile wide zone of chlorite-sericite schists which form a tabular schistose zone within a granodiorite porphyry batholith. The schistosity and mineralization, pyrite, chalcopyrite, bornite and molybdenite which occur mainly as blebs and small seams paralleling schistosity, strike N.W. and dip S.W. at 20° - 30°. This orebody is a true porphyry copper in the early strict sense of the term in that a supergene chalcocite blanket is superimposed on the deposit with the best mineralization occuring as chalcocite and covellite coatings on chalcopyrite.

The early history of the property saw exploration, mainly based on I.P. surveys followed by drilling, going on independently on 3 adjoining properties. Although good grade copper was found in drilling near some I.P. highs, because of the almost total lack of outcrop no real conception of the zonal significance of mineralization was possible before all the I.P. data was combined and it was only then that the total orebody was successfully drilled out.


GIBRALTAR
FIGURE 6
PERCENT FREQUENCY
EFFECT MAP
N = 1
0
2000
4000
FEET
ULTIMATE PITS
0-3% F.E.
3-5% F.E.
5-10% "
N

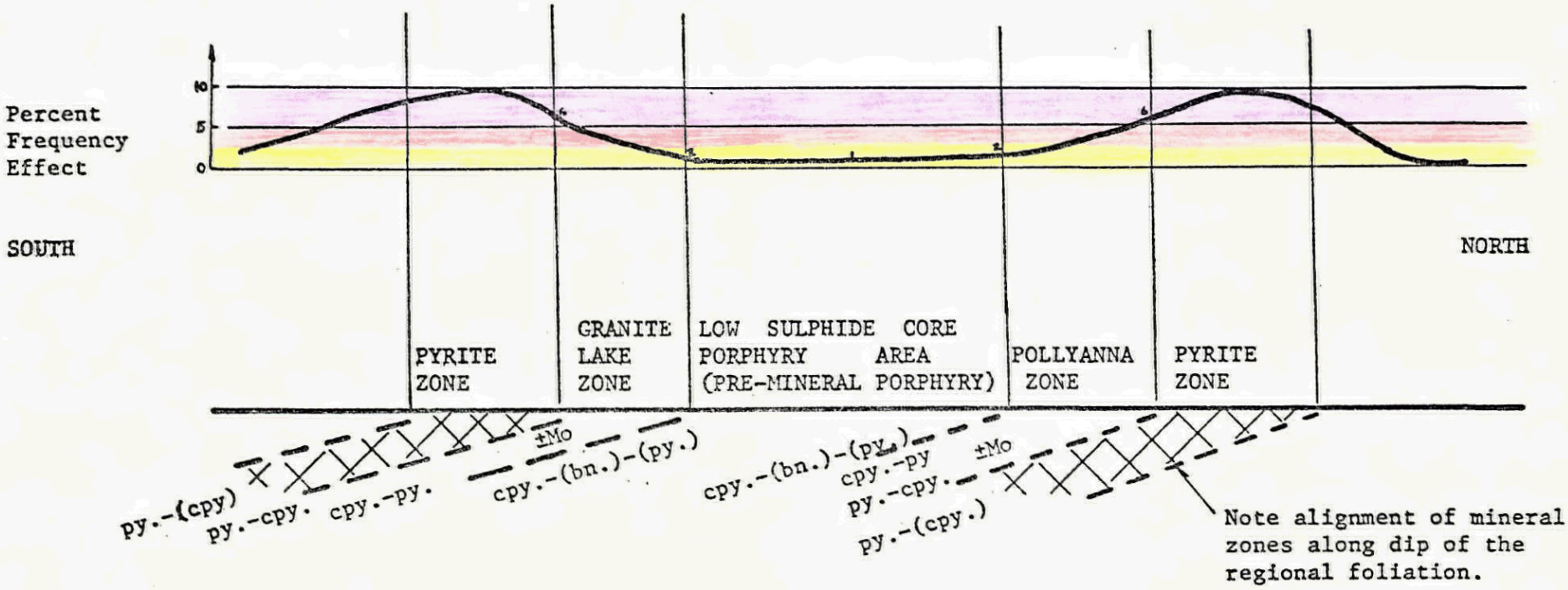


FIGURE 7: Diagrammatic North - South Cross-Section Of The Pollyanna And Granite Lake Zones Showing The Relationship Of I.P. Response, Primary Sulphide Mineral Zoning, And Location Of The Respective Open Pits. (py. = pyrite, cpy. = chalcopyrite, bn. = bornite, Mo = molybdenite, brackets indicate minor amount, if no brackets then both minerals are present in approximately equal amounts.)

Figure six shows the zonal pattern of I.P. frequency efforts at Mission. It became obvious from this zonal pattern that a pyrite halo represented by the strongest I.P. effects graded into a copper-rich zone of more moderate I.P. effect closer to the core of the orebody. It was first inferred and later proven by drilling, that a relatively barren quartz porphyry stock, about which the orebody is zoned, occupied part of the core area showing low I.P. effects. The drilling also proved that a subtle zoning was distinguishable from the fact that close to the core area weak chalcopyrite-bornite and magnetite occur, grading outward into chalcopyrite-molybdenite-pyrite, and near the fringes of the orebody, strong pyrite with traces of chalcopyrite occur. Chalcocite enrichment, superimposed on the zonal scheme enhances the copper content but does not seriously modify the hypogene zoning. The zonal pattern at Gibraltar is seen in Figure seven.

CONCLUSION

The most important factor in the use of zonal interpretation of combined I.P. and geological data to find orebodies is that sufficient work of both types must be done to establish the form and the center of the whole mineralized zone so that drilling can be directed to the most favorable part of a broad target area.

Any potentially extensive alteration zone in intrusive rocks, which is poorly exposed, and which carries pyrite and traces of valuable sulfides should be covered by an I.P. survey, with sufficient coverage to outline the limits and form of the whole altered and mineralized zone. If a porphyry copper deposit is present within the alteration halo, it is probably zoned with respect to copper and pyrite and this zoning should be predictable with correct interpretation of I.P. data and available geology. The copper-rich zone, should be on the inside edge of the barren pyrite halo and should thus be readily drilled out.

The zonal concepts of porphyry copper deposits and other types of ore deposits should be borne in mind when exploring prospects. It may sometimes be premature to reject a prospect on the basis of low grade alone if the alteration zone is not well exposed and we do not have a good idea which part of a large porphyry target we are sampling, because the extent and form of the target are not apparent.

The Gibraltar property, among others, is an example of a prospect known for over 30 years in which only the low grade pyritic halo zone was exposed and was sampled by numerous geologists who failed to recognize the zonal possibilities. Not until a complete I.P. picture was constructed was the overburden-covered copper-rich zone revealed and drilled out to give a large open pit orebody. There are undoubtedly other known prospects in British Columbia and elsewhere which can be discovered applying knowledge of zoning in conjunction with an I.P. survey and available geological data.

R. E. Gale.

COPPER IN BIOTITE AS A GUIDE TO PORPHYRY COPPER DEPOSITS

F. T. Graybeal

INTRODUCTION

Numerous papers have appeared in the last decade concerning the application of trace element analyses of biotite during base metal exploration. The emphasis of this work was on copper because it tends to vary over a much greater range of concentration than other trace elements. Although statistical correlations with productive and barren intrusions were often demonstrated, the causes of the significant variations found were largely unexplained.

The present paper, as indicated by the change in title, is an abridged version of the talk given at the annual exploration meeting in November 1971. The purpose is to summarize briefly the behavioral characteristics of the distribution of copper in biotite and to evaluate some of the possible applications to exploration for porphyry copper deposits in light of available sample results. The details of the behavior of copper in biotite, as given at the exploration meeting, are briefly summarized below. These details are discussed in depth in my dissertation to which the reader is referred for greater understanding (Graybeal, 1971).

BEHAVIOR OF COPPER IN BIOTITE

The copper content of biotite is controlled only by magmatic processes operating in the Laramide plutons investigated, and is uneffected by adjacent hydrothermal alteration. It is probable that this conclusion may be applied to all Laramide plutons, and perhaps to all plutons genetically related to porphyry copper deposits. The copper content of biotite does not appear to be effected by surface weathering until the biotite itself is destroyed.

The magmatic processes which cause the greatest change in the copper content of biotite can be correlated with variations in rock types and with textural variations in a single rock type. Knowledge of these variations, gained through reconnaissance mapping and petrographic work, is necessary to interpret correctly the analytical data and can usually be obtained by an experienced geologist in a minimum amount of time.

It was also established from an evaluation of chlorite-biotite equilibria that the copper content of biotite is equivalent to the minimum concentration of copper in the coexisting trapped hydrothermal solution. The copper content of biotite thus provides a direct semi-quantitative estimate of the amount of copper in the hydrothermal solution, which is the amount available to form a mineral deposit.

It is emphasized that all biotites studied in this investigation were of unquestioned magmatic origin, and that the above conclusions only apply to biotites similarly formed. Judging from the known intimate association of hydrothermal biotite with primary copper mineralization, if a sample contained a significant amount of hydrothermal biotite the question of its origin and the use of the biotite sampling technique would be rendered moot by the presence of accompanying sulfides.

APPLICATIONS

Parry and Nackowski (1961) were the first to show that the copper content of biotite was increased in quartz monzonite stocks related to porphyry copper deposits in Utah and Nevada. A recent paper by Lovering, Cooper, Drewes, and Cone (1969) demonstrated that the copper content of biotite in the Ruby Star Granodiorite increased from a background of 15 ppm copper to 10,000 ppm copper adjacent to the Sierrita Mine. These large variations in concentrations and correlations with productive intrusions have generated considerable previous interest in the analysis of copper in biotite as an exploration tool.

The basis for analyzing biotite rather than the whole rock sample from which the biotite was separated is due to a greater contrast between background and anomaly for biotite. In addition, the size of the anomaly formed by copper in biotite is greater than the anomaly formed by the whole rock sample. Regardless of the absolute values, if the contrasts were the same for biotite and whole rock then the rock would be the preferred sample due to a greater ease of preparation.

The theory behind the use of biotite analyses is graphically illustrated in Figure 1. This shows that the copper content of biotite rises faster and at a greater distance from the altered zone than does the copper content of the whole rock. The lower portion of this same figure also illustrates that the ratio of copper distributed between biotite and whole rock samples also rises very rapidly. As will be seen below, the idealized behavior shown on Figure 1 has been verified by field work from several different intrusions associated with porphyry copper deposits.

The locations of the plutons studied in this investigation are shown on Figure 2. This is a combination of plutons studied by myself and by John King. The results of all copper analyses completed to date are plotted in ppm on the accompanying figures.

Tyrone Quartz Monzonite

The Tyrone quartz monzonite pluton is medium to coarse grained with a possibly porphyritic core which parallels the long axis of the intrusion. The Tyrone ore body is a chalcocite blanket which has formed

in the quartz monzonite and in the Precambrian granite wall rock within a zone of strong shearing.

The copper contents of biotite in the Tyrone quartz monzonite are given on Figure 3 (sampling by John King and Barry French). An irregular but strong copper in biotite anomaly is present which extends roughly 3 miles southwest of the ore zone. This anomaly appears to follow the porphyritic zone in the central portion of the quartz monzonite. Several high values are also found along the southeast side of the pluton.

The whole rock copper values for the same samples are given on Figure 4. These values indicate a strong anomaly along the southeast side of the quartz monzonite pluton in an area of low-grade copper oxide mineralization. Thus, the whole rock analyses do not provide a good guide to the zone of ore grade copper sulfide mineralization.

The ratios of copper in biotite/whole rock are given on Figure 5. These ratios show a strong and regular increase toward the ore zone which corresponds closely with the porphyritic core. It is particularly important to note that anomalously high values for the ratio of copper in biotite/whole rock and in biotite alone extend for 1.5-2 miles beyond any visible hydrothermal alteration associated with the Tyron ore body, and thus provide a much more extensive and accurate guide to the ore than the copper content of the whole rock samples.

Schultze Granite

The Schultze granite is a medium to coarse grained quartz monzonite (mineralogically and chemically) with orthoclase grains occasionally reaching phenocryst size. This intrusion is extremely homogenous with the exception of small zones of granite porphyry along the north side. The Schultze and genetically related intrusions are the hosts for three major porphyry copper ore bodies.

The Schultze granite was sampled both by myself and by John King. The results of my work are given on Figure 6. This illustrates that the copper content of biotite rises from a background of roughly 10 ppm to 360 ppm along the north contact. All known porphyry copper ore bodies in the district are located along this contact indicating that the variations of copper in biotite are quite compatible with the known geology.

The results of Mr. King's more detailed sampling are shown on Figure 7 and are not easily comparable with Figure 6. The significance of the several high values detected along the west end of the Schultze granite is not yet known. The copper contents of whole rock samples are given on Figure 8 which also shows several high values in the western portion of the Schultze granite. The ratios of copper in biotite/whole rock are shown on Figure 9. These ratios are erratic and do not show any wide or systematic variations.

The data from the Schultze granite suggest that detailed sampling may be unnecessary. The lack of systematic variations noted in the detailed work may be due to the current level of exposure being deep within the intrusion, although this assumption lacks proof.

Ruby Star Granodiorite

The Ruby Star granodiorite is medium grained with a more porphyritic core which parallels the long axis of the intrusion. Quartz monzonite porphyry phases of this pluton have been mapped in the Sierrita pit. This intrusion and genetically related offshoots were the sources of three major porphyry copper ore bodies.

The copper content of biotite in the Ruby Star granodiorite is given on Figure 10 (sampling by John King). This shows a copper in biotite anomaly which extends 3 miles north of the Sierrita-Esperanza ore zone. The anomaly is well defined and appears to follow a porphyritic core within the pluton. The highest value found in this work is 1530 ppm Cu, as compared to 10000 ppm Cu reported by Lovering et al (1969). However, the Lovering samples were impure and I regard Mr. King's results as more accurate.

A well-defined copper in whole rock anomaly is shown on Figure 11. The 500 ppm contour extends outward 1-2 miles from the Sierrita - Esperanza ore zone and coincides roughly with the limit of visible hydrothermal alteration in the granodiorite. In this pluton variations in the copper content of biotite give the geologist an additional 1-2 miles of anomalous halo and provide exploration guidance which would not otherwise be available from geologic mapping or whole rock analyses.

The ratios of copper in biotite/whole rock are shown in Figure 12. The values appear to rise abruptly to 10 approaching the ore zone and then fall quite rapidly at a point about 2 miles north of the ore body. The ratios also rise to the north where the pluton disappears under the gravel cover on the San Xavier Indian Reservation.

Three Peaks Pluton

This pluton is compositionally zoned with the three phases elongate parallel to the long axis of the pluton. The rocks are all medium grained, equigranular, and everywhere fresh where exposed. The projection of this pluton extends through the Santa Cruz deposit which lies about 5 miles to the southwest.

The copper content of biotite in the Three Peaks pluton is shown on Figure 13. (Sampling by John King and John Balla.) This illustrates that the copper content of biotite is highest in the border diorite phase, although not anomalously higher than the central quartz monzonite phase. Figure 14 gives the copper content of the whole rock which is also highest in the border diorite phase. The whole rock variation can be related to the much higher biotite content of the border diorite as compared to the central quartz monzonite phase.

The ratio of copper in biotite/whole rock is shown on Figure 15. The ratios are highest in the quartz monzonite core where they average 6 and lowest in the border diorite where they average 1.5. The interpretation of this variation is uncertain at the present time; however, the high ratio in the core may be considered favorable in the absence of any other positive data.

Cornelia Pluton

The Cornelia pluton contains concentrically distributed separate intrusive phases which become younger and progressively more felsic toward the core. The New Cornelia mine, which lies about 1 mile east, is interpreted to be the down-faulted hood portion of the area shown in Figure 16. The transitional and core phases, although larger, have a shape similar to the ore zone in the pit suggesting that the level of the pluton now exposed is the root zone of a porphyry copper deposit.

The copper content of biotite in the Cornelia pluton is shown on Figure 16 (sampling by F. T. Graybeal). This shows that the copper content of biotite rises as the rock becomes more felsic but falls rapidly in the rock most closely associated with the ore - the porphyritic micro-quartz monzonite. Average values of copper in biotite for each rock type are given in Table 1. This variation suggests that copper was removed from the innermost portions of the pluton by hydrothermal solutions which ultimately formed the then overlying New Cornelia ore body. Subsequent crystallization of a copper-impoverished prophyritic micro-quartz monzonite melt resulted in the formation of biotite which contained only small amounts of copper. Thus copper is lowest in biotites which occur in rocks most closely associated with ore deposition.

TABLE 1

Variation of copper in biotite with rock type in the Cornelia pluton

Rock type	ppm Cu
granodiorite	66
equigranular quartz monzonite	70
transitional porphyritic micro-quartz monzonite	170
porphyritic micro-quartz monzonite	7

Patagonia granodiorite

The central portion of this pluton is an equigranular granodiorite which changes gradually to a porphyritic granodiorite along the eastern contact. Numerous mineralized structures occur in the outer portions of the porphyry and this area has been drilled several times as a copper prospect. The porphyry is clearly a rock in which volatiles were concentrated during crystallization of the pluton. Gradual degassing of the magma in this area caused the central portions to quench progressively more rapidly developing the porphyritic texture.

The copper content of biotite in the Patagonia granodiorite is shown on Figure 17 (sampling by F. T. Graybeal). Although quite variable, the copper content of biotite is generally high throughout the equigranular granodiorite and then falls to very low levels in the porphyritic granodiorite. This variation of copper in biotite with texture is shown on Table 2. The depletion of copper in biotite from the porphyritic granodiorite was clearly caused by a removal of copper from the magma during a progressive degassing of the remaining magma. Thus, the biotite from the inner still-molten portions of the pluton crystallized in a melt relatively impoverished in copper. The important point to note here is that the productive portion of this intrusion actually carries biotites with very low copper content.

TABLE 2

Variation of copper in biotite with texture in the Patagonia granodiorite

Texture	ppm Cu
equigranular	1029
weakly porphyritic	338
moderately porphyritic	46

CONCLUSION

Data from the Cornelia and Patagonia intrusions clearly demonstrate that the rocks most closely related to ore deposition contain biotites with abnormally low copper contents. The interpretation given for this behavior, that these biotites grew in a melt which was previously stripped of its copper, is entirely consistent with the magmatic history of these intrusions. Similar behavior may also be indicated for the Three Peaks and Ruby Star plutons. It is concluded that high or low copper concentrations in biotite can have favorable exploration implications, and that the proper interpretation of the analytical results depends on a clear understanding of the cooling history of the intrusion. However, as the ore-forming portions of an intrusion are often destroyed during alteration so also are the contained copper-impoverished biotites. Thus, high concentrations of copper in biotite would probably be the more common occurrence.

It has also been demonstrated that the copper content of biotite is a better exploration guide to porphyry copper deposits than the copper content of whole rock samples. Analyses of copper in biotite provide:

1.) Greater contrast between background and anomaly

2.) A wider anomalous halo than could be detected by whole rock analyses or geologic mapping

3.) Better correlation with the ore-bearing areas and with textural variations in the igneous rock.

The ratios of copper for biotite/whole rock can also be useful, and emphasize the need for whole rock analyses.

IMPLEMENTATION OF A PROGRAM

An exploration program for porphyry copper deposits using variations in the copper content of biotite could be applied to several different situations. These would include intrusions which extend under post-mineral cover, intrusions intersected by deep drill holes but which are otherwise unexposed, and intrusions in remote areas.

The sampling done during the work by myself and John King was performed on a character basis (sample locations were adjusted to rock type, not to a grid), and was done after the geology had been mapped. The average number of samples taken was less than 1 per square mile. A similar procedure would be recommended for any new work, but should be modified as follows:

1) At least 2 samples should be taken from each phase adjacent to cover.

2) A closer spacing is necessary near cover, as compared to a wider spacing in well-exposed areas.

The samples should be taken from a single outcrop and should weight 10-15 pounds. In addition a small hand specimen should also be collected from the same site.

The importance of supporting geologic mapping and petrographic work cannot be overemphasized. The mapping and petrography provide the geologic framework in which the analytical results can be interpreted. Mapping also reduces the number of samples needed by eliminating excessive sampling of any one phase, and may result in a considerable saving of money and time. A large number of samples is unnecessary as this is not a statistical method; rather, each sample provides solid quantitative data interpretable as such. It should also be noted that the type of mapping necessary can be done rapidly and again the cost is not excessive.

The time interval between mailing of the sample and receipt of analytical results varies from about 3 to 4 weeks. The mineral separation costs at the Colorado School of Mines Research Institute average about $21 per sample. To date they have done excellent work and since sample purity is one of the most important aspects to be considered in the entire program, this cost is not considered excessive.

The biotite sampling technique could best be used where detailed work is already progressing and further exploration guidance is needed. It could also be used on selected other intrusions depending on their age, their occurrence along productive lineaments, and other favorable geological characteristics. I estimate that one pluton could be mapped and sampled in approximately 2-3 weeks in Arizona. The total cost per pluton is estimated to be $1000-$1200, assuming an average of 20 samples is collected.

An attempt should be made by the group doing the mineral separations to recover as much biotite as possible. Although the present work, and subsequent data to be summarized by Mr. King, has been restricted to analyses of trace amounts of base metals in biotites, much further information is available. In a recent paper Stollery et al (1971) have noted the potential use of chlorine analyses of biotite, and fluorine might also be sought. In addition, data from my dissertation indicate that variations in the iron-magnesium ratio of biotite is directly related to the presence or absence of a hydrothermal phase. Further research concerning the application of these or other ideas to porphyry copper exploration will await time and need; however, access to clean biotite samples would greatly reduce the cost and increase the speed of such work.

Sufficient research of the technique has been completed to establish its value, and a recommendation is hereby made for the initiation of a carefully controlled biotite sampling program. At this particular time, I believe that ASARCO has significant lead in the understanding of the complexities involved. However, S. A. Anzalone informed me that Noranda considered work of this type adjacent to their Brenda deposit, and I have learned from Continental Oil that they are investigating the method for possible use in Arizona.

REFERENCES

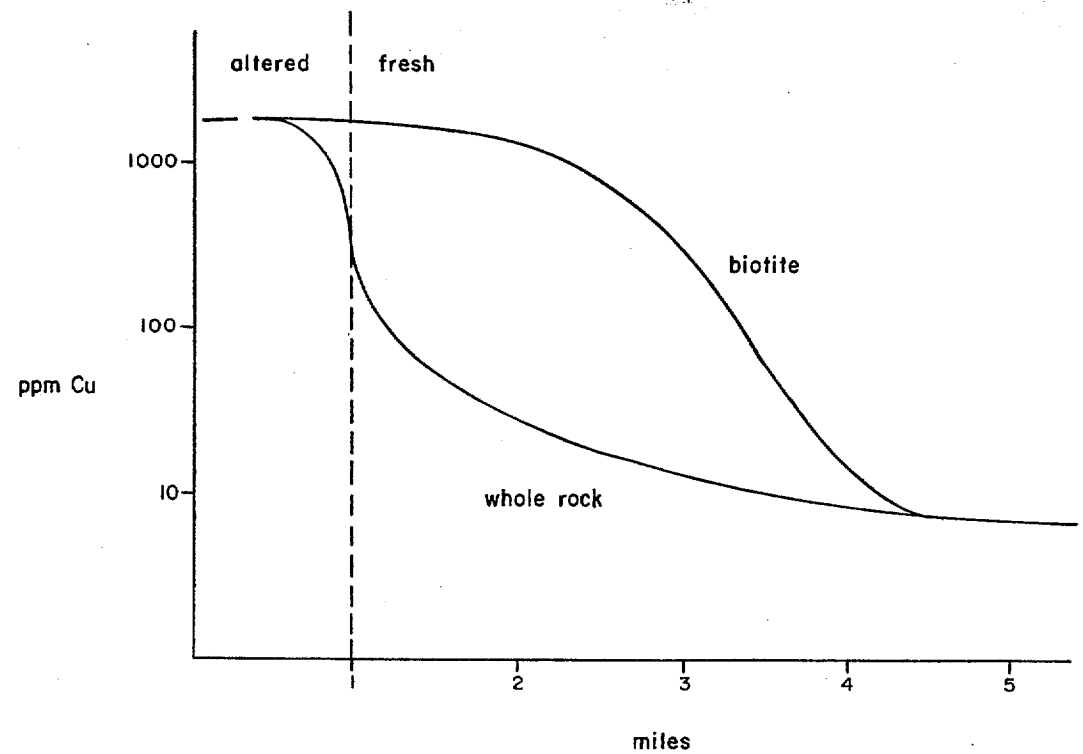
1.) Graybeal, F. T., 1971, The partition of trace elements among coexisting minerals in some Laramide intrusive rocks in Arizona: Univ. of Arizona PhD dissertation.

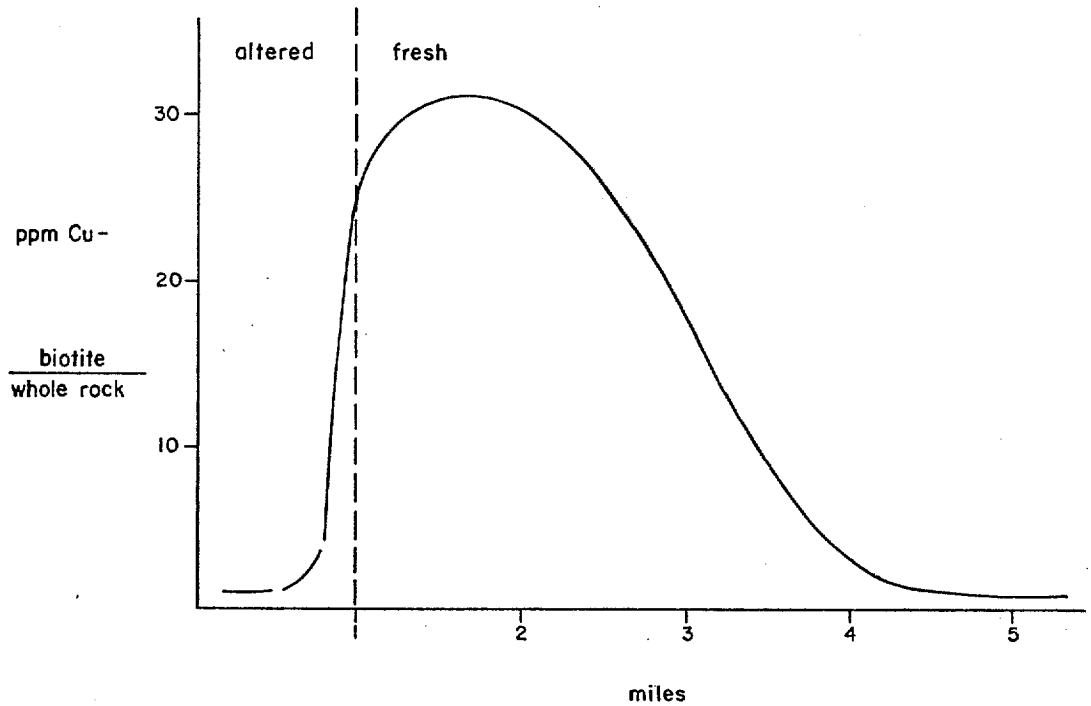
2.) Lovering, T. G., J. R. Copper, H. Drewes, and G. C. Cone, 1970, Copper in biotite from igneous rocks in southern Arizona as an ore indicator: U.S.G.S. Prof. Paper 700-B, p. B1-B8.

3.) Parry, W. T., and M. P. Nackowski, 1963, Copper, lead, and zinc in biotites from Basin and Range quartz monzonites: Econ. Geol., 58, p. 1126-1144.

4.) Stollery, G., M. Borcsik, and H. D. Holland, 1971, Chlorine in intrusives: A possible prospecting tool: Econ. Geol., 66, p. 361-367.

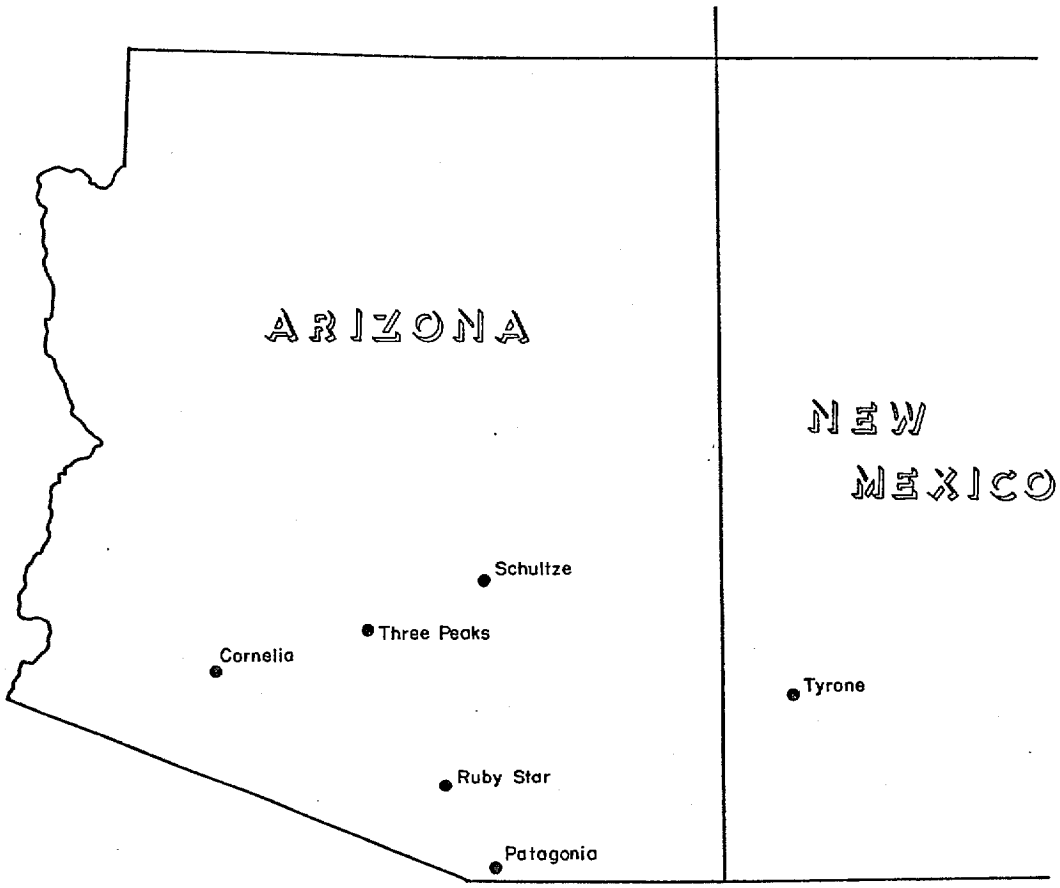
Figure 1





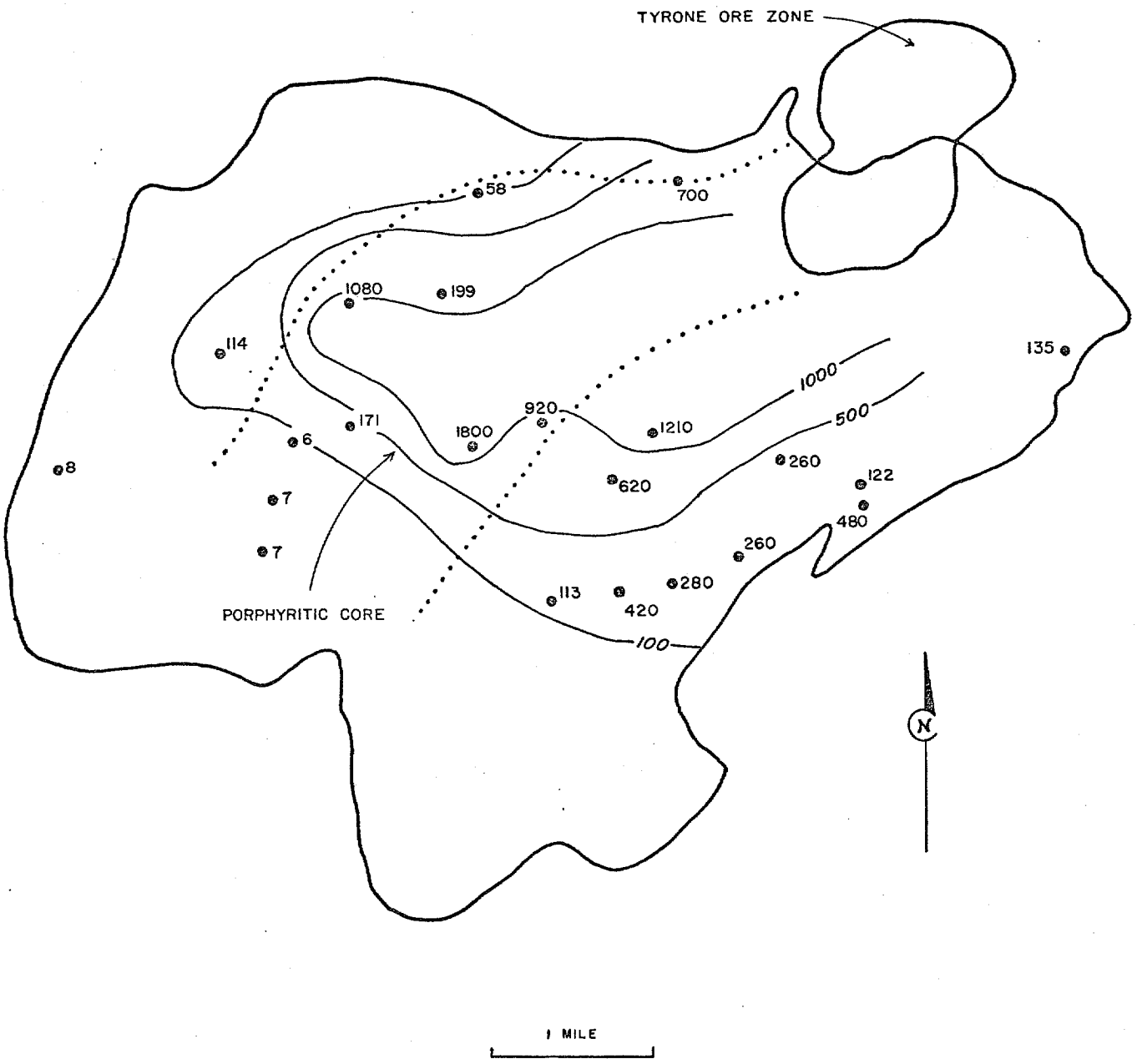
Idealized behavior of Cu in biotite and whole rock samples from a porphyry copper - bearing intrusion.

Figure 2



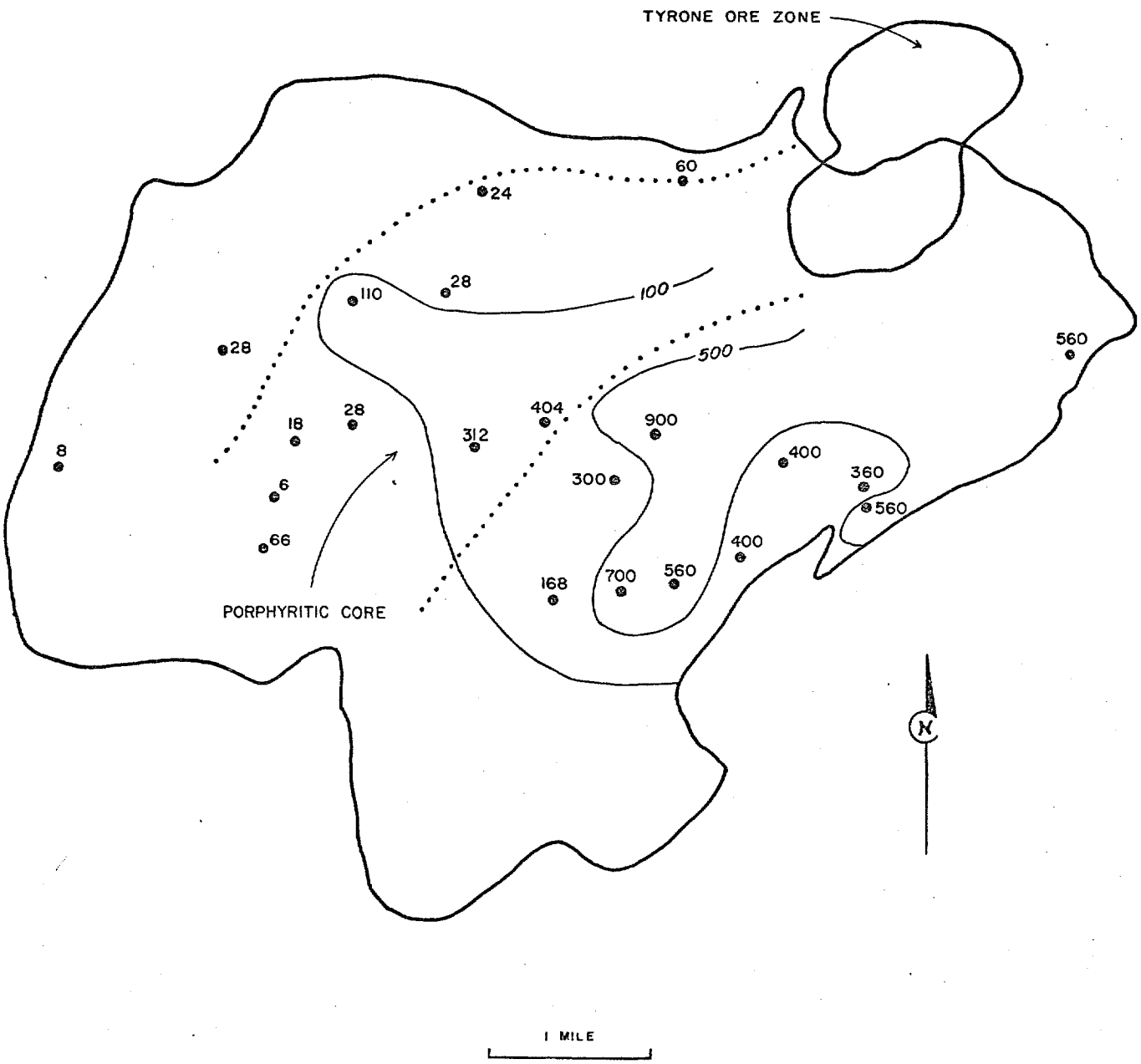
LOCATION MAP OF AREA INVESTIGATED

Figure 3



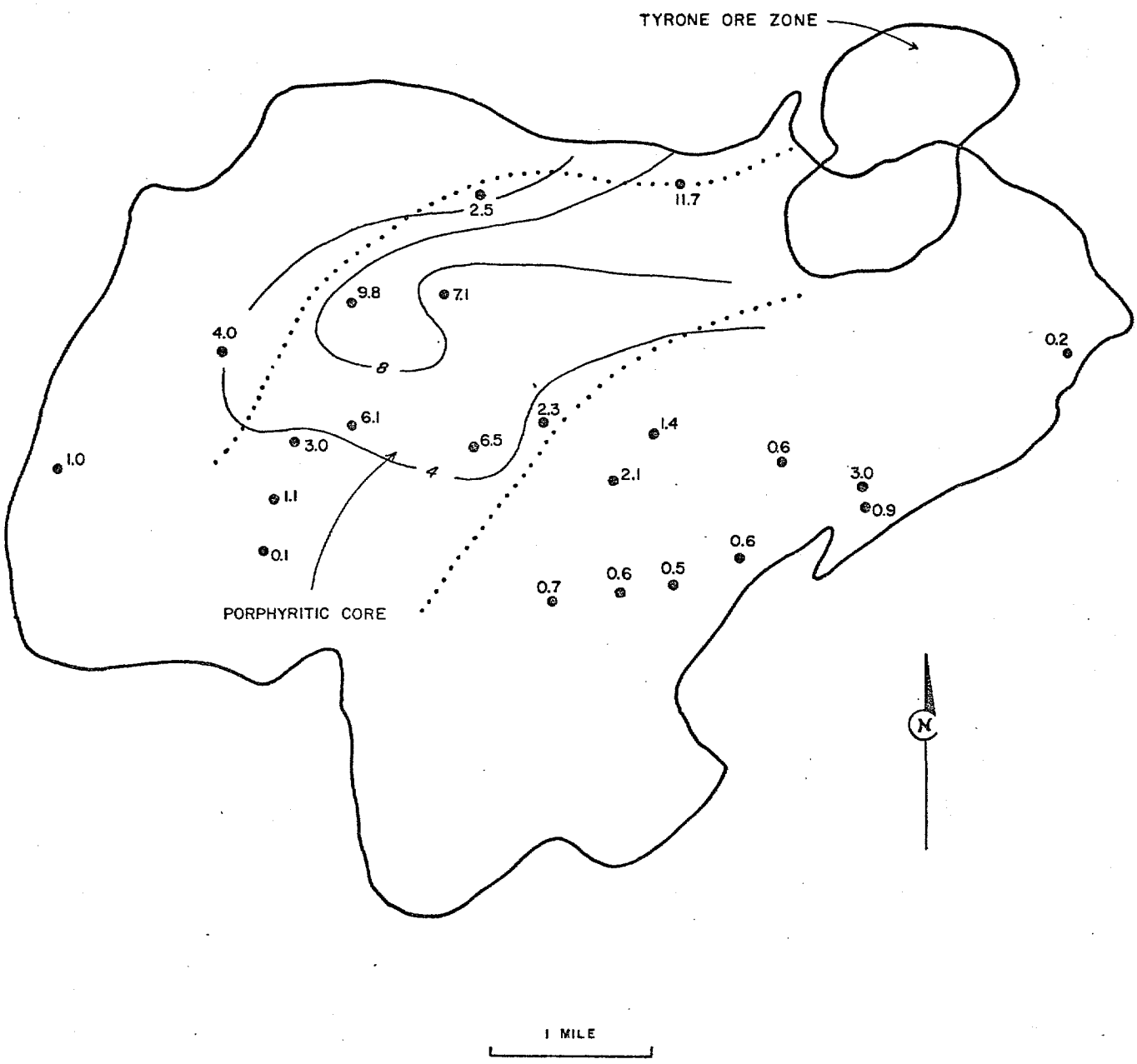
TYRONE QUARTZ MONZONITE
COPPER IN BIOTITE

Figure 4



TYRONE QUARTZ MONZONITE
COPPER IN WHOLE ROCK

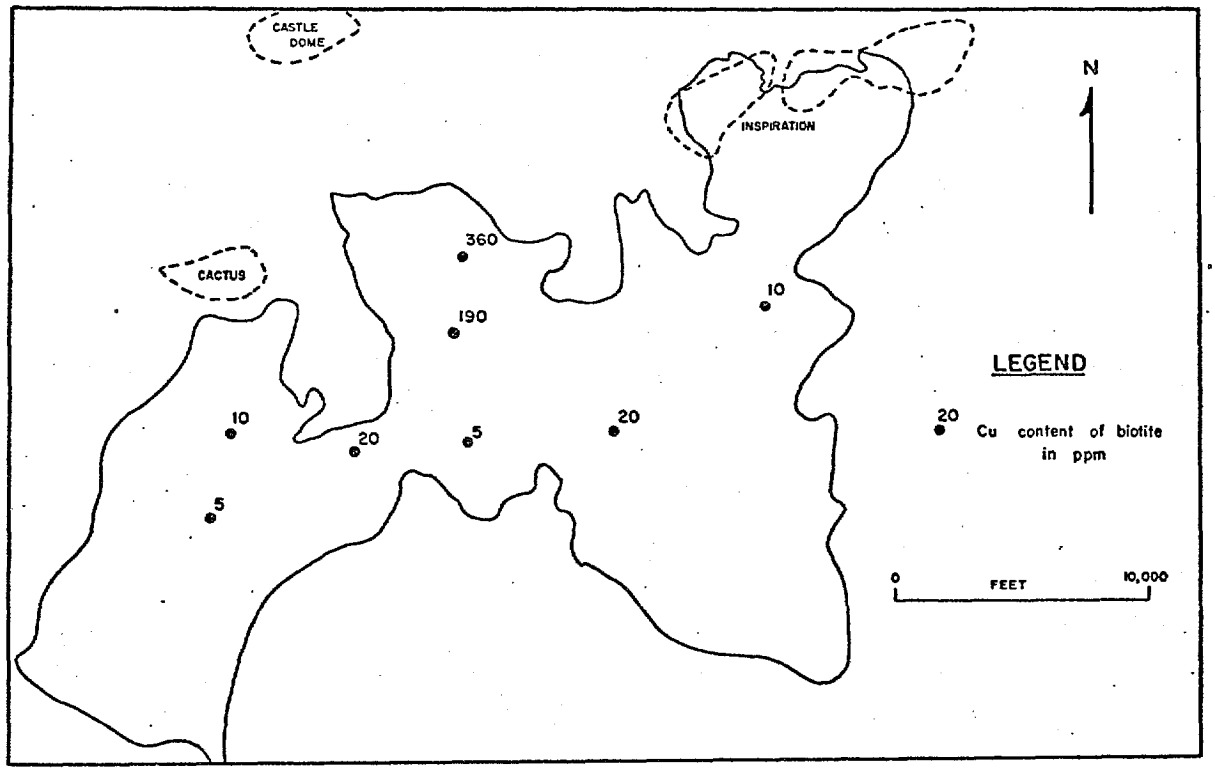
Figure 5



TYRONE QUARTZ MONZONITE

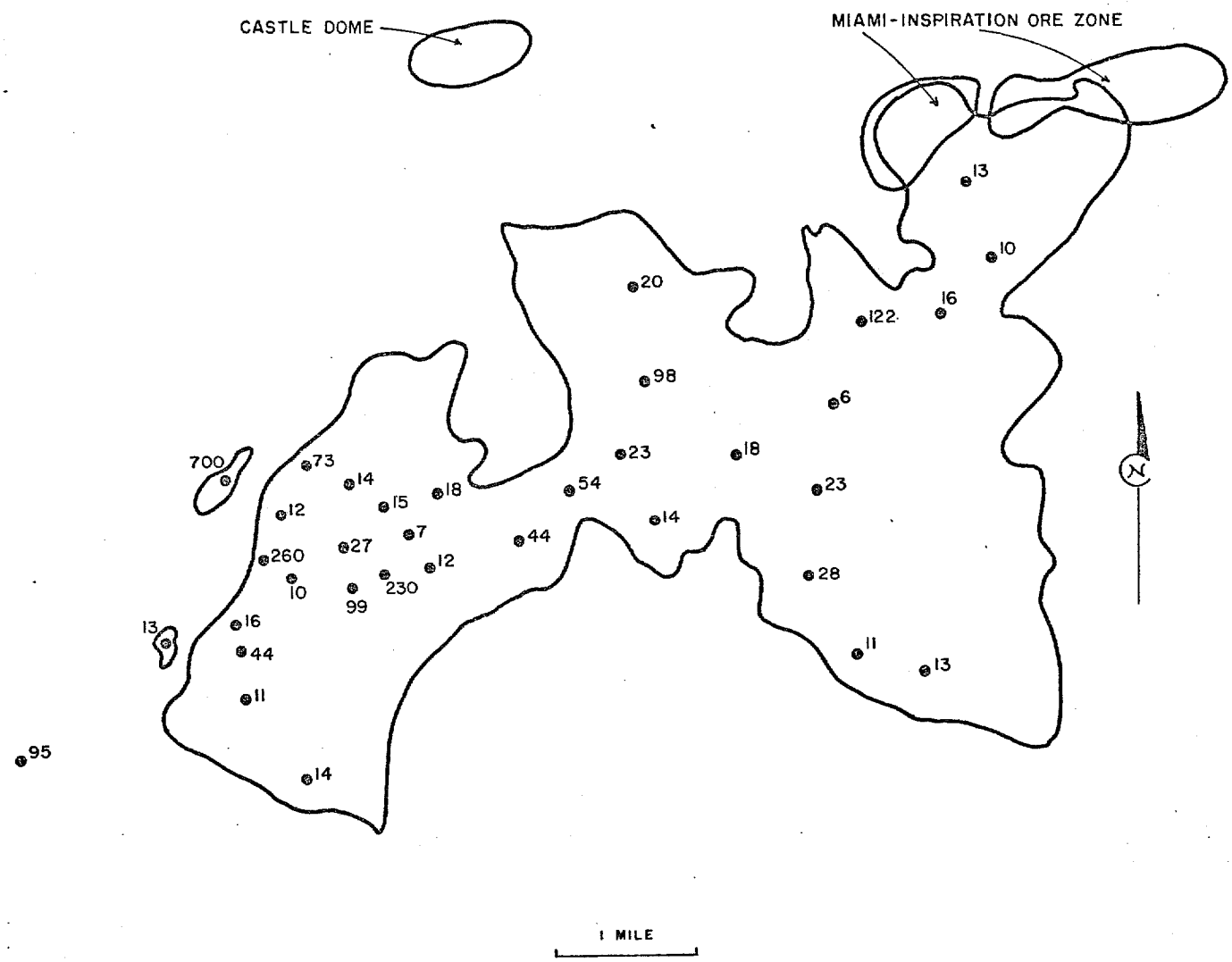
COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 6



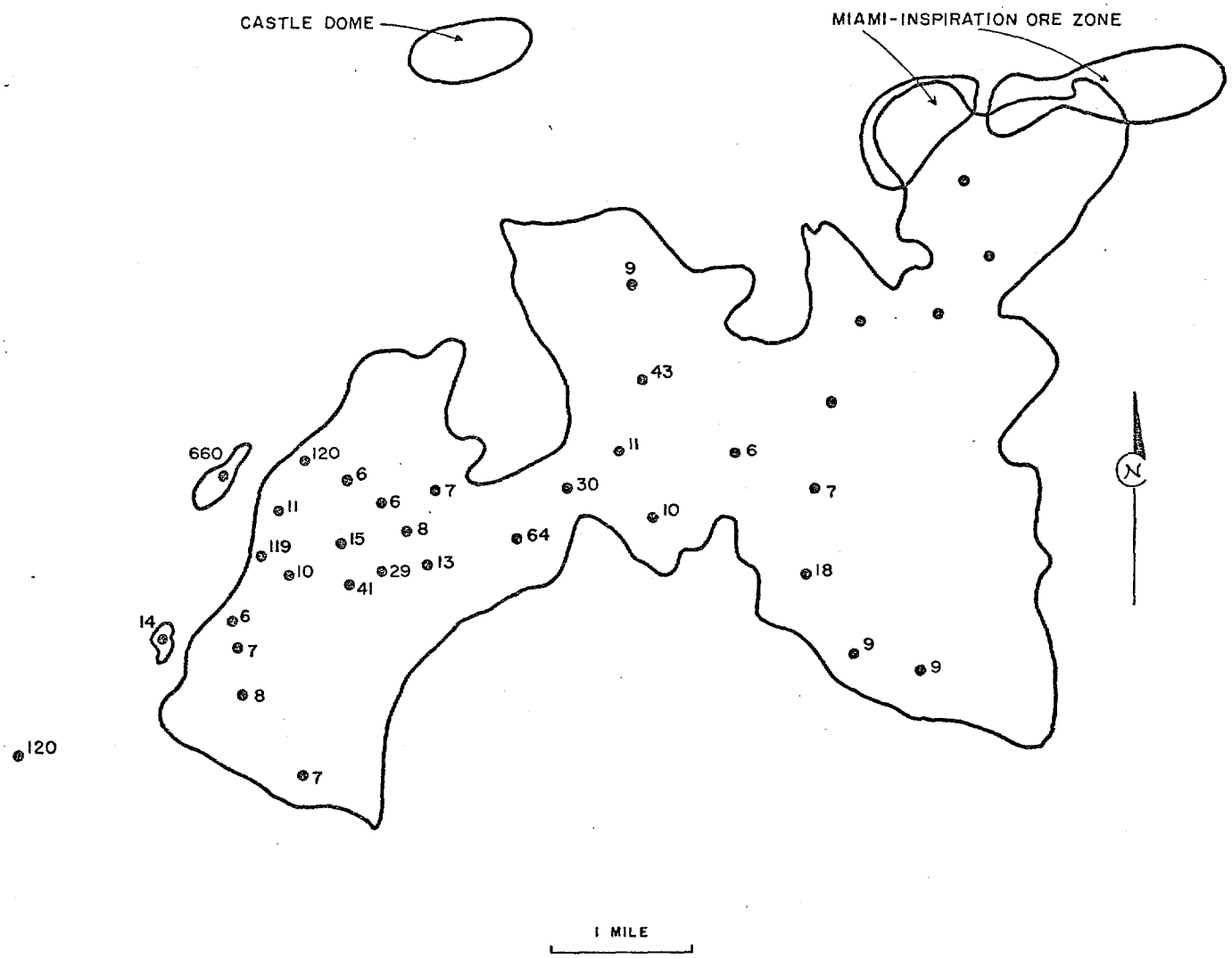
SCHULTZE GRANITE
COPPER IN BIOTITE

Figure 7



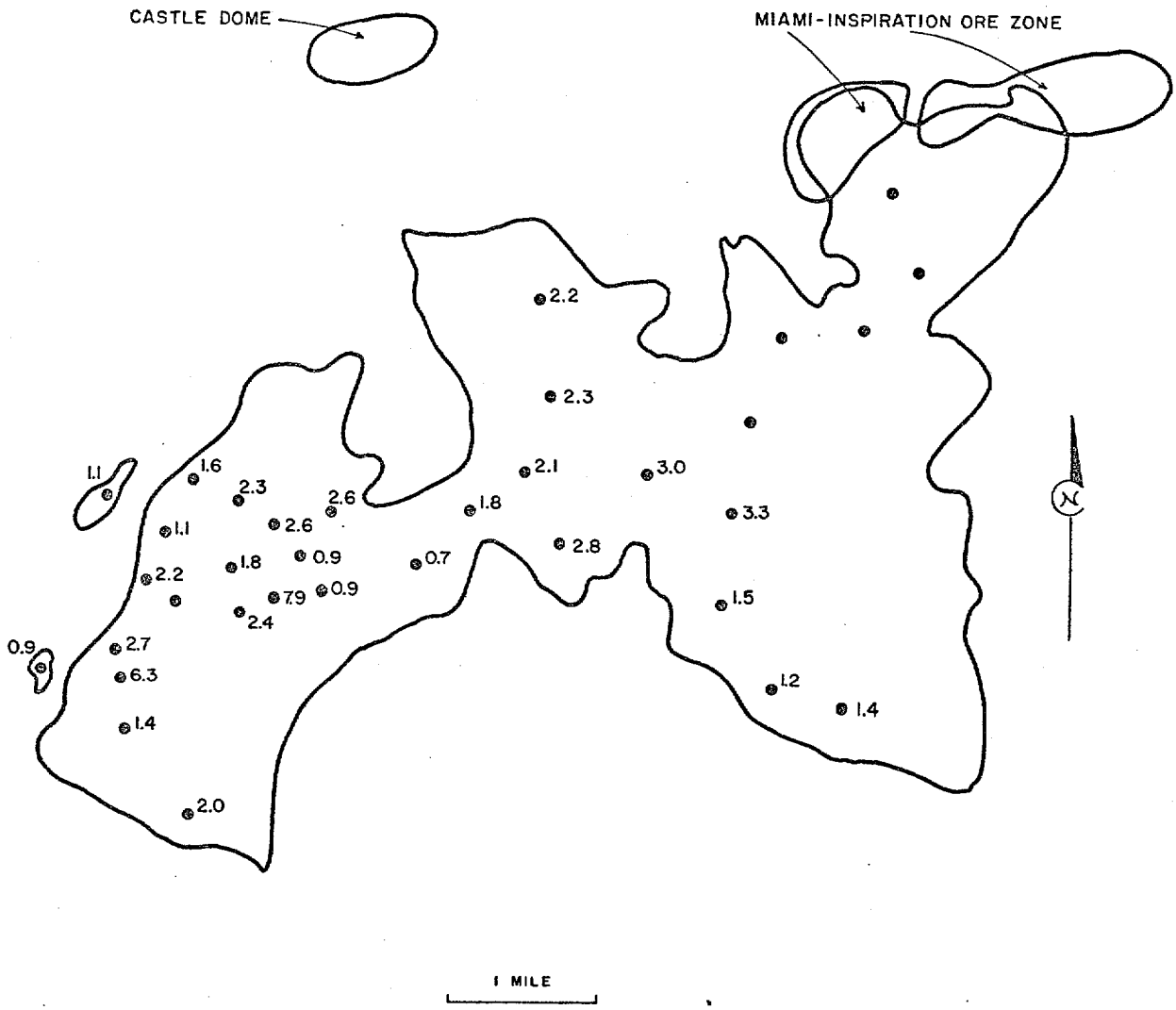
SCHULTZE GRANITE
COPPER IN BIOTITE

Figure 8



SCHULTZE GRANITE
COPPER IN WHOLE ROCK

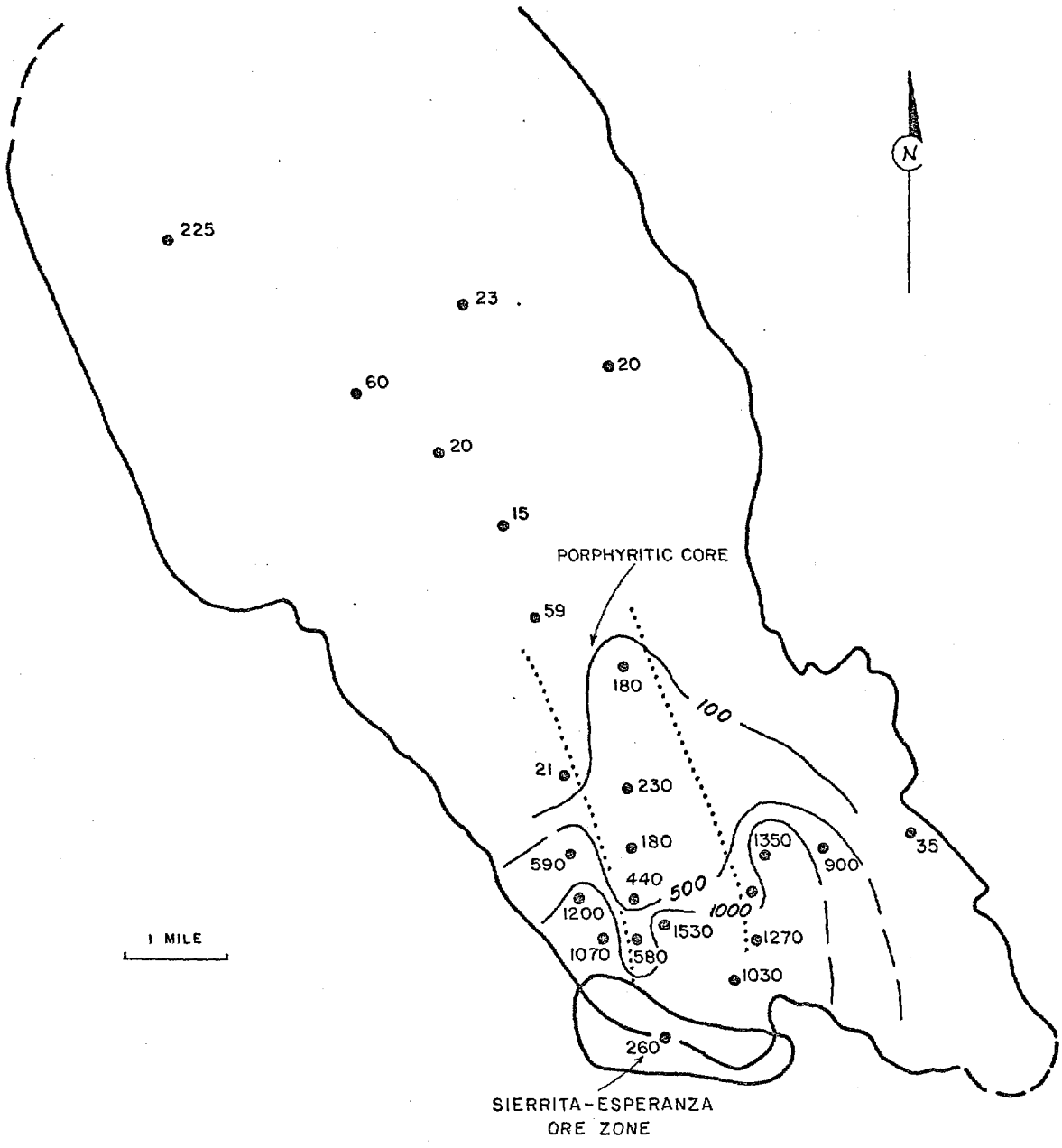
Figure 9



SCHULTZE GRANITE

COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 10

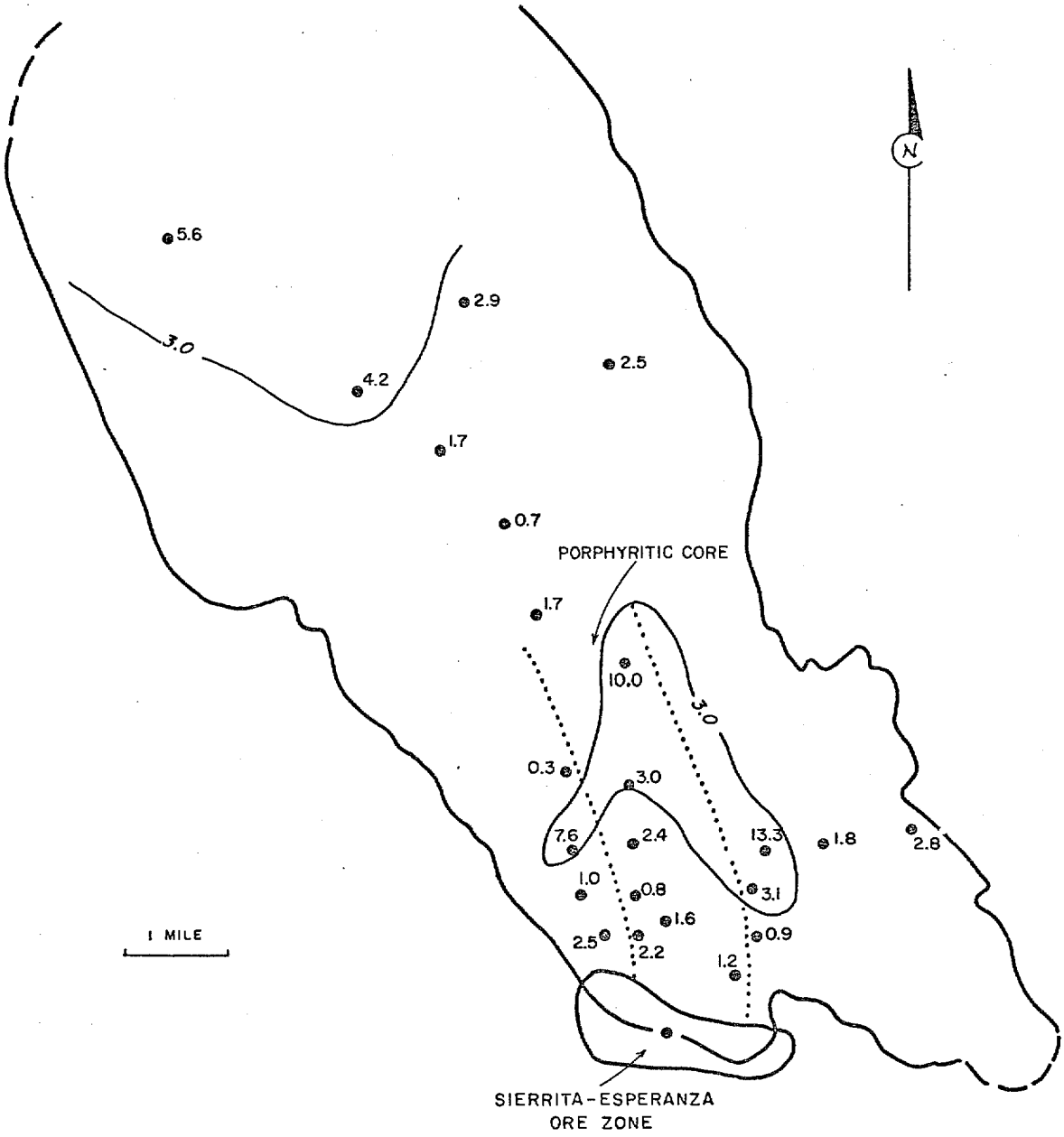


RUBY STAR GRANODIORITE
COPPER IN BIOTITE

Figure 11

RUBY STAR GRANODIORITE
COPPER IN WHOLE ROCK

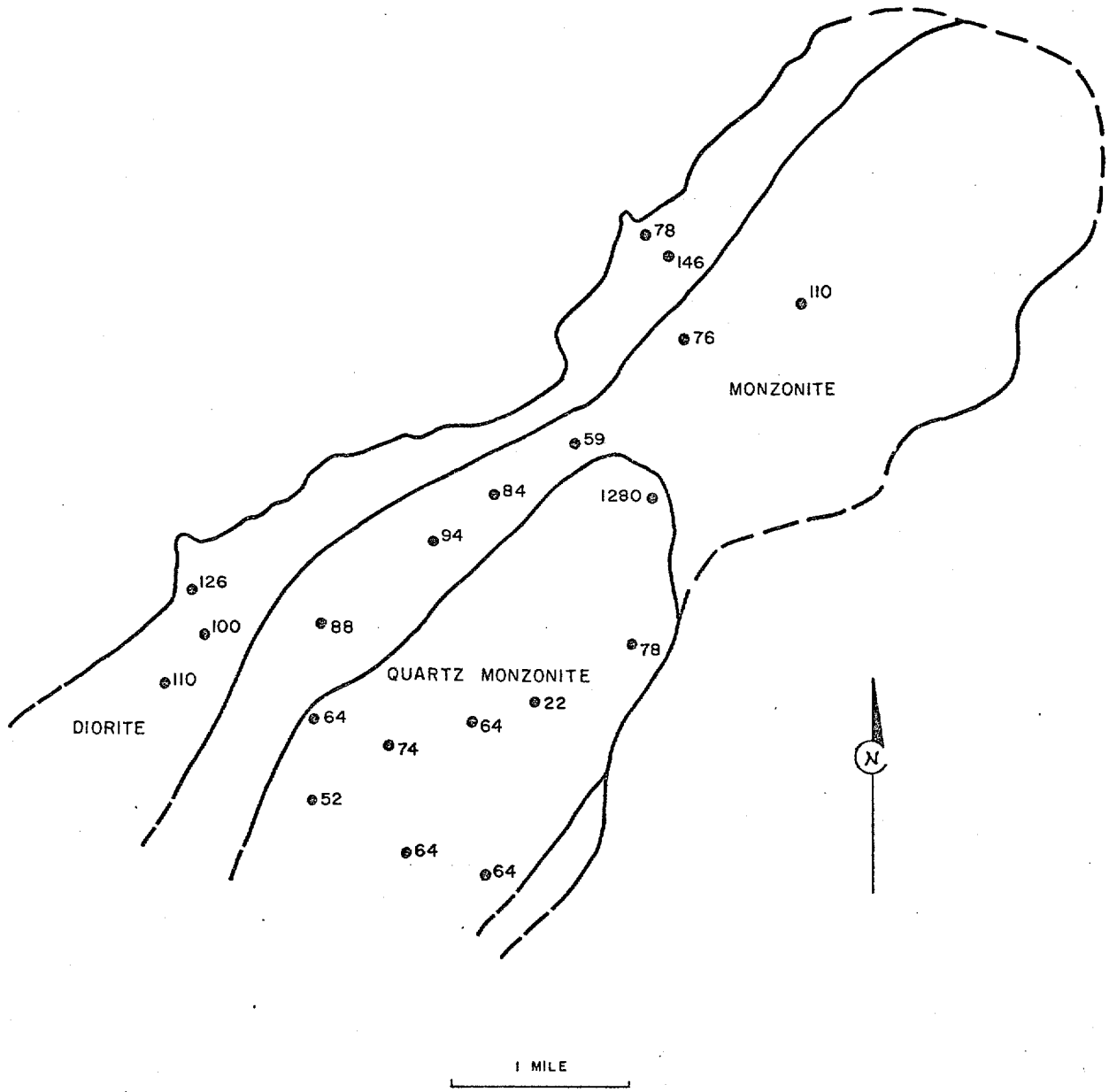
Figure 12



RUBY STAR GRANODIORITE

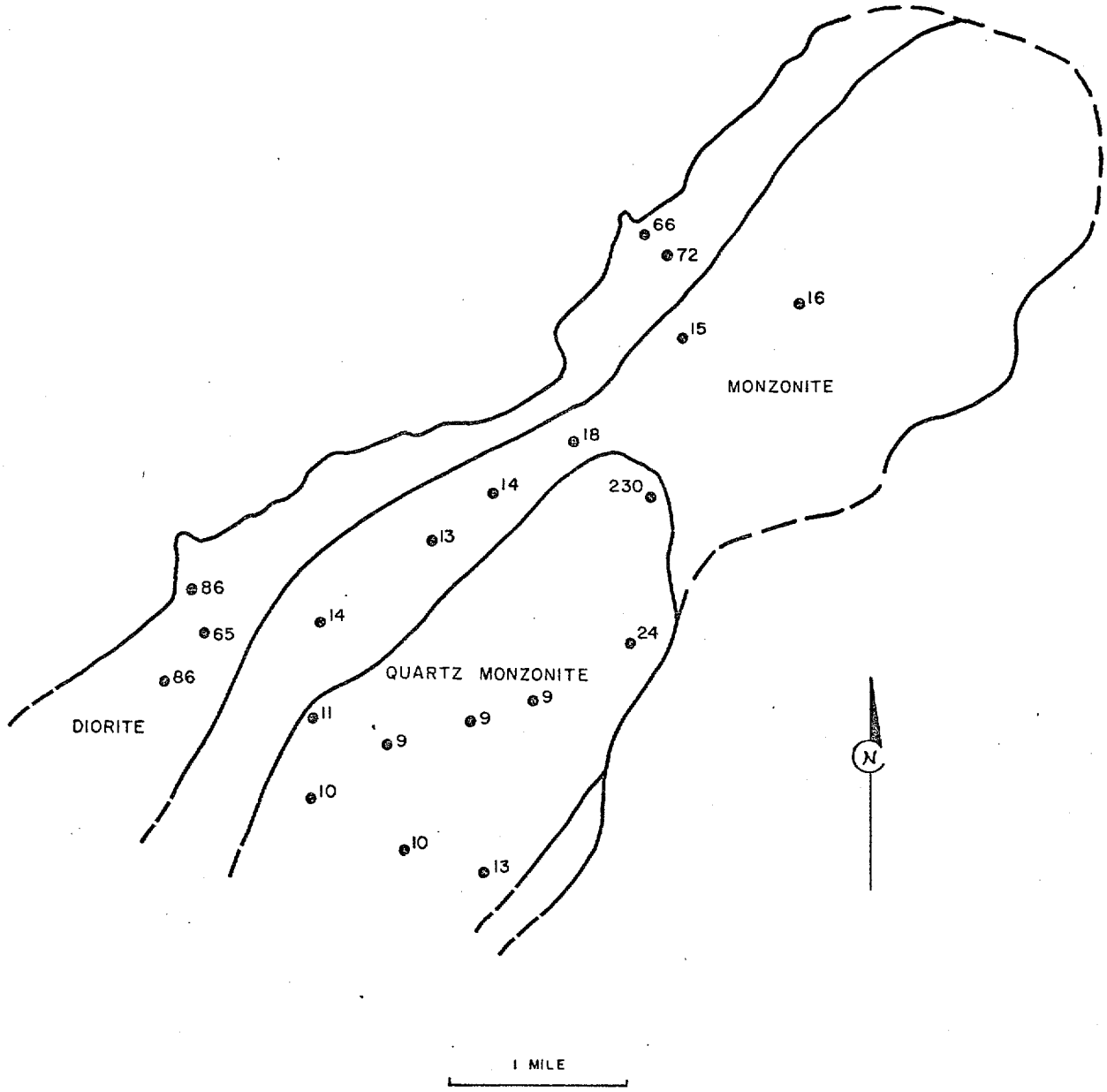
COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 13



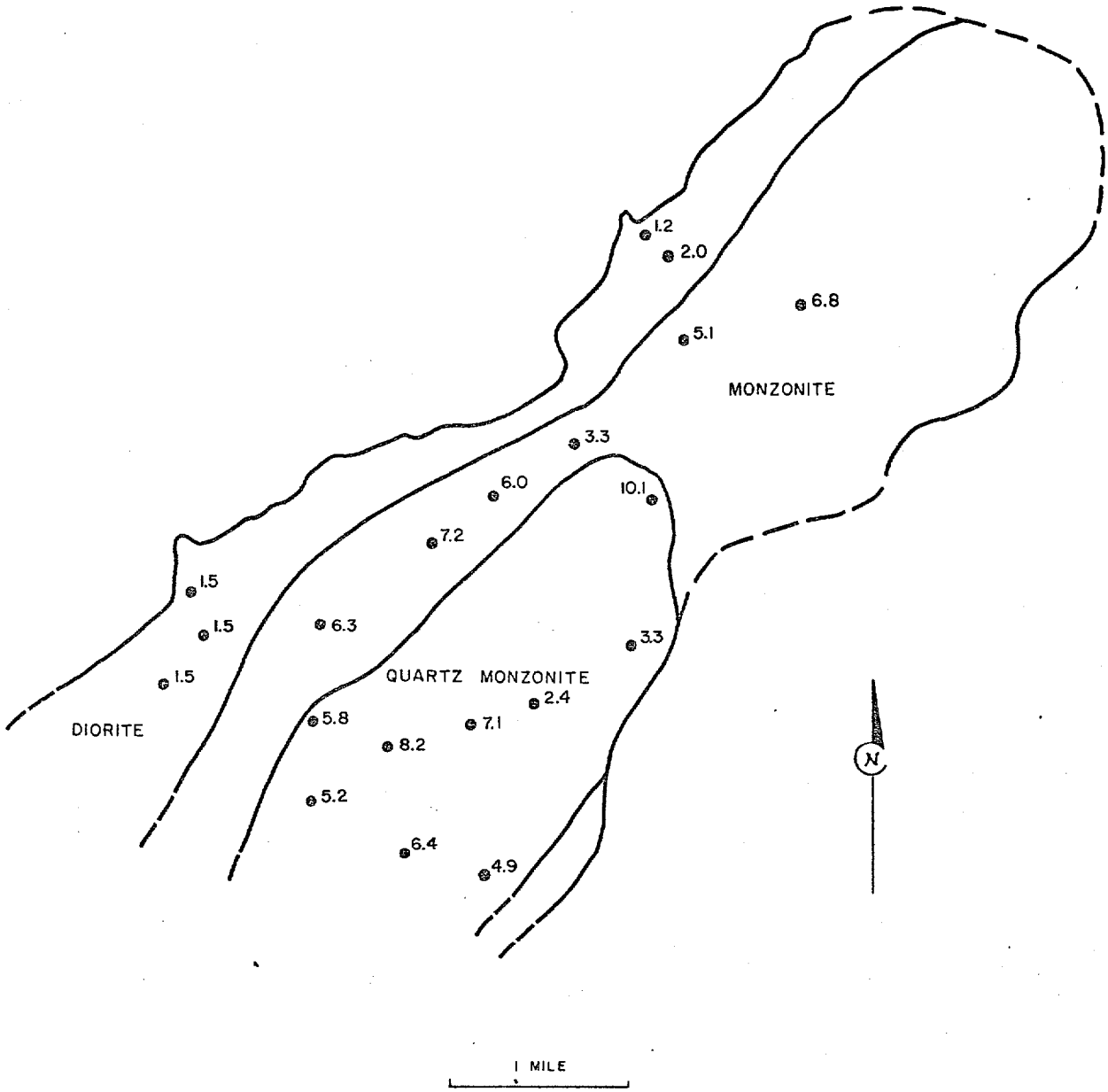
THREE PEAKS STOCK
COPPER IN BIOTITE

Figure 14



THREE PEAKS STOCK
COPPER IN WHOLE ROCK

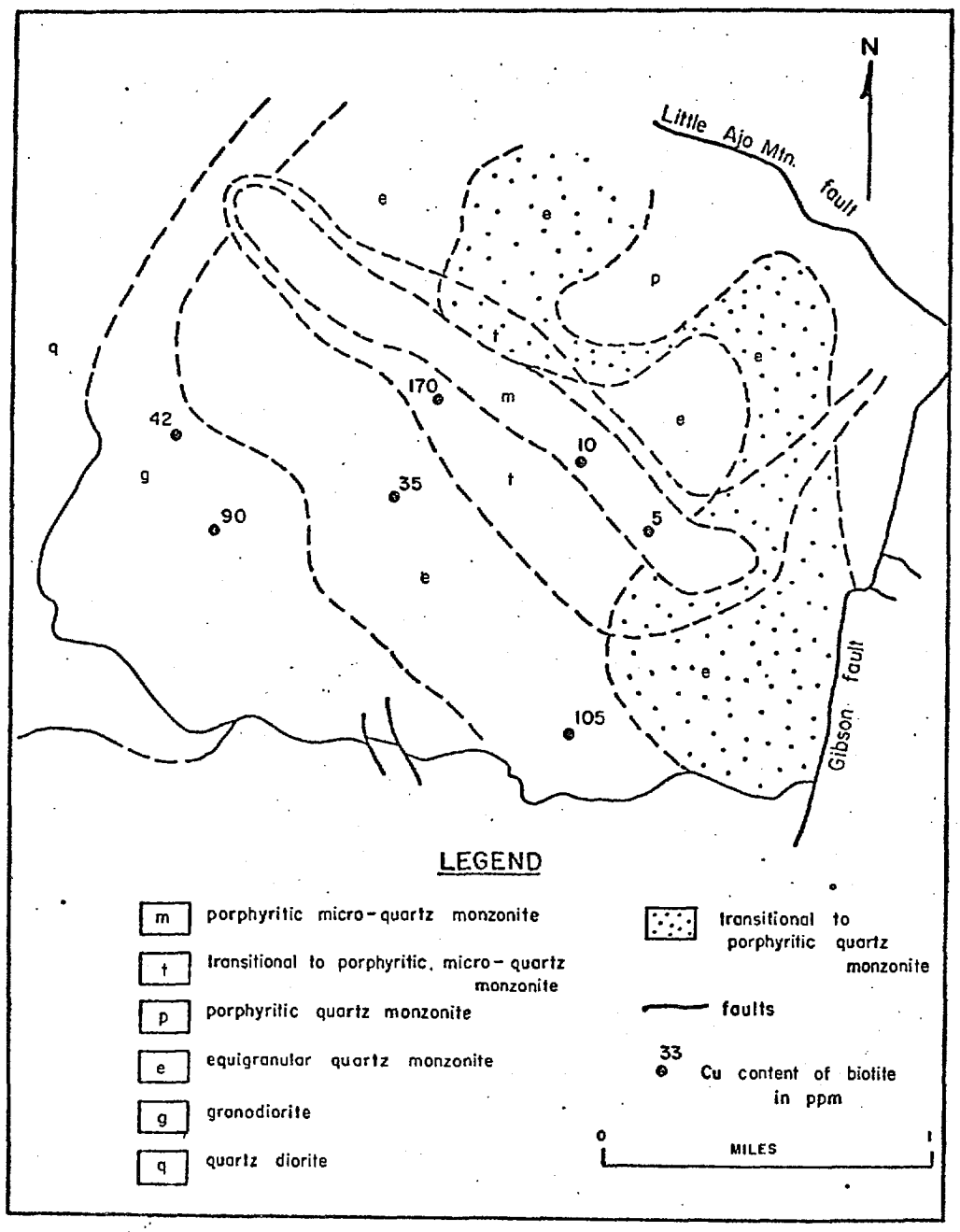
Figure 15



THREE PEAKS STOCK

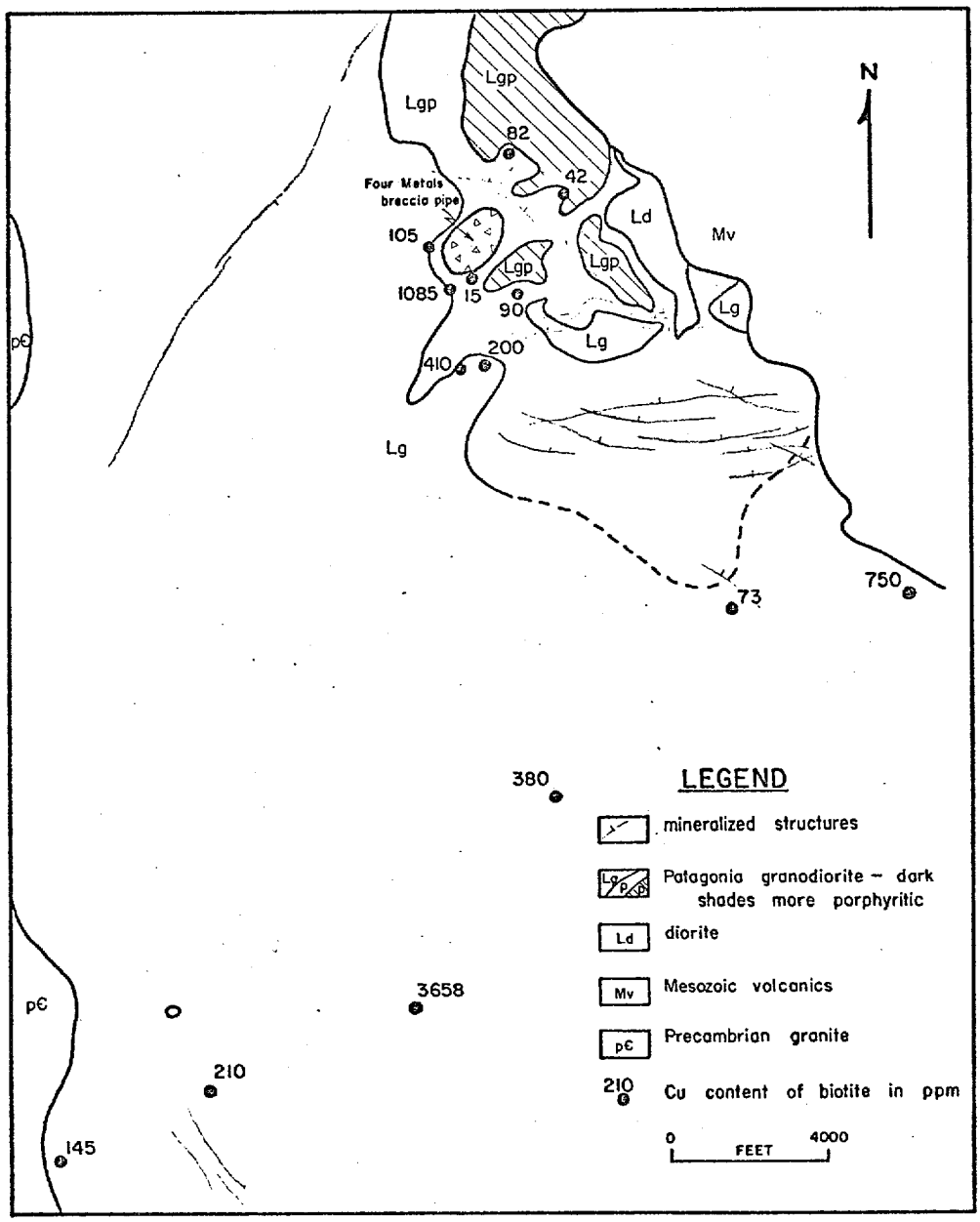
COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 16



CORNELIA PLUTON
COPPER IN BIOTITE

Figure 17



PATAGONIA GRANODIORITE
COPPER IN BIOTITE