The Geology and Mineralogy of the Northstar Copper Prospect

north central British Columbia

A thesis submitted during fourth year in Honours Geology at the University of British Columbia.

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INTRODUCTION

The Northstar Copper Prospect is located in the Caribou Heart Range, on the west flank of the Hogem Ranges. It is about 100 miles North-east of Smithers B.C. at a Longitude of 56°03' N; and a Latitude of 126°16' W. Access to the property is by float plane to Kaza Lake (elevation 3935 ft.), or by helicopter. From Kaza Lake a blazed trail leads to the mineralized showings about 1½ miles north (elevation 5000 ft.).

The Caribou Heart Range consists of a series of large cirques separated by comparatively small ridges. No glaciers remain in the range, but several small ice patches stay on the ground all year. The range is bisected by an East-West running valley of glacial origin. The Northstar Copper prospect lies on a hill forming the northern side of this valley. The hill has been eroded by glaciation to about 5000 feet. Above this a mature rolling topography is visible, somewhat altered by solifluction ridges where the ridges separating cirques are very narrow, topography is extremely rough. This is common north of the Northstar Prospect. Glacial debris is found right up to the peaks of the mountains, at 6500 feet, but there was apparently little ice erosion. Below 5000 feet a valley glacier has formed a steep sided valley. Slopes above 5000 feet are very regular, about 15°. Below this they become steeper, especially in valleys cutting through glacial deposits.

Soil cover is fairly thin near the top of the mountain, generally less than 2 feet, but outcrop area averages less than 5%. Lateral moraines are found up to 5000 feet. Below 4100 feet all outcrop on the mountain slopes is buried by thick glacial deposits.

The valley bottom is mostly covered by glacial debris and alluvial fans, from streams out of the cirques. The east end has several pothole lakes. Kaza Lake appears to have built up behind a terminal moraine. The southern side of the valley is occupied by a fairly large stream, possibly following a fault lineament. Rocks are fairly well exposed here as well as on most of the southern side of the valley, which is considerably steeper than the northern side and has less morainal cover.

Vegatation in the valley is mostly spruce with some pine and balsam. Further up the hillsides the forest becomes nearly all balsam. The tree line is between 5100 and 5200 feet, with only scattered brush above this. Alpine meadows extend to the mountain peaks.

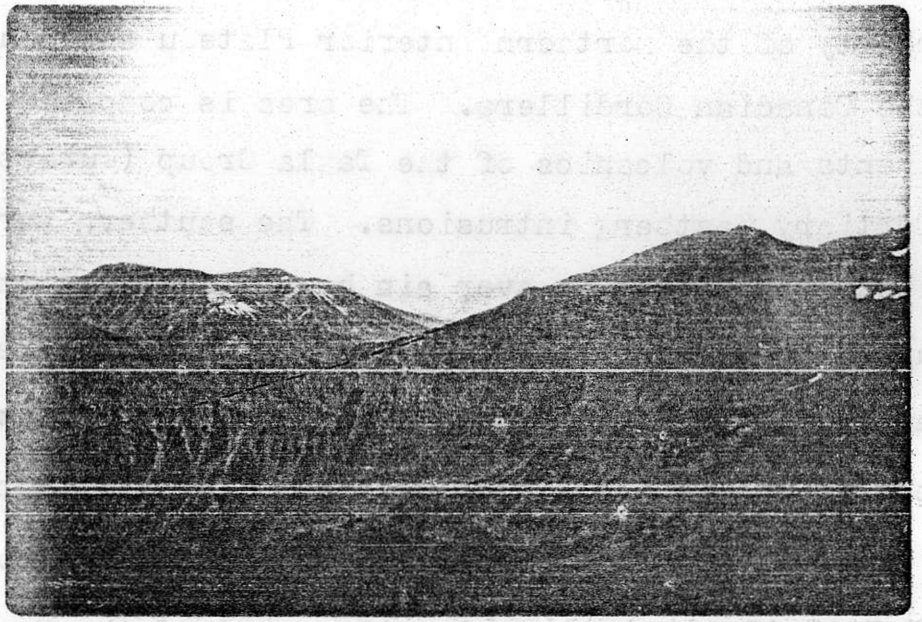


Plate 1

View of cirque behind Kaza Peak, looking south. A sharp unconformity can be seen, dipping towards the east. This surface is also exposed in some cirques in the northern part of the Caribou Heart Range. It is not certain if the contact is faulted or just unconformable.

The point where the unconformity reaches the slope is about 800 feet above the cirque bottom.

Regional Geology

Structually the Caribou Heart Range lies in the Southern extremity of the Northern Interior Plateau and Mountain area of the Canadian Cordillera. The area is composed of mixed sediments and volcanics of the Takla Group (Jurassic) intruded by Tertiary Kastberg intrusions. The southern part of the Caribou Heart Range is overlain by a flat lying thrust plate of upper Cretaceous Sustut Rocks. Ultamafic rocks, probably Jurassic, intrude the Pennsylvanian or Permian Cache Creek and Asitka groups in the Axelgold Range. They are separated from the later rocks by major faults. The closest exposure of intrusive rocks is about six miles west of the Caribou Heart Ra Range. Here a Tertiary Kastberg porphyritic stock intrudes upper Takla Group rocks. The only other major intrusive body is the Hogem batholith which lies ten miles to the east. (see GSE map 962 A).

TABLE OF FORMATIONS

FORMATION	AGE	CHARACTER
Unit I	Lower, Upper Takla (Jurassic-Lord 1948)	Meta-volcanics and meta-sediments. Characteristcally green. Much epidote and chlorite. Minor disseminated pyrite and chalcopyrite.
	FAULT CONTACT	
Unit II	Upper, Upper Takla (Jurassic)	Purple & green Na-metasomatized plagioclase porphyry volcanic rocks. Limestones, tuffaceous limestones and limy tuff. Volcanic shales, siltstones sandstones & pebble conglomerates.
	CONTACT NOT OBSERVED	
Unit III	Upper, Upper Takla(?) Not seen in contact with Units I & II, May be part of Unit II.	Marine siltstone and coarser sediments. Minor coal, some marine invertebrate fossils.
	INTRUSIVE CONTACT	
Intrusive rocks	Age Unknown cuts rocks of Units I and III	Biotite-quartz-albite porphyry dykes.

Local Geology

The Caribou Heart Range has a core of Upper Takla meta-volcanics and meta-sediments, contorted by complex folds, generally showing a north-east trend. At least two, probably more, periods of folding must be postulated to account for the complexity of folds.

These rocks are unconformably overlain by rocks of upper Upper Takla group which, on the east side of the range, dip to the east at about 30°. The younger rocks were not seen in the west side of the range. It is not certain if the younger rocks have been thrust over the older. The rocks at the Northstar Prospect apear to be in fault contact with the older rocks, however these are not the same rocks as the younger rocks in other parts of the range. The nature of the contact is uncertain, but there appears to have been a major break (see plate 1). The Sustut rocks on Kaza Peak form part of a thin, flat-lying, thrust sheet, probably coming from the south.

A few dyke rocks of undetermined age were discovered in the older rocks near the Northstar rospect, as well as in the younger rocks further north.

Structural Geology of the Northstar Prospect

The structure of the rocks of the Northstar Prospect itself, especially Unit II, is highly complex and can only be described in very general terms.

The two major structural, as well as petrologic, units are;

1) A basement of highly contorted meta-volcanic and meta-sediments.

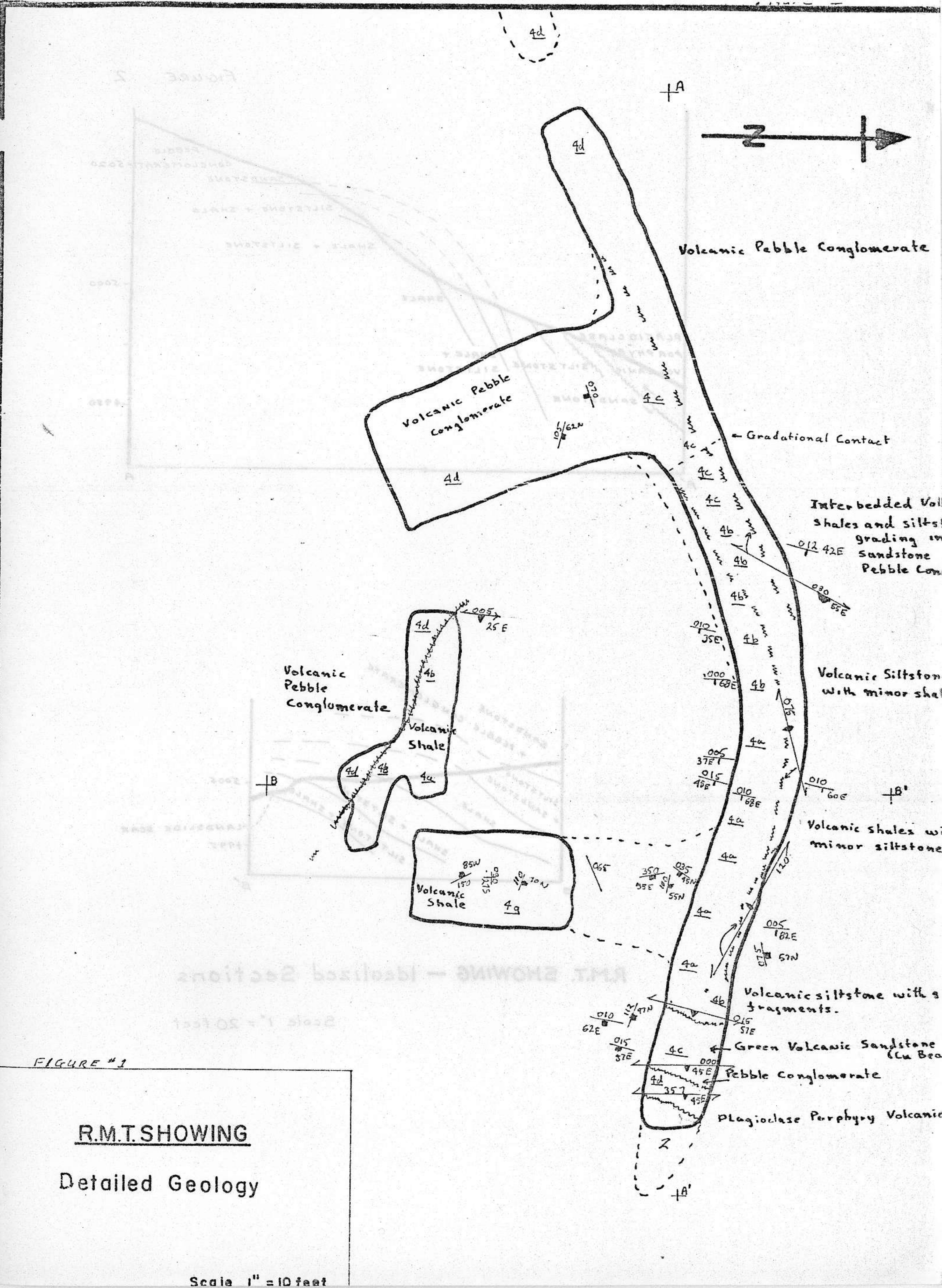


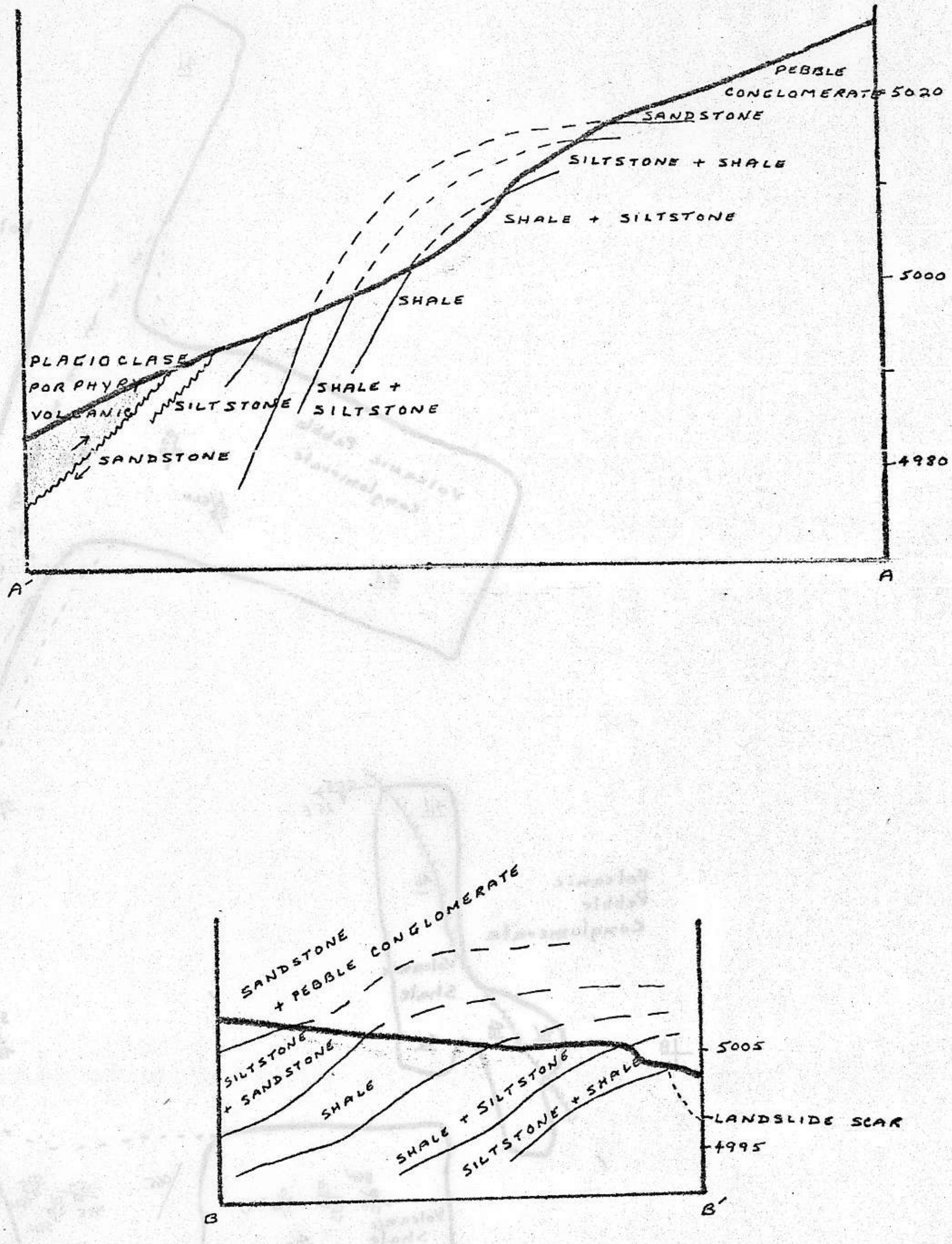
FIGURE #1

R.M.T. SHOWING

Detailed Geology

Scale 1" = 10 feet

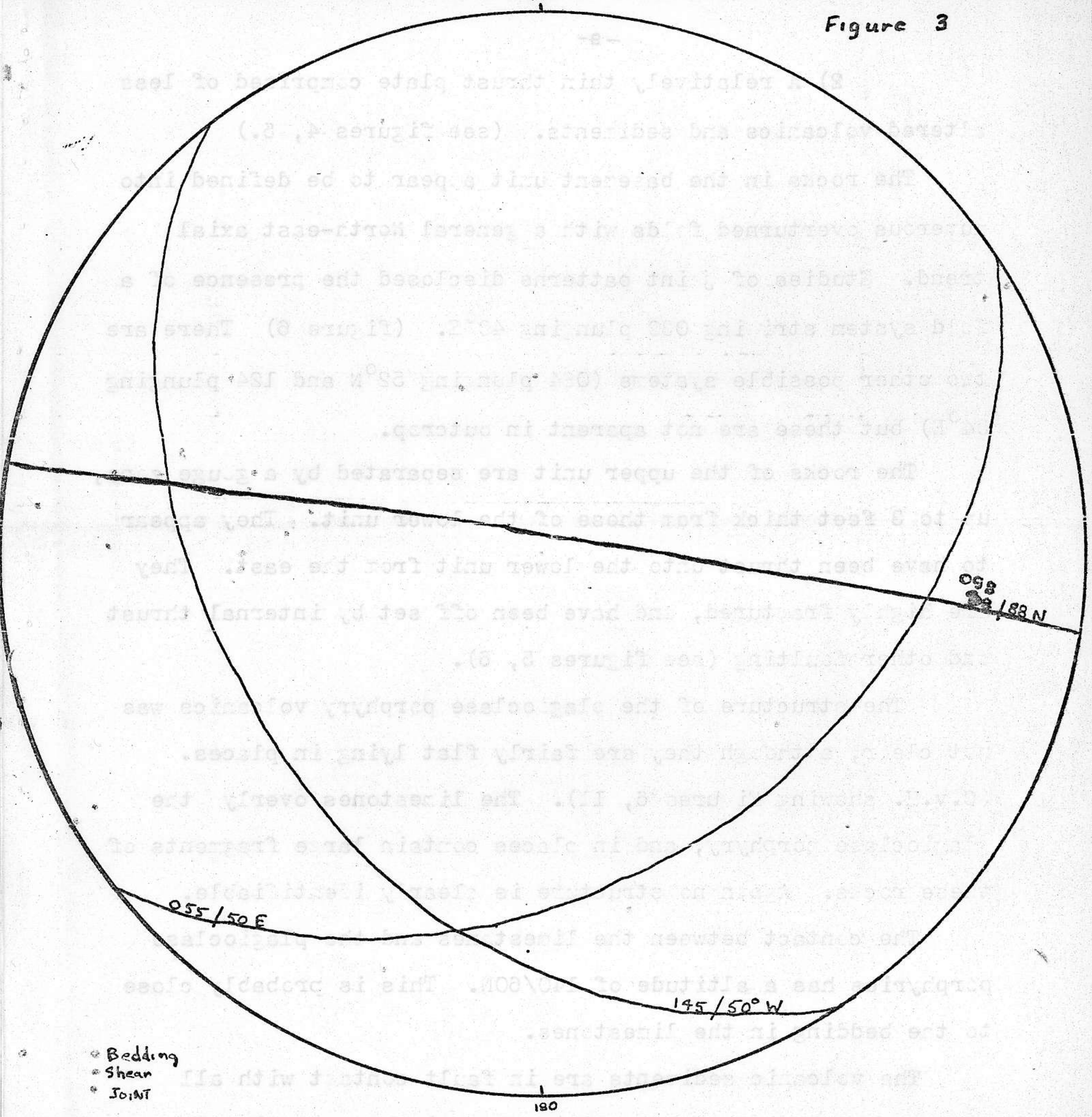
FIGURE 2



R.M.T. SHOWING — Idealized Sections

Scale 1" = 20 feet

Figure 3



Poles to Bedding, Shear, and Joint Surfaces
R.M.T Showing

2) A relatively thin thrust plate comprised of less altered volcanics and sediments. (see figures 4, 5.)

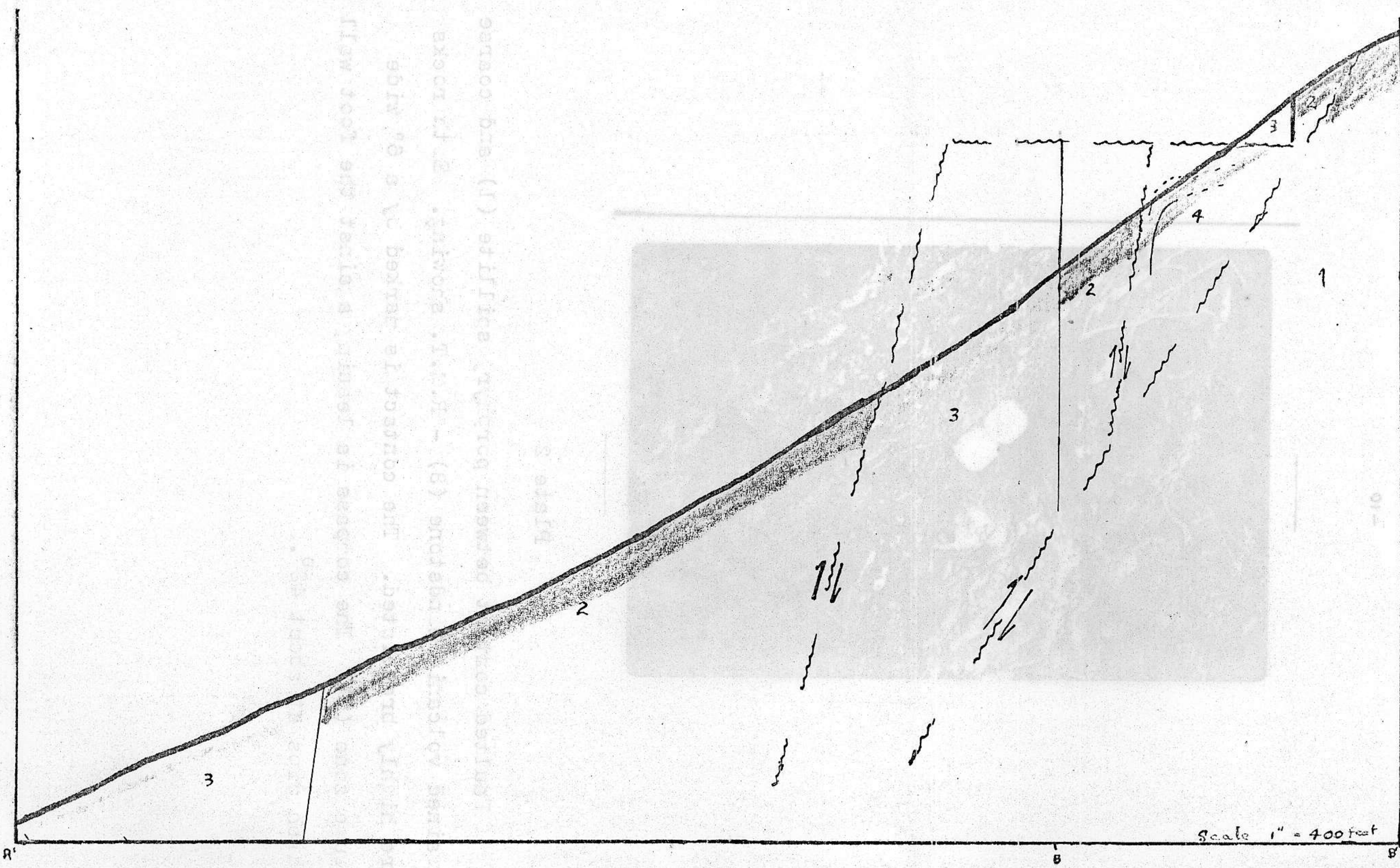
The rocks in the basement unit appear to be defined into numerous overturned folds with a general North-east axial trend. Studies of joint patterns disclosed the presence of a fold system striking 030 plunging 40°E. (figure 6) There are two other possible systems (084 plunging 52°N and 124 plunging 54°E) but these are not aparent in outcrop.

The rocks of the upper unit are separated by a gouge zone, up to 3 feet thick from those of the lower unit. They appear to have been thrust onto the lower unit from the east. They are highly fractured, and have been off set by internal thrust and other faulting (see figures 5, 6).

The structure of the plagioclase porphyry volcanics was not clear, although they are fairly flat lying in places. (C.v.H. showing Figures 6, 11). The limestones overly the plagioclase porphyry, and in places contain large fragments of these rocks. Again no structure is clearly identifiable.

The contact between the limestones and the plagioclase porphyries has a altitude of 140/60N. This is probably close to the bedding in the limestones.

The volcanic sediments are in fault contact with all other rock types, and thus their place in the stratigraphy is in question. Almost certainly they overlie the limestones. Whether there is a large gap between them is not known. Two flexures (055 plunging 50°E, 145 plunging 50°W) can be indentified in both outcrop and joint pattern studies (figures 2, 3). A third flexure (098 plunging 88°N) may be present



Section A - A' Map 3 - Line 136+00 N

Figure 4

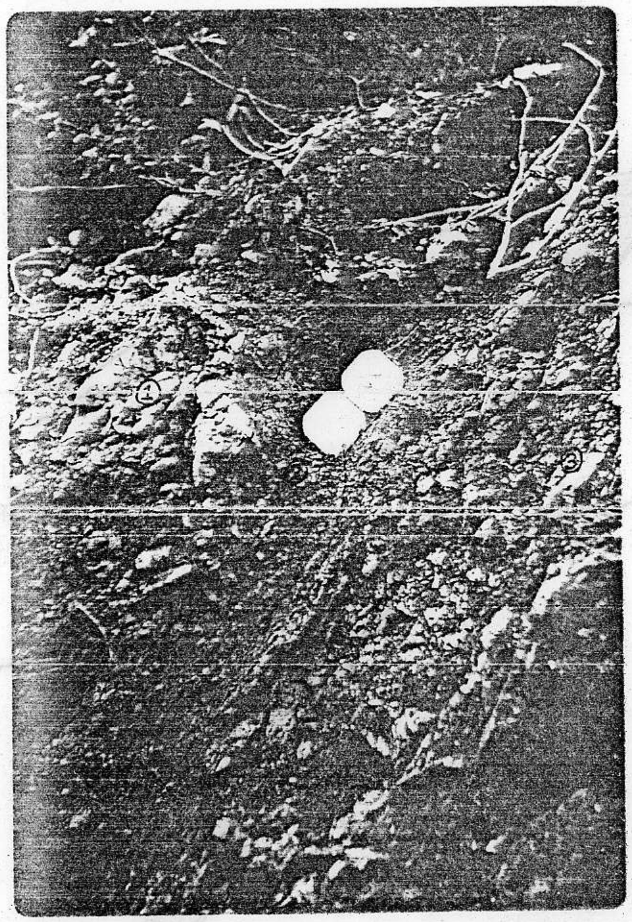
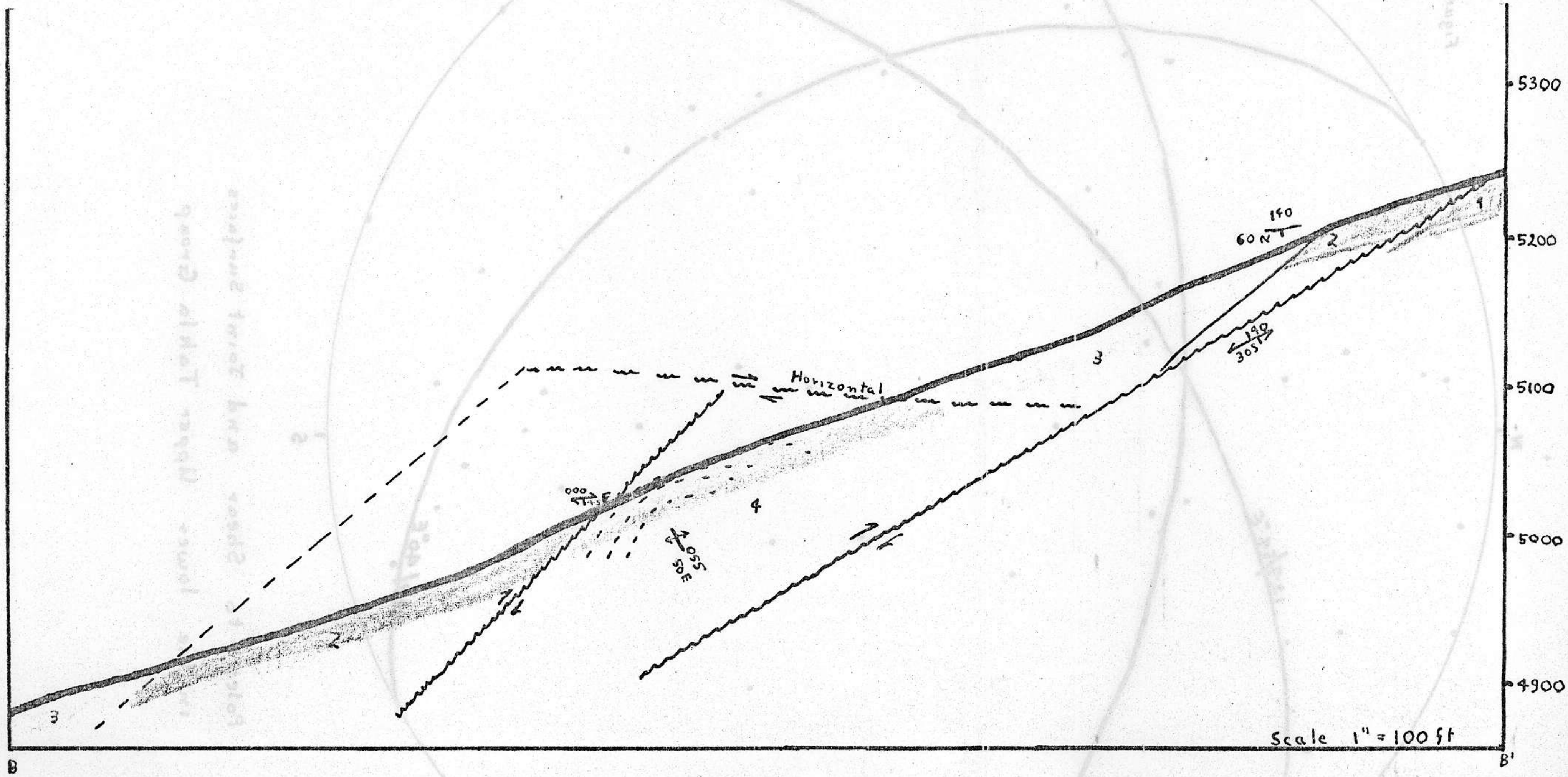


Plate 2

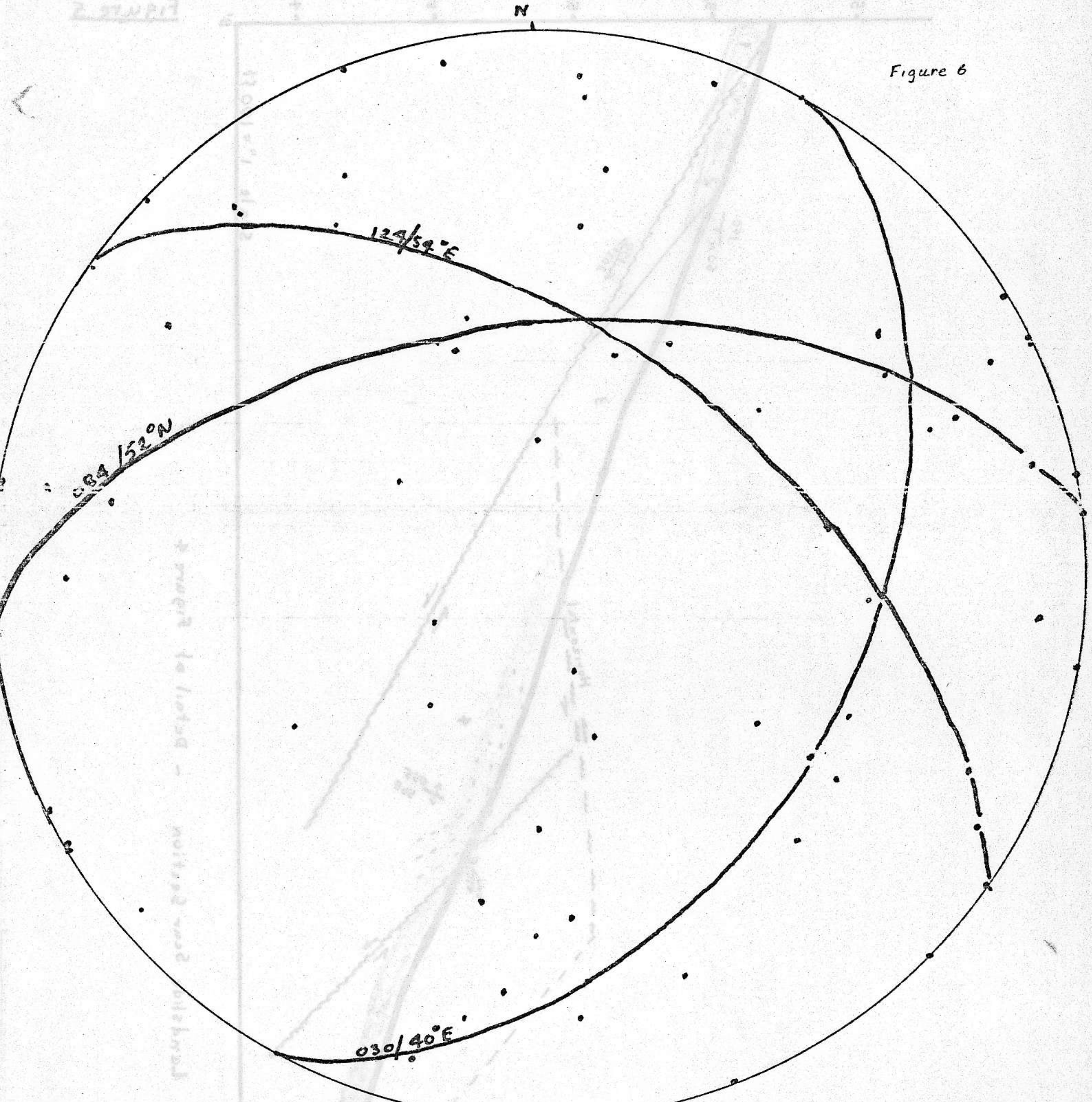
Faulted contact between porphyry spillite (1) and coarse grained volcanic sandstone (3) - R.M.T. showing. Both rocks are highly brecciated. The contact is marked by a 6" wide gouge zone (2). The compass is leaning against the foot wall which dips at about 45°.



Landslide Scar Section - Detail of Figure 4

Figure 5

Figure 6



Poles to Shear and Joint Surfaces in the lower Upper Takla Group

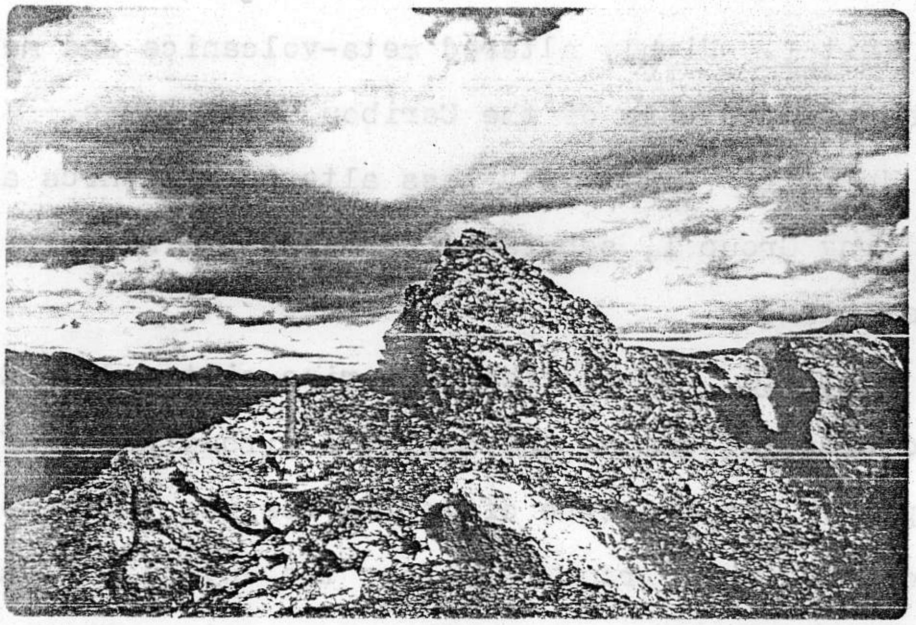


Plate 8

Large boulder of porphyry spillite completely surounded by limestone - landslide scar. The contacts are generally obscured by debris from the volcanic rock. This, and similar boulders in the limestone, prove conclusively that the porphyry spillite preceded the limestone. The volcanic rock is badly broken and cut by numerous calcite veinlets.

PETROLOGY

The rocks found near the Northstar Prospect can be divided into three units:

Unit I. Highly altered meta-volcanics and meta-sediments which form the core of the Caribou Heart Range.

Unit II. Relatively less altered volcanics and sediments overlying Group I, separated from it by a steeply inclined thrust plane.

Unit III. Fossiliferous marine silt and sandstones were found cropping out at the top of a cirque north of the Northstar Prospect. The presence of marine fossils indicates the rocks are of the Takla group. Whether they overly or ynderly Unit II is not certain. Minor coal found in this unit indicates that it is of shallow marine origin - possibly in part continental.

Two, relatively small, biotite-quartz-albite dykes cutting Unit I rocks were found about 1½ miles from the nearest outcrop of Unit II rocks. Similar dykes , as small swarms, cut Unit III rocks. A general description of the rock types is given below. Description of individual rock specimens is provided in Appendix I.

Unit I.

These rocks are included by C.S. Lord (1948 Geological Survey of Canada - Memoir 251) in the Upper Division of the Takla Group (Unit 4). They are probably equivalent to the Hazelton Group, and possibly also the Nicola Group. The local distribution is shown on maps 1 and 3.

The rocks are characterized by a light to dark olive green colour. They weather grey. The rocks contain both sedimentary and volcanic fractions, with volcanics apparently dominant in the upper sections. The volcanics can be subdivided into 3 colour groups; 1) Dark Green, 2) Light Green, and 3) Dark Green fragments in a Light Green matrix. The first two are flows - in part altered to amphibolites and epidotized; the third probably an agglomerate with an epidotized matrix. They generally contain numerous small (¼x¼") phenocrysts of pyroxene altered to chlorite. The rocks are generally highly altered and large irregular masses or stringers of epidotes or calcite can be found in them (up to 1½ feet diameter). They are cut by numerous faults and conplex joint sets, some of which contain calcite and epidote. Many specimens have minor sulphides - Chalcopyrite and pyrite disseminated in the vicinity of fractures. A thick sequence of sediments is found below the volcanics, mostly grits and silt or sandstones. No important mineralization was found in these rocks and they were not studied in detail.

Unit II.

Unit II rocks are the host rocks for the major mineralization zones found on the Northstar property. The rocks of this unit include plagioclase porphyry volcanics (spillites), limestones and volcanic sediments. The local distribution is shown on maps 1, 2, & 3.

Plagioclase Porphyry Volcanics

In rocks of this type are found all but one major mineral-

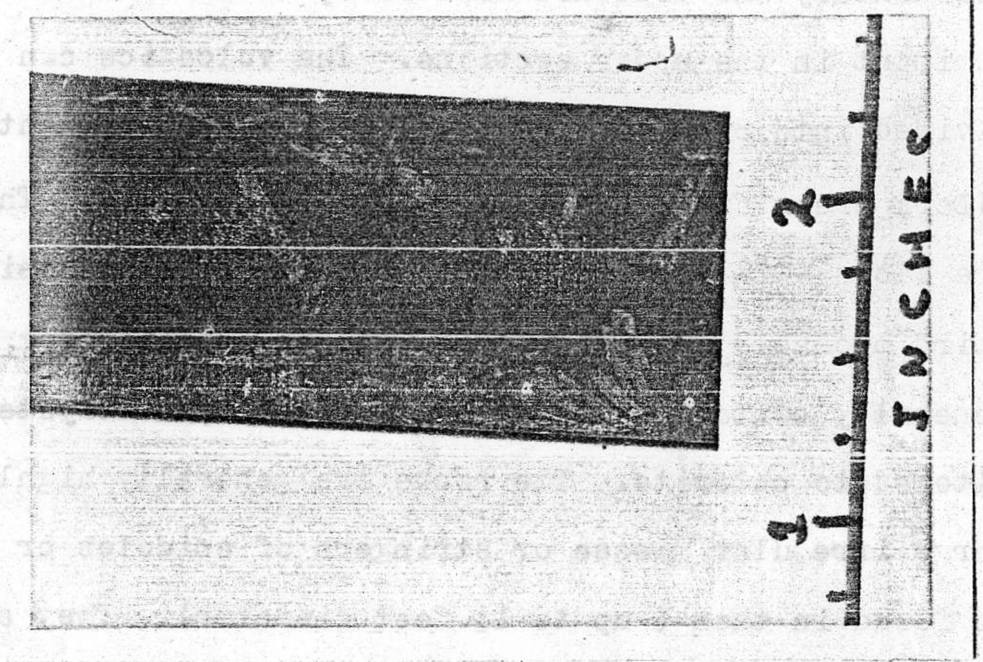
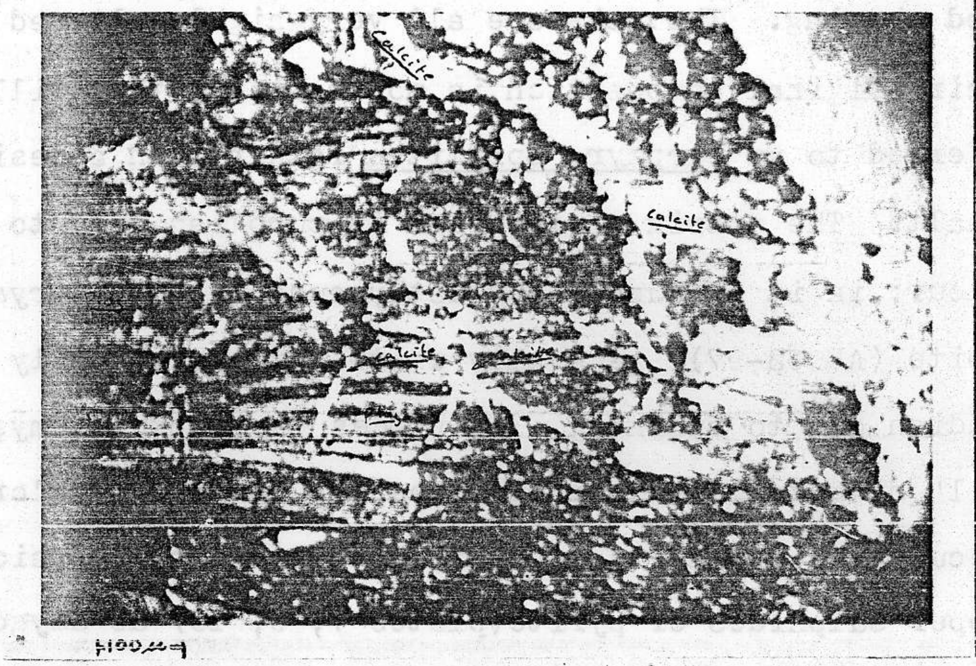


Plate 4

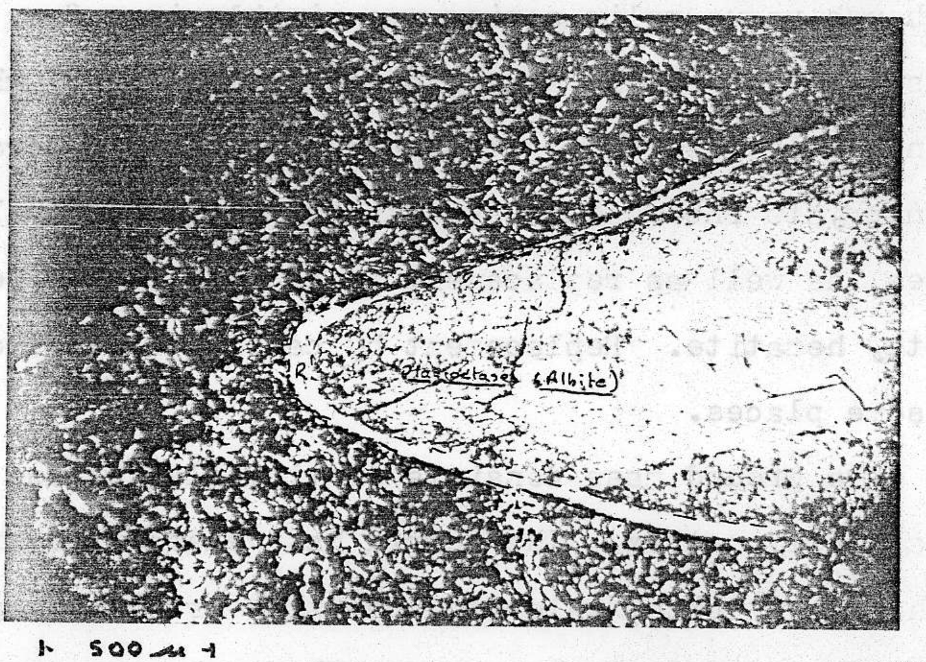
Drill Core Hole B - 28'

Amygdaloidal porphyry spillite. Note size of amygdules which are all chlorite-filled. A thin rim of fine grained chlorite coats the wall of the amygdule, while the center is filled by coarser grained chlorite. Plagioclase phenocrysts are relatively scarce, and evenly distributed. A few are in clusters. The purplish brown colour is caused by hematite which has replaced much of the matrix.



Thin Section Hole 5-103 ft.   Plate 5

A plagioclase crystal has been brecciated. Calcite has deposited in the fractures, deforming the crystal.



Thin Section Hole 8-28 ft.   Plate 6

A plagioclase phenocrysts has been attached by the magma, forming a reaction rim around the crystal.

ized showing. The rocks are all very highly altered and, as their original composition is not certain, they will be referred to as <u>Porphyry Spillites</u> rather than andesite or basalt. The matrix of the rock is purplish grey to green in colour; in it lie up to 60% lathy euhedral phenocrysts of albite (Ab 93-97), generally white but occasionally greenish or reddish due to staining. In places the rock is amygdular (up to 1" diameter) with calcite, earthy hematite, chlorite(2 phases) specularite, prehnite, copper carbonates and occasionally copper sulphides or pyrite(plates 7, 9, 10) as amygdule fillings. Vesicles are rare and probably formed by solution of amygdule fillings.

Microscopic studies showed that the rocks were fairly highly altered. Plagioclase phenocrysts were all albitized, although vague relic zoning was visible in a few. Reaction rims occurred around some phenocrysts (plate 6) where they had been partly resolved by the magma. Further alteration of the phenocrysts included saussuritization (generally light) in all cases, as well as replacement by calcite, chlorite, epidote or earthy hematite. Replacement by carbonate is almost complete in some places.

The ground mass consists of tiny plagioclase crystallites in a glassy matrix. The matrix has generally been replaced, either by calcite, chlorite, hematite or occasionally copper sulphides. Streaming of crystallites around phenocrysts is sometimes visible (plates 10, 11). It is possible that some of the chlorite derived from mafic phenocrysts which are no longer indentifiable.

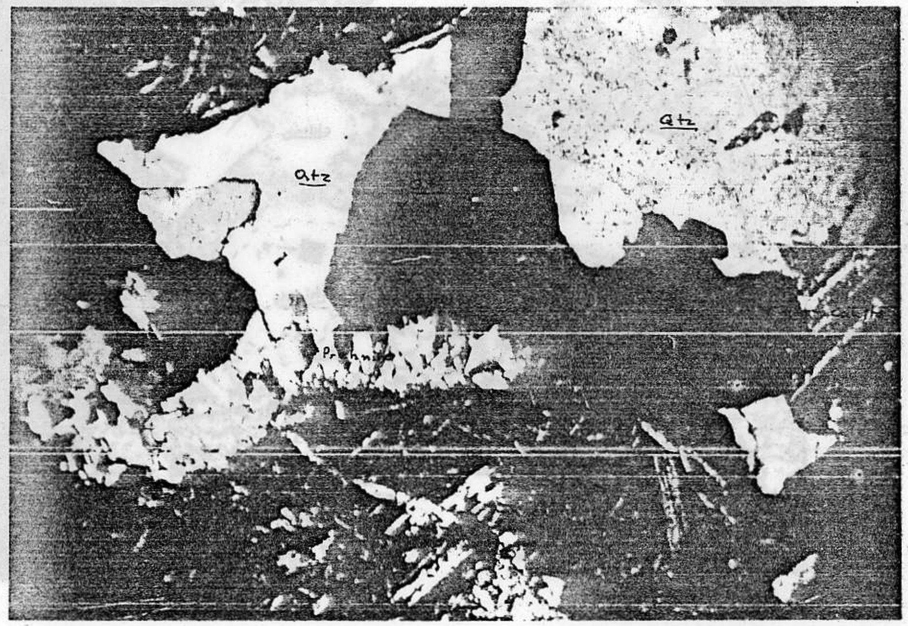


Plate 7

Thin Section 12-8-67-H-1

Prehnite, quartz, and calcite filling in amygdule in a porphyry spillite. Prehnite was introduced first, followed by quartz and finally by calcite.

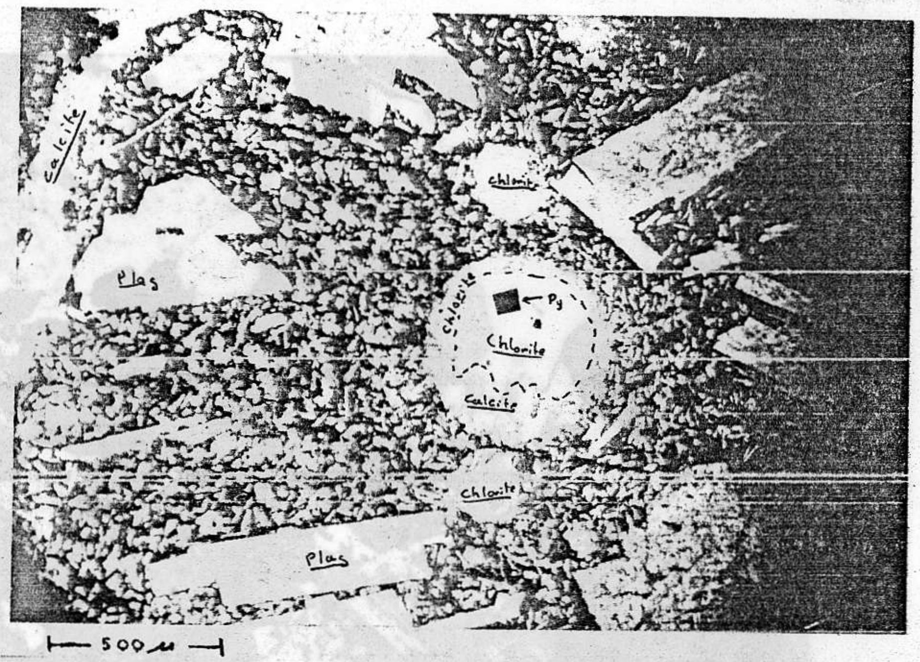


Plate 8

Thin Section 5-219 ft.

Small, slightly fractured plagioclase phenocrysts in a fine grained ground mass. Some of the crystallites are in glomeroporphyritic clusters (g). The amygdules are filled by chlorite and calcite. Chlorite, in 2 phases appears later than calcite. The euhedral pyrite crystal in the chlorite filled amygdule indicates a close relationship between chlorite and sulphide minerals.

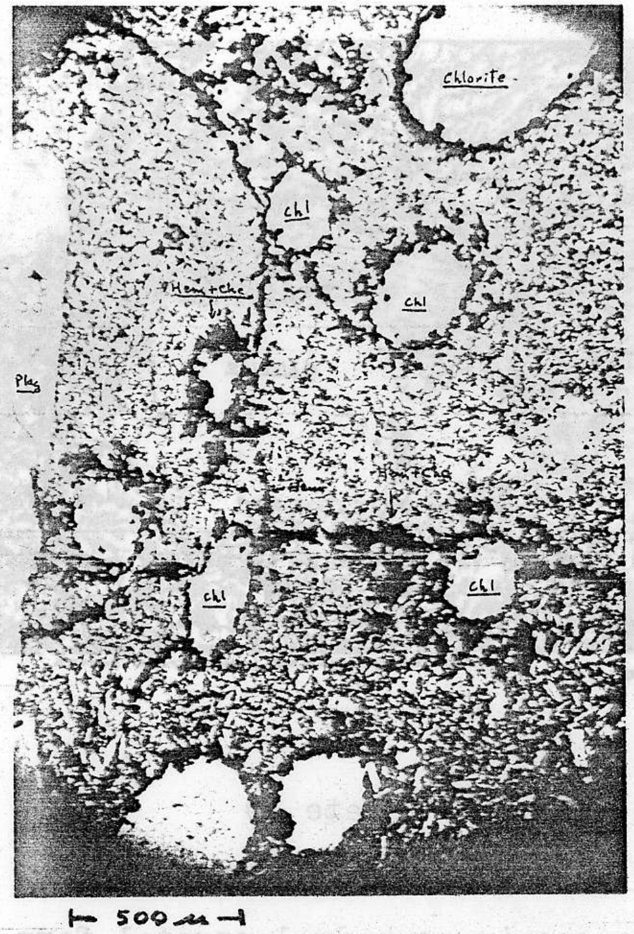


Plate 9

Thin Section Hole 7-40 ft.

Chlorite filled amygdules with closely associated hematite and chalcocite. The hematite and chalcocite appear to have been fixed, in some way, by the presence of chlorite. Hematite in fractures is possibly somewhat later.

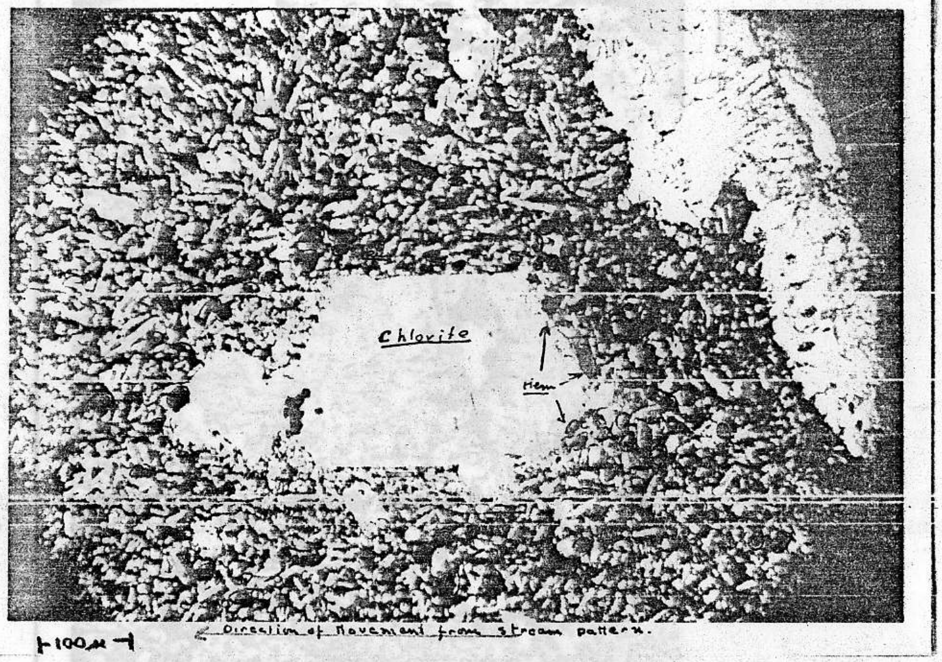


Plate 10

<u>Thin Section 10-9-67-H-2</u>

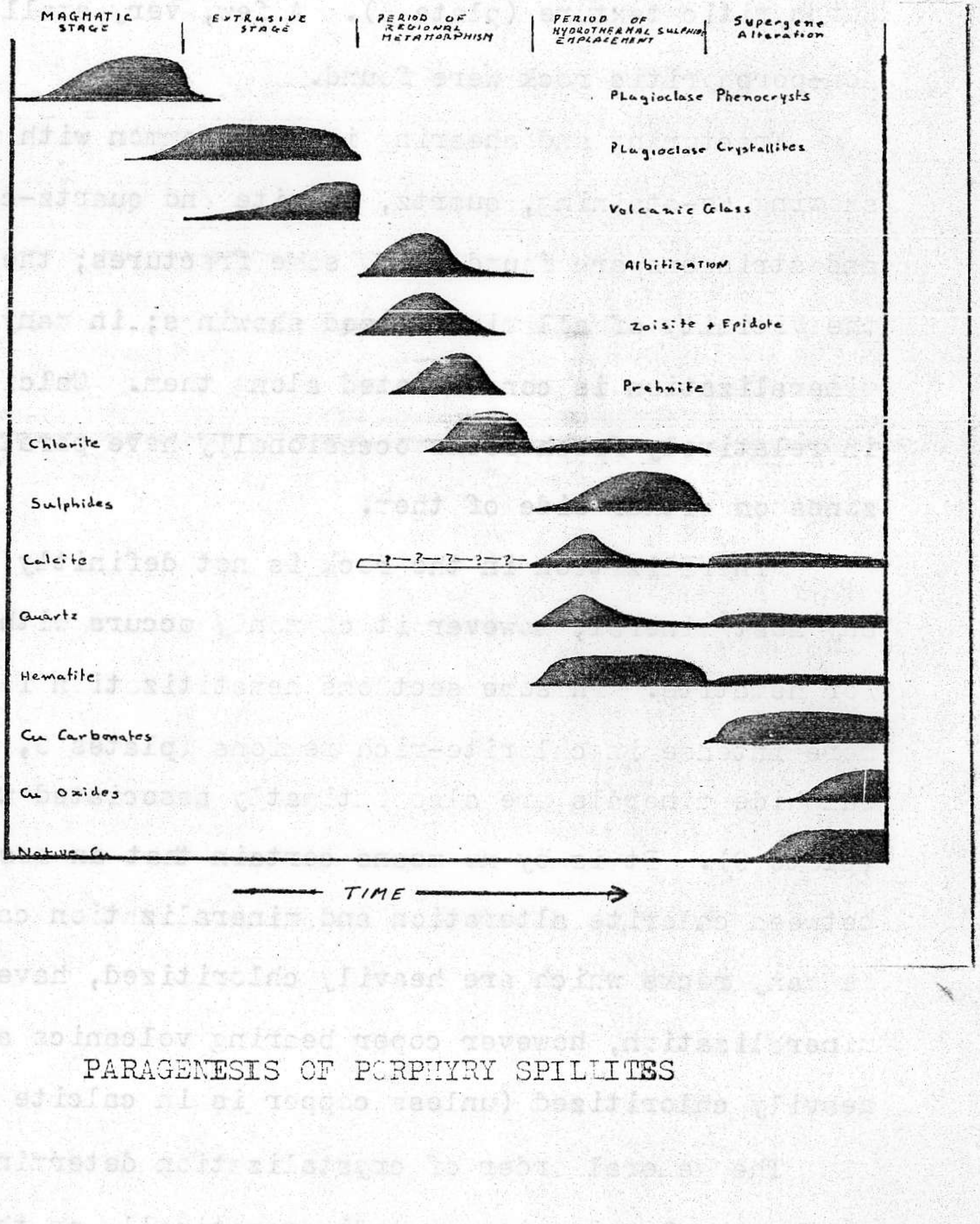
Chlorite showing euhedral crystal form. Chlorite pseudomorphous after some earlier mineral, possibly plagioclase, possibly a mafic mineral. Note "halo" of Hematite - black specks. A certain amount of streaming of plagioclase crystallites can be seen.

In a few places trachytic alignment of phenocrysts was visible, in others they were unaligned or showed a glomero-porphyritic texture (plate 8). A few, very small, zones of non-porphyritic rock were found.

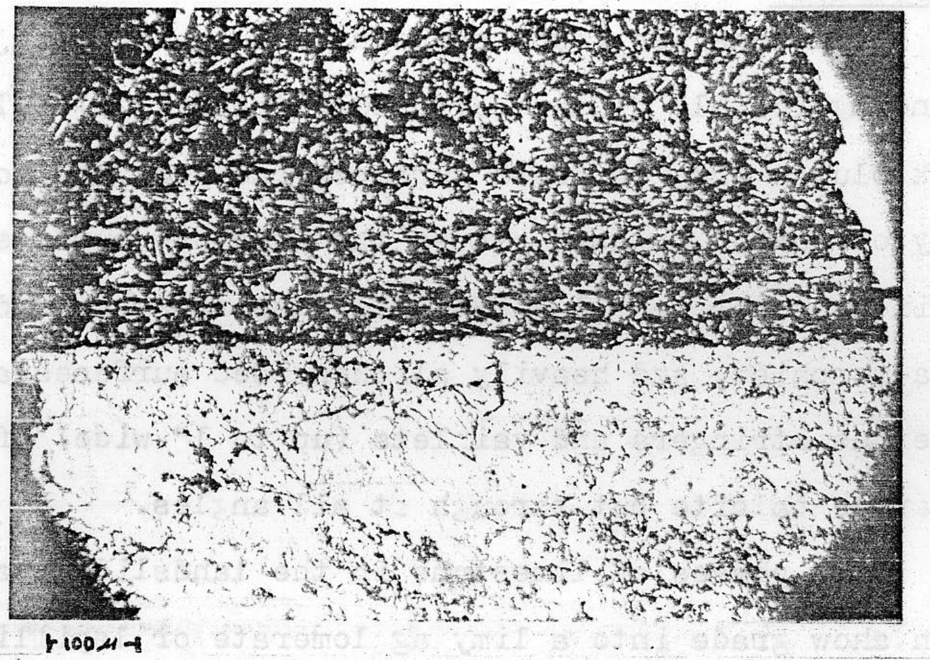
Fracturing and shearing is very common with most surfaces showing Fe-staining, quartz, calcite and quartz-calcite veins and stringers are found along some fractures; they appear in the vicinity of all mineralized showings;.in many cases mineralization is concentrated along them. Calcite stringers in relatively fresh rocks occasionally have parallel hematized zones on either side of them.

Mineralization in the rock is not definitly confined to any host mineral, however it commonly occurs with chlorite and /or hematite. In some sections hematitization is definitly more intense in chlorite-rich regions (plates 9, 10); in others sulphide minerals are also intimatly associated with chlorite (plate 9). It is by no means certain that an association between chlorite alteration and mineralization can be proven, as many rocks which are heavily chloritized, have no apparent mineralization, however coper bearing volcanics are invariably heavily chloritized (unless copper is in calcite veins).

The general order of crystalization determined for the porphyry volcanics is shown diagramatically on the next page.

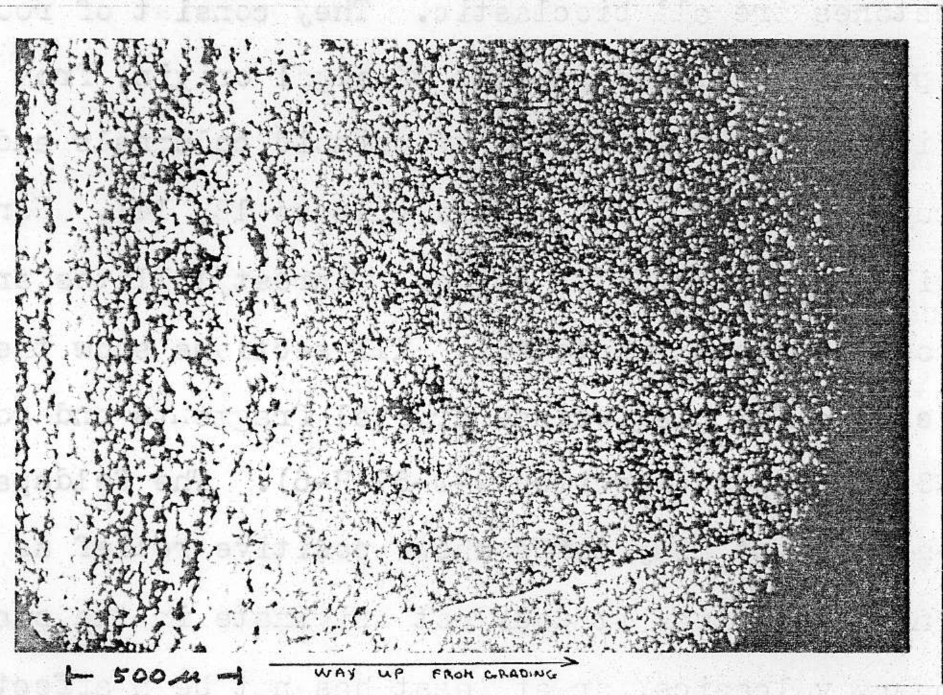


PARAGENESIS OF PORPHYRY SPILLITES



Thin Section 10-9-67-II-2 Plate 11

Streaming of plagioclase crystallites at the edge of a plagioclase phenocryst.



Thin Section Main Show Shale Plate 12

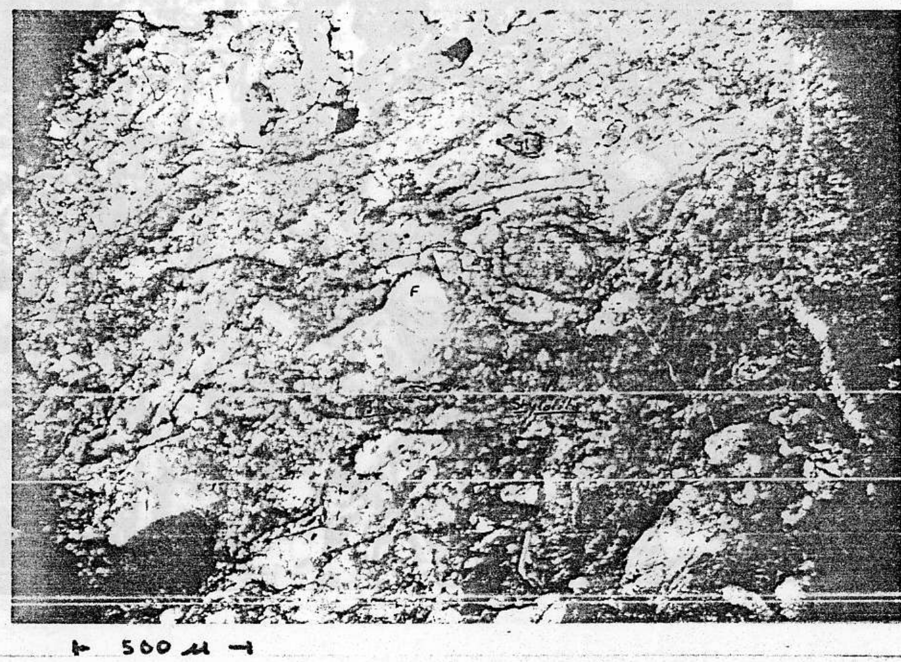
Thin laminated shale-siltstone showing well developed grading, and sharp contacts between beds.

Limestones

Limestone was found cropping out in three major zones trending roughly N10E - North 30E. (maps 1, 3). The rock is a dark bluish grey on fresh surfaces and weathers to a light grey or buff. In some places the fracture surfaces are iron stained. (specimen 11-8-67-H-6a) The rock has undergone slight meta-morphism, and heavily slickensided surfaces are common. Numerous stringers and veinlets (up to 1" wide) of pure white cleavage calcite cut through at all angles.

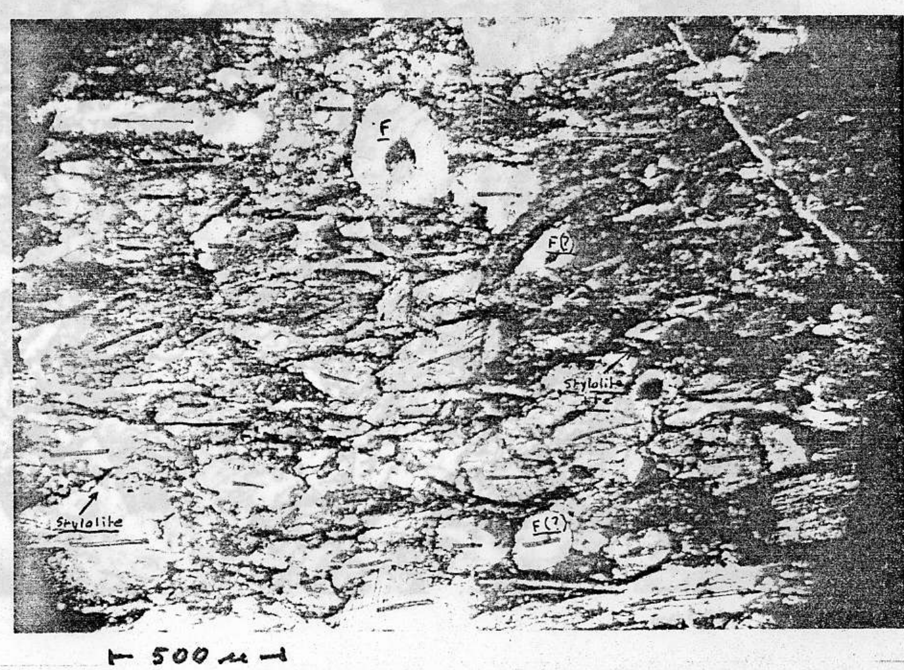
Some phases of limestone in the landslide scar at the main show grade into a limy agglomerate or lapilli tuff, with a calcareous mud cement. The volcanic fragments show some alteration to glauconite (plate 13).

Thin section examination shows that the relatively pure limestones are all bioclastic. They consist of round to ellipsoidal pellets; perhaps of algal origin, from 1/4 - 3/4mm in diameter, and fragments of crinoid columnals and echnoid spicules in a limy mud matrix (plates 13, 14). None of the fossils have diagnostic value. Microstylollites are visible in most sections (plate 14). All sections show the presence of at least a few plagioclase crystal fragments and some have up to 25% feldspar (specimen 9-9-67-H-6). The feldspar in both limestones and limy tuffs shows positive relief as well as zoning, indicating it does not originate in the plagioclase porphyry volcanics, or at least has not been affected by the same process of albitization. Minor amounts of chlorite have been found in several sections - probably derived from break-down of volcanic fragments. Minor pyrite and chalcocite are seen in places - especially on stylollite surfaces.



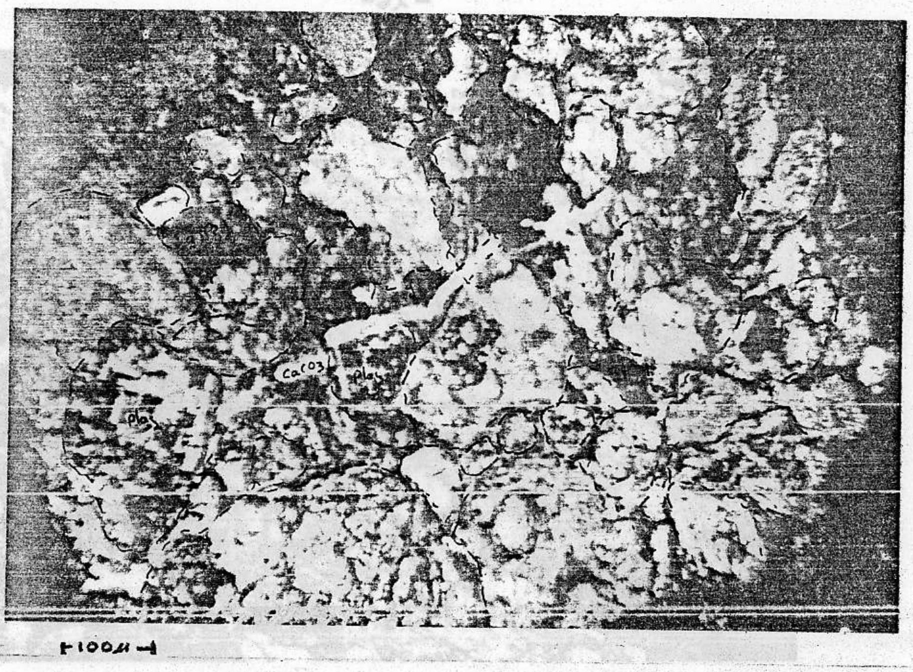
Thin Section 9-9-67-H-3 Plate 13

Bioclastic limestone with minor glauconite (gl). Note section of echinoid spicule (F), and faint stylotites.



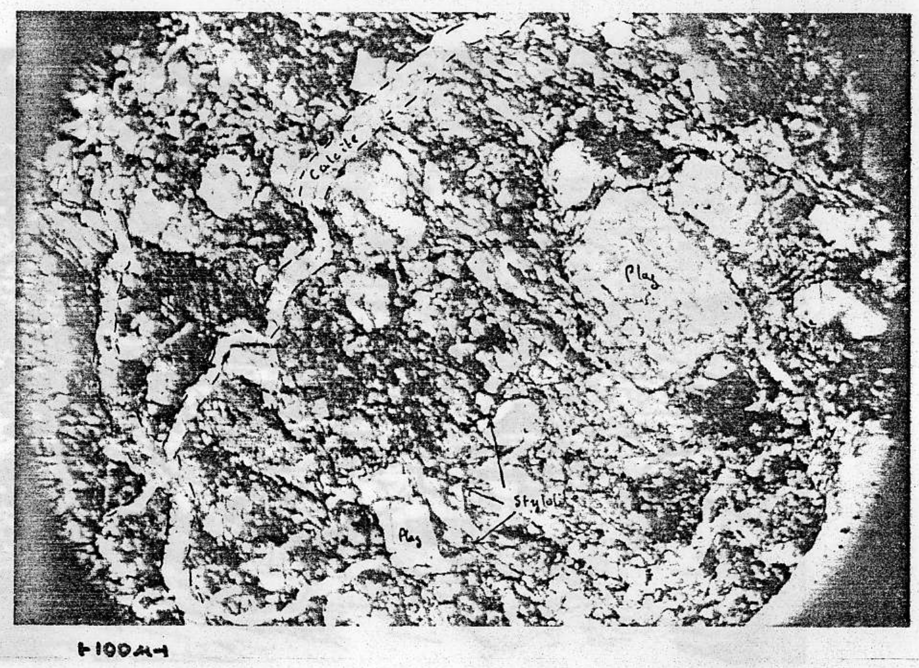
Thin Section 11-8-67-H-6a Plate 14

Bioclastic limestone. Note alignment of pellets - probably due to shearing. Several fossil fragments can be seen - probably crinoidal.



Thin Section 9-9-67-H-6 Plate 15

Well rounded volcanic clasts in a limy matrix. The rock is a limy volcanic sandstone.



Thin Section Copper-bearing Limestone Plate 16

Plagioclase clasts in a limy argillite matrix. A few faint stylollites can be seen. Fragments show vague alignment.

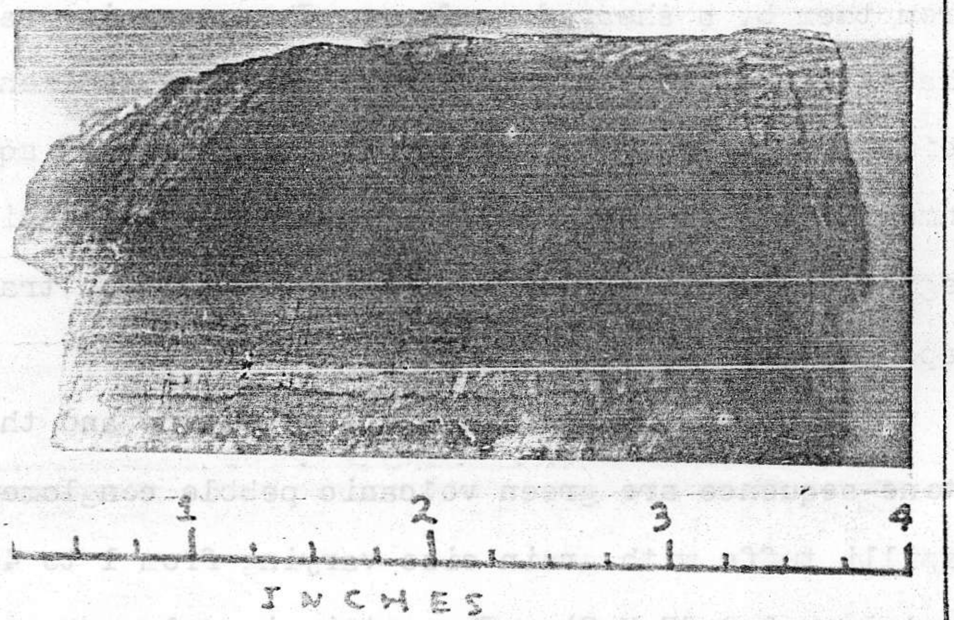


Plate 17

Laminated Siltstone-Shale R.M.T. Showing

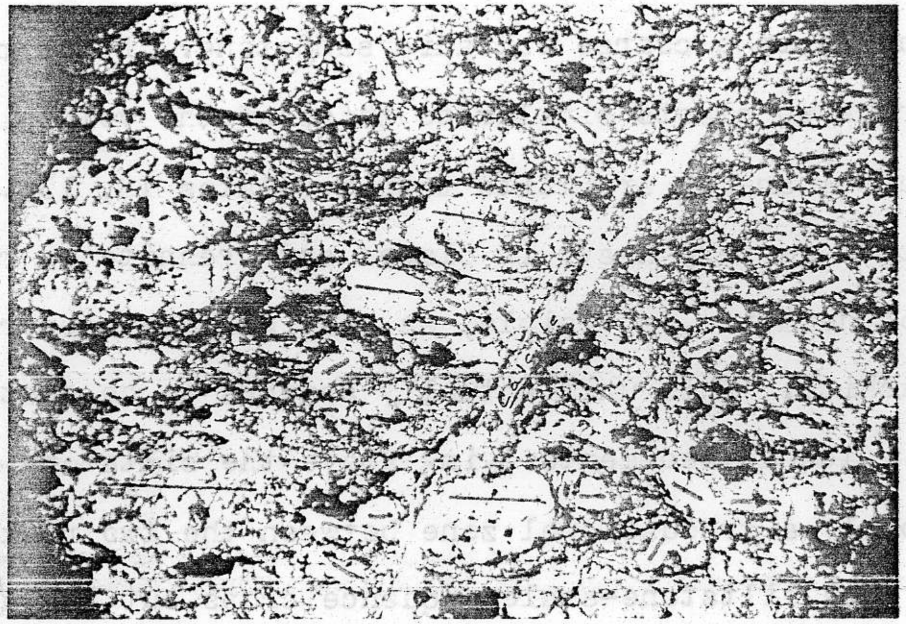
Thin black layers of shale can easily be distinguished from the coarser, lighter, siltstone. Note numerous fractures, and small scale offsets. Many fractures are not filled. On one side, a fracture surface shows malachite and hematite staining.

Volcanic Sediments

The volcanic sediments lie below the limestones, separated from them by a sheared surface. They vary in grain size from shales to pebble conglomerates. The fine sediments have well defined thin beds, indicating deposition in an aqueous environment. The coarser sediments do not show bedding, but the degree of particle rounding indicates aqueous transport and deposition.

The rocks lying between the limestone and the shale-siltstone sequence are green volcanic pebble conglomerates or lapilli tuffs with grain size varying from 1 to 40 mm. (specimen 9-9-67-H-7). The matrix is calcareous, silty or clayey with most of the detrital material probably also of volcanic origin. Clasts are generally subrounded with a fairly high sphericity. Clasts in some instances are quite similar to the plagioclase porphyry volcanics in appearance, others have numerous mafic phenocrysta, while the remainder are fine grained throughout.

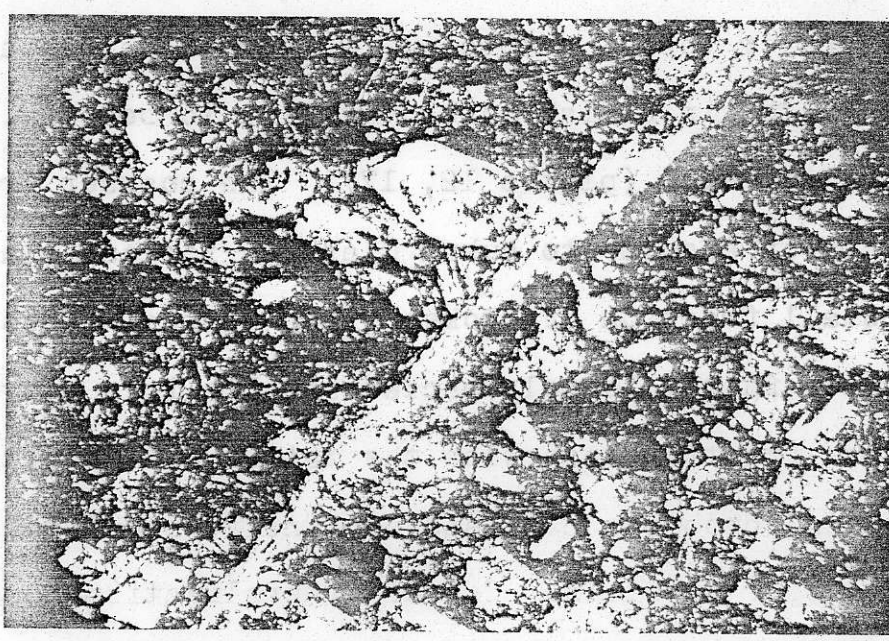
Alteration is quite extensive in both clasts and groundmasses. It includes the alteration of mafic minerals to chlorite (plate 20), replacement of groundmass and clasts by calcite or hematite, and introduction of prehnite. Prehnite is a major constituent of some phases making up as much as 5% of the rock. Calcite veinlets are common but generally are less than 5% of the total. Chloritization was evident, but not extensive, in the thin section studied. Hematite films cover some fracture surfaces.



⊢ 500 µ ⊣

Thin Section Copper-bearing Sandstone Plate 18

The clasts are apparently all of volcanic origin. Some are fine grained, others have phenocrysts of plagioclase. Note alignment of clasts. This may be bedding alignment, or shear deformation of clasts.



⊢ 500 µ ⊣

Thin Section Copper-bearing Sandstone Plate 19

As above, Crossed Nicols.

The green altered "tuff" found below the siltstone-shale sequence is a coarse volcanic sandstone. It is made up of subrounded clasts similar to those of the volcanic conglomerate in a calcareous argillite matrix (plates 18, 19). Chloritization is very heavy in places and prehnite is relatively low. Minor hematite is visible, as well as some copper sulphides and malachite. This unit actually appears to be continuous with the volcanic sediments lying above the siltstone, and is probably a graduational zone between the two rocks.

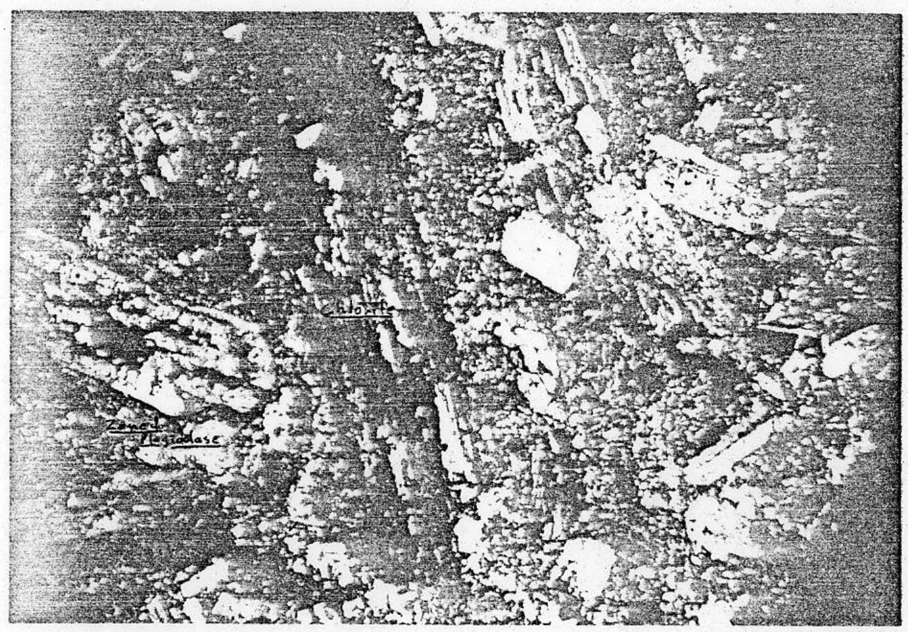
The siltstone-shale sequence crops out for about 25 feet near the bottom of the landslide scar. It grades into coarser sediments both at the top and at the bottom of its exposure. The rock is olive to bluish with heavy malachite stain. It is generally highly fractured, but retains its fissility. Fractures are mostly open, but in places contain calcite stringers or copper sulhides. Copper sulphides are also disseminated in bluish zones parallel to bedding. The rock is thinly laminated (plates 12, 17). The coarser fraction consists of angular to subangular plagioclase clasts, with a very small fraction of broken glass shards. These clasts are generally fairly loosely packed and lie in a clayey matrix. The fine fraction resembles the matrix of the siltstone in colour and probably consists of finely ground volcanic glass a and feldspar crystals. Copper mineralization appears to be concentrated in t e shaley fraction.

The feldspar clasts in the volcanic sediments are similar to those in the limestones in their positive relief and zoning.

⊢ 500 μ ⊣

Thin Section 9-9-67-H-7 Plate 20

Chlorite has replaced large mafic phenocrysts in clasts in the volcanic pebble conglomerate. Some glauconite is present (gl). Some clasts contain mafic minerals, others do not - possibly clasts come from different sets of flows.



⊢ 500 μ ⊣

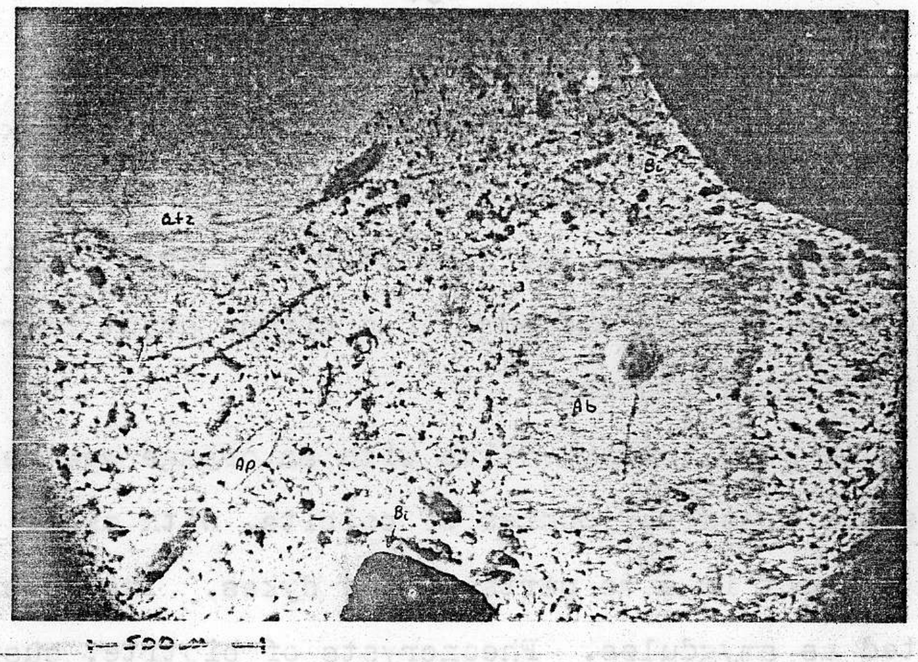
As above -- Crossed Nicols. Plate 21

It is apparent that they are of different origin from the porphyry volcanics or they were not affected by the albitization process which altered the flows. The later appears unlikely, as albite is not uncommon in impure meta-limestones.

Biotite-Quartz-Albite Porphyry Dyke

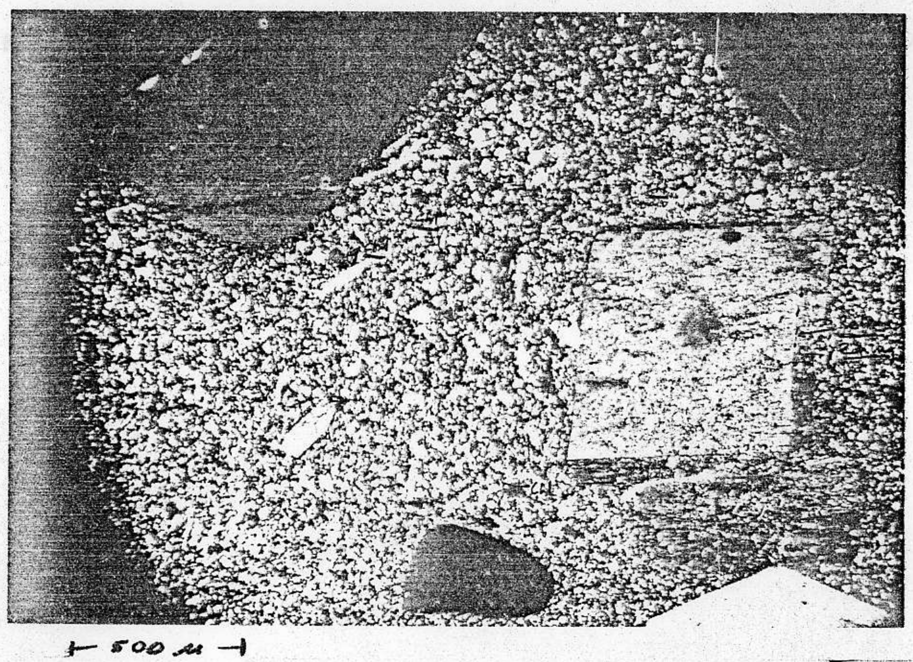
Two small biotite-quartz-albite porphyry dykes found about two miles south-east of the R.M.T. showing are the only intrusive bodies on the Northstar Prospect. Similar rocks have been seen at the edge of a cirque about four miles north of the R.M.T. showing.

The rock is dark olive with an orange weathered surface. Numerous spherical bodies of calcite, with minor chalcopyrite, are present in some parts of the dykes. The zones are interpreted as amygdules. Pheoncrysts of biotite, quartz and albite (Ab 96) make up about 60% of the rock in a 2 : 10 : 18 ratio. K-feldspar is practically absent although one small corroded crystal was observed. The matrix is very fine grained. It has been partly altered to chlorite. Calcite veinlets cut the rock in places. Opaque minerals disseminated through the matrix include chalcopyrite, magnetite, and pyrite.



Thin Section Biotite-quartz-albite Porphyry Plate 22

Phenocrysts of albite (Ab), biotite (Bi), and quartz (Qtz) in a fine grained matrix. A few quite large crystals of Apatite (Ap) are visible.



As above -- Crossed Nicols. A few specks of chlorite can be distinguished. Plate 23

Alteration

The rocks in the vicinity of the Northstar Copper Prospect have undergone three periods of alteration; one during regional metamorphism (phase I); one during emplacement of sulphide ores (phase II); and one of later, supergene, origin (phase III).

The first stage of alteration is characterized Na-Mg-Fe metasomatism producing chlorite, epidote, and albite. This app appears to be regional in scope, as chloritization and albitization have taken place in rocks of both Unit I and Unit II. Na-metasomation of feldspar seems to be complete, as no feldspars but albite were found, except insignificant amounts of K-feldspar in dyke rocks. In the limestone and volcanic sediments near the R.M.T. showing albitization of feldspar clasts had either not taken place, or it was incomplete. This may be due to the high concentration of lime in the sediments, inhibiting regional Na-metasomatism. The presence of chlorite in these rocks, apparently independant of any sulphide minerals, indicates that these rocks were subjected to the same degree of metasomatism as all others in the area. Prehnite is probably from this phase or phase three.

Phase II alteration which may actually have occured before Phase I, included addition of chlorite, hematite, calcite and silica - associated with sulphide mineral deposition. No exact age relationship with phase I can be determined, but as calcite, even in heavily carbonatized rocks, is still very fine grained, it seems likely that these minerals were not subjected to any appreciable metasomatism, and were thus emplaced after PhaseI.

Phase II has been observed in detail only in the porphyry spillites, and in the copper-bearing volcanic sediments.

Hematite appears spread evenly through the rock, resulting in a purplish colour in some volcanics. It also occurs as a narrow aureole parallel to Calcite stringers, in areas of heavily chloritized rock, intimatly associated with Chlorite (plates 9, 10). Chlorite and hematite occur both in vesicles, in fractured rocks, or disseminated through the entire rock, often replacing volcanic glass.

Chlorite cannot be positively ascribed to either Phase I or Phase II, but the occurrence of some chlorite intimatly associated with various sulphide minerals and hematite, as well as quartz and calcite, indicated that these minerals all represent one phase of alteration. The presence of Chlorite completely unassociated with the above group of minerals, but apparently associated with albitized Plagioclase, indicates a separate phase. The occurrence of two different chlorites in intimate contact, without evidence of reaction between them, must be taken as indicating a sudden change in conditions, such as sudden release of pressure, rather than as indicating two phases. If the latter were the case, there should be pronounced replacement of one by the other, This is not evident.

Carbonates and silica are definitely associated with sulphide minerals. Carbonization varies from imperceptable, to extreme (Specimen Hole 7 - 80'), probably depending on the presence of some minor element which made carbonate minerals stable. Quartz is a very minor constituent of veins and amygdules.

Phase III products are distinctly separable from those of the other two stages. It probably took place in 2 or more subphases, one immediatly after emplacement of the rock, and one taking place presently. Other subphases, associated with erosion cycles, may also have taken place, but cannot be proven. Phase III is characterized by typically supergene mineral assemblages. Earthy hematite, limonite, native copper with calcite (from break down of malachite), copper carbonates, cuprite, tenorite, and manganese oxides. Supergene calcite and quartz are also of this phase. Some of the specular hematite found with copper sulphides may originate in an earlier supergene phase, and have been recrystallized due to thermal activity.

Prehnite found in some vesicles, may be from this phase, but is more likely to originate in Phase I. Possibly it, as well as some chlorite have formed by regional metasomation of some earlier Phase III amygdules fillings. This again cannot be proven.

Mineral Deposits

SURFACE SHOWINGS

Six mineralized showings, identified as R.M.T., North or D.D., H.G. #2, B.C., C.v.H., and C.V., (maps 1,3), were studied in detail. Copper mineralization was observed in several other places, but it was not possible to study all occurrences. All showings occur in an area about 1000 feet by 3000 feet, with a range in elevation of about 800 feet. The mineralized showings can be divided into four groups on the basis of environment and type of mineralization.

Mineralogically there appear to be two major divisions of the surface showings: Those of a mostly bornite-chalcocite-digenite mixture, and those of a native copper-hematite mixture. Minor amounts of disseminated chalcopyrite and pyrite have been found; mostly in the Lower Takla greenstones, but some in fractures in limestone. These are not economically significant. All major showings are of the first type. Native Copper-hematite veins (plate 32) and veinlets have been found mostly in rubble and in a few, scattered, showings near the north showing. Minor amounts of Native Copper were found with the bornite-chalcocite-digenite mixture of the B.C. showing; this is definitly of secondary origin. The occurrence of the native copper-hematite mixtures with calcite, malachite, cuprite, and a black mineral suspected to be tenorite, as a fracture filling in the porphyry volcanics is indicative of secondary origin. The crystalline texture of the native copper brought out by etching normally indicates a hypogene origin or fairly intense thermal metamorphism. It is suspected that in the specimen it was formed either by intense heating of the surface during diamond polishing, or it is a relict texture originating from chalcocite which the copper has replaced.

The mineralogy of the Bornite-chalcocite-digenite is quite uniform, but they occur in two distinctly different rock types: 1) porphyry volcanics, 2) siltstone with a volcanic provenance. In both cases the three copper minerals occur in veins with quartz, calcite, chlorite, and hematite, either in veinlets or disseminated through the host rock. The ratio of quartz to calcite is highly variable but quartz usually predominates.

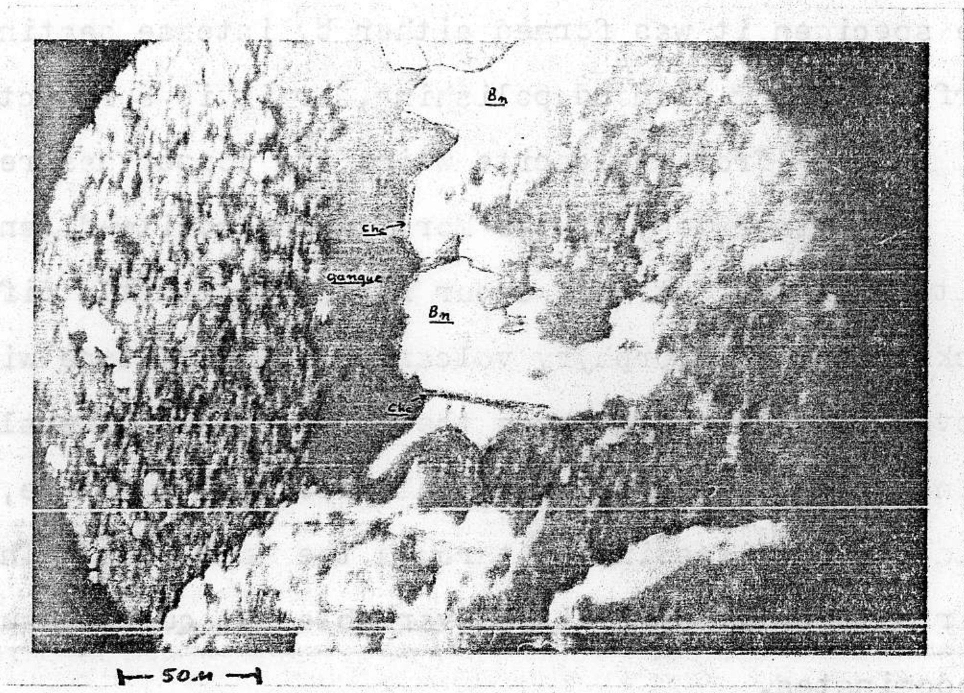
R.M.T. Showing

The original discovery of copper bearing sediments was made in 1965 at this showing. It lies at the south side of a landside scar on the eastern slope of the mountain, at about 5000 feet. The copper bearing beds are of two types:-

1. Interbedded, laminated siltstones and shale with some tuffs;

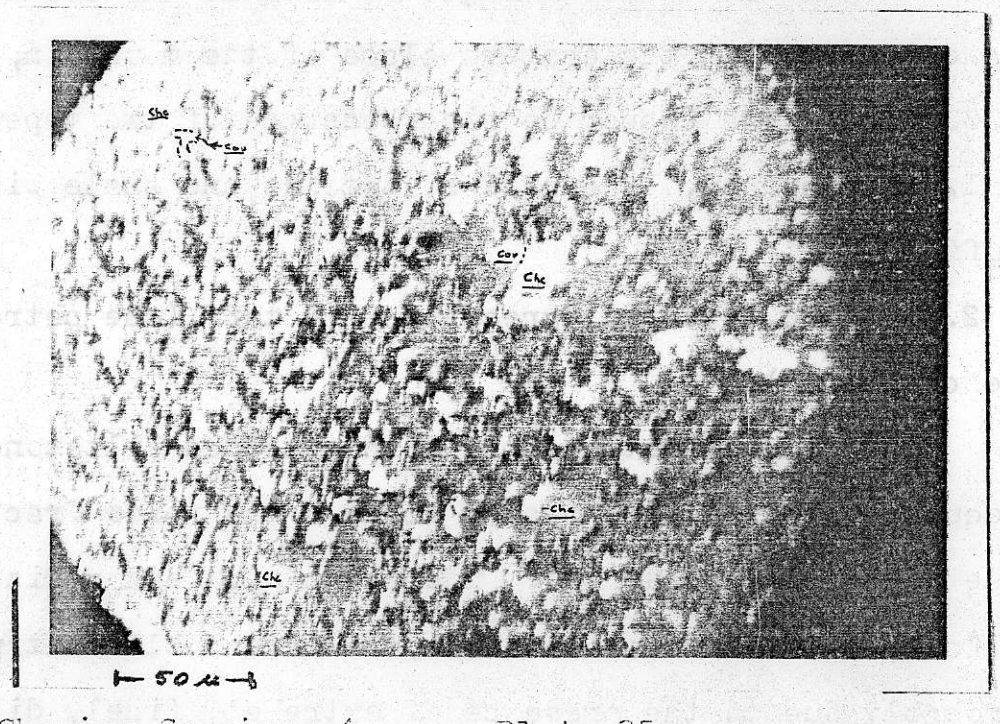
2. Altered, sheared, green lapilli tuff (see petrographic descriptions).

The mineralization in the interbedded siltstone-shale sequence occurs disseminated through the finer fractions of the rock (plates 24, 25). The fresh rock has a distinct olive colour, but the mineralized layers have a bluish tinge, probably due to the presence of extremely finely disseminated sulphides. Three primary sulphide minerals are present; bornite, chalcocite and digenite. In addition to these there is some



R.M.T. Showing Specimen 4 Plate 24

A thin rim of chalcocite (chc) has surrounded bornite (Bn). In some places chalcocite cuts the bornite as small stringers. Note relative scarcity of disseminated sulphides.



R.M.T. Showing Specimen 4 Plate 25

Evenly disseminated, fine grained chalcocite (Chc), with minor bornite and secondary covellite (Cov).

secondary, earthy, hematite or limonite, and malachite, usually along fractures but occasionally replacing plagioclase fragments in the host rock. Gangue minerals include quartz, calcite and very minor chlorite; calcite predominates.

Textural relationships between sulphide minerals are visible only in the veinlets. They show that chalcocite and digenite act as a single mineral with respect to bornite. The two minerals are in extremely fine intergrowth and often cannot be distinguished. Most common are various mutual boundary features, but, in places, chalcocite appears as a rim about bornite or in tiny veinlets cutting it (plate 24). The finely disseminated mineralization (plate 25) is usually in monomineralic grains (10-75 microns in diameter), but fine intergrowths can be seen under high power, and bornite, or chalcocite are of variable shade, probably because of minute blebs of one mineral in the other. Very minor covellite, of secondary origin, is present in some polished sections. In the coarser tuff beds mineralization is concentrated in blebs (up to ½ inch in diameter) of the bornite-chalcocite-digenite mixture. Textures are similar to those found in the finer grained rock, but no veinlets were observed. The only polished section from this rock was a bakelite mount which had been subjected to considerable heating. This had caused the formation of bluish reaction rims around the bornite (by addition of bornite molecules to chalcocite-digenite). The Lamellar intergrowths are exceedingly fine grained because of rapid cooling. The copper sulphides occur in a bornite: chalcocite:digenite ratio of 8:1:1. They constitute between

0.5% and 3% of the rock.

The origin of sulphide mineralization in the rocks has been the subject of some controversy. Originally it was described as having a syngenetic relationship with the sediments. The main support for this theory was the discovery of minute spherical concentrations of sulphides in the rock - similar to those formed by sulphide secreting bacteria. No features of the nature were discovered in the thin or polished sections studied, however this does not preclude the possibility of direct precipitation of minerals during deposition. If this was the case it would be impossible to prove or disprove it. Post-depositional hydrothermal activity definitly took place. Whether this brought in the sulphides or whether it merely remobilized previously deposited copper minerals, emplacing them in their present position, cannot be determined. In some places it appears that there is a lower concentration of copper minerals on the sulphide veinlets compared to regions away from these (plate 24). This might favour the remobilization theory.

North Showing

The North or D.D. showing lies 1500 feet west of the E.M.E showing at an elevation of 5800 feet. Mineralization occurs in highly sheared zone within the porphyry spillites near their contact with the underlying Lower Takla greenstones. The contact is a 2 foot thick zone of red and green mylonite with an altitude of 095/25N. Mineralization is found mainly as malachite along numerous fractures faces in a zone between two shears 5 feet apart (145/72E, 105/75E). A polished section of this rock showed the presence of bornite as small specks in crystallized hematite masses or as blebs with small hematite crystals. The bornite shows a bluish replacement rim on all fractures - this is pobably secondary chalcocite. Small specks of covellite are visible in some fractures. Some bornite was found in a breccia with a quartz matrix. Mineralization is apparently very light, and the showing is of little importance economically.

In the porphyry volcanics north of this showing several small quartz-calcite veinlets have been found as outcrops or talus slopes. These veinlets are mostly barren; but several contain native copper and cuprite. In one some chalcocite was found with the native copper. This, together with the presence of quartz, would indicate the copper is a secondary surface enrichment of a bornite-chalcocite vein. The veinlets are no more than 2 inches wide and quite discontinuous, often due to minor faulting.

H-G #2 Showing

This showing is situated about 500 feet north-east of the D.B. showing (elevation 5200 feet). Mineralization is in a complex set of quartz-calcite veinlets, ½ - 3 inches wide in porphyry spillites. Many are barren but some (140/55?) contain up to 20% of bornite-chalcocite-digenite. Minor malachite and considerable hematite are present. The surface of the veins has been nearly completely leached of calcite and sulphides to a depth of 6 inches, leaving only a crumbly quartz box-work. The sulphide textures are similar to those seen in specimens

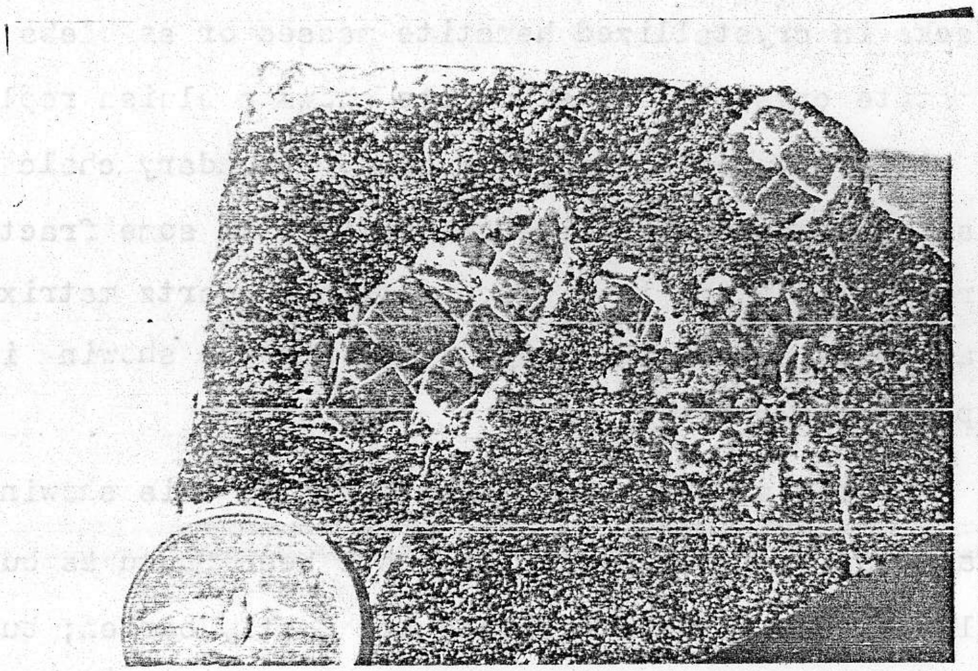


Plate 26

Inclusions of Porphyry spillite in copper-sulphide vein

B.C. Showing

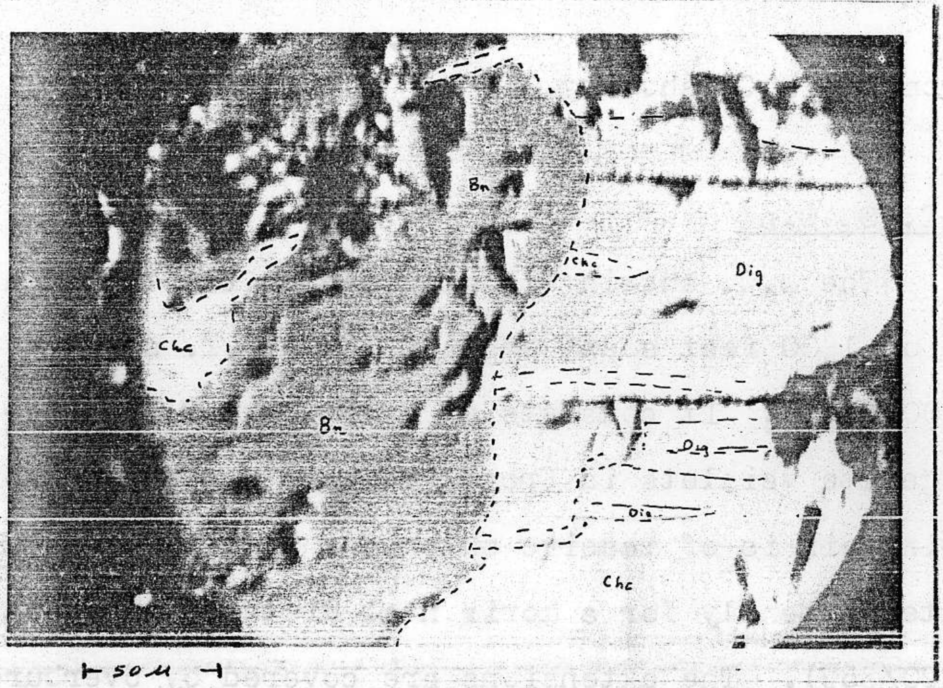
All inclusions have a narrow rim of quartz, much of which is stained by secondary hematite and malachite. The inclusions are fractured, and cut by quartz stringers. Some contain minor copper sulphides. The reason for this is not apparent.

from the B.C. showing.

B.C. Showing

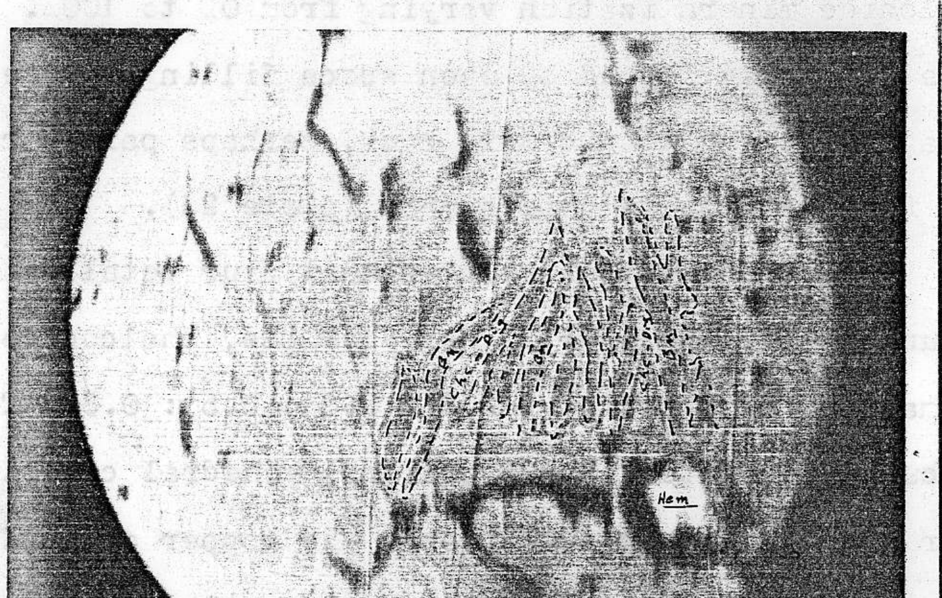
The B.C. showing is situated at the top of a steep hill about 1600 feet south east of the R.W.T. showing (elevation 4800 feet). It consists of a network of bornite-chalcocite-digenite veinlets in fractured purple porphyry spillites. The main vein is of massive sulphides 3 to 8 inches wide exposed intermittently for a horizontal distance of about 100 feet, (020/35W). The extensions are covered by overburden. The footwall is barren, but a series of randomly oriented veinlets extends at least 8 feet into the hanging wall rock. The gangue in all veinlets is quartz (90%) or calcite (10%) with the sulphide mineralization varying from 0% to 100%. The veins are definatly formed by open space filling. Some places fragments of volcanic wall rock, perhaps partly replaced, can be found in the sulphides mass (plate 26).

Polished section studies that four metallic minerals are found in the sulphide veins: bornite, chalcocite, digenite, hematite, in a ratio of 2.5 : 3.5 : 3.5 : 0.5. The hematite occurs as minute (100x25 microns) euhedral crystals scattered through the copper sulphides. The copper sulphides exist t together in highly irregular intergrowth. The chalcocite and digenite show lamellar exsolution textures (lamellae up to ¼x½ mm.), but appear to have acted as one mineral in their relationship to the bornite. The chalcocite-digenite intergrowth is definitly later than the bornite. Good crosscutting textures are fairly common (plate 27). In a few specimens



B.C. Showing Specimen 3 Plate 27

Chalcocite (Chc) and Digenite (dig) have bornite (Bn) acting as one mineral.



C.V. Showing Specimen 4 Plate 28

A pseudo-eutectic replacement texture between chalcocite-digenite and bornite.

pseudo-eutectic intergrowths were found (plate 28). These are identical to eutectic features but, as the chalcocite-digenite is definitly later than the bornite, it must be assumed that they are replacement features. It was found that on heating, during preparation of bakelite mounts, a bluish reaction rim, about 20 microns wide, was formed between the chalcocite-digenite and bornite (plate 31). Apparently these rims formed by the addition of bornite molecules to the chalcocite-digenite, very rapid cooling prevents their segregation by exsolution. Such sub-microscopic intergrowths have a typically blue tinge. No such rims were found in unheated specimens.

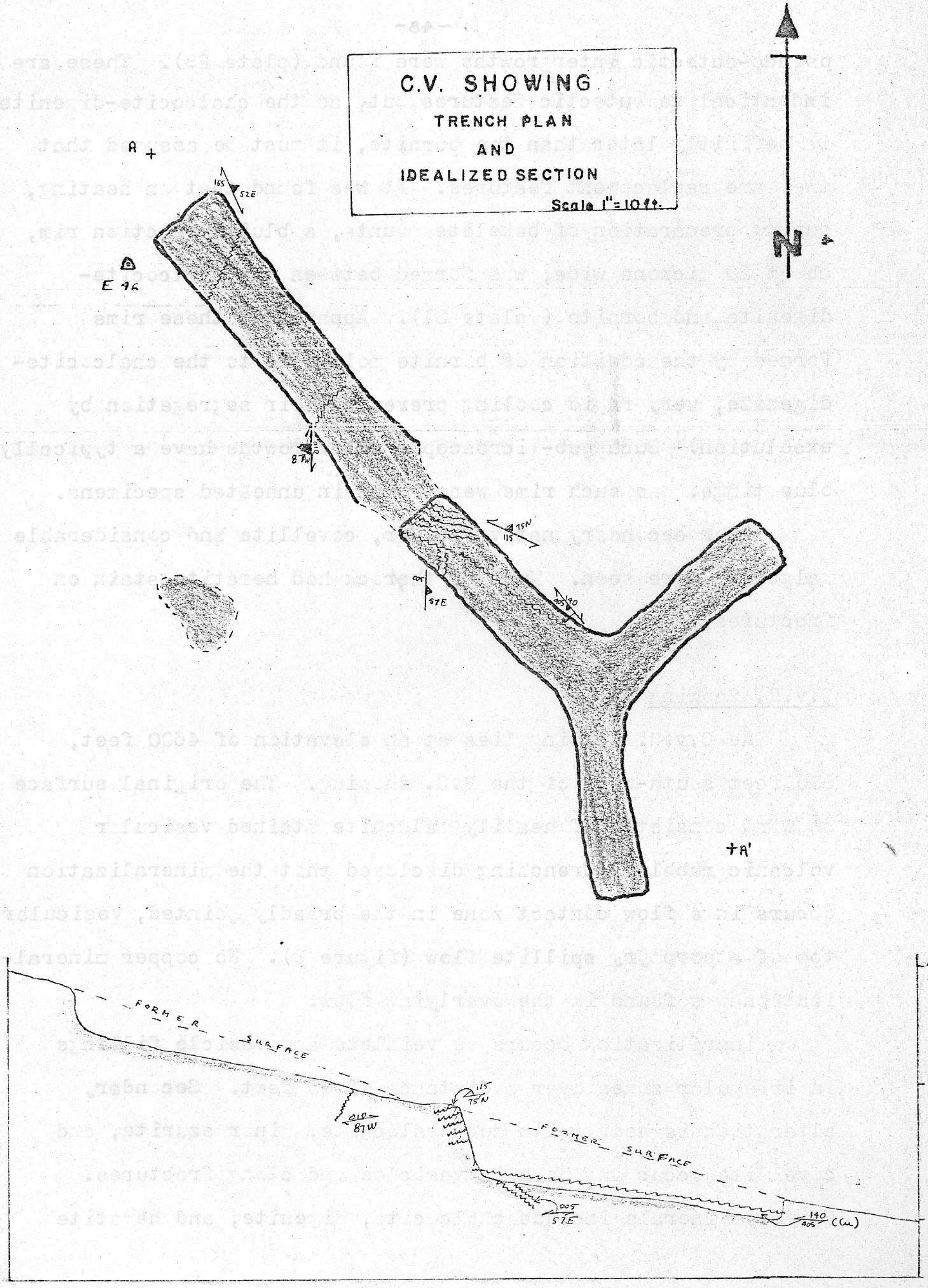
Minor secondary native copper, covellite and considerable malachite were seen. Much of the rock had hematite stain on fractures.

C.v.H. Showing

The C.v.H. showing lies at an elevation of 4600 feet, 800 feet south-west of the B.C. showing. The original surface showing consisted of heavily malachite stained vesicular volcanic rubble. Trenching disclosed that the mineralization occurs in a flow contact zone in the broadly jointed, vesicular, top of a porphyry spillite flow (figure 8). No copper mineralization was found in the overlying flow.

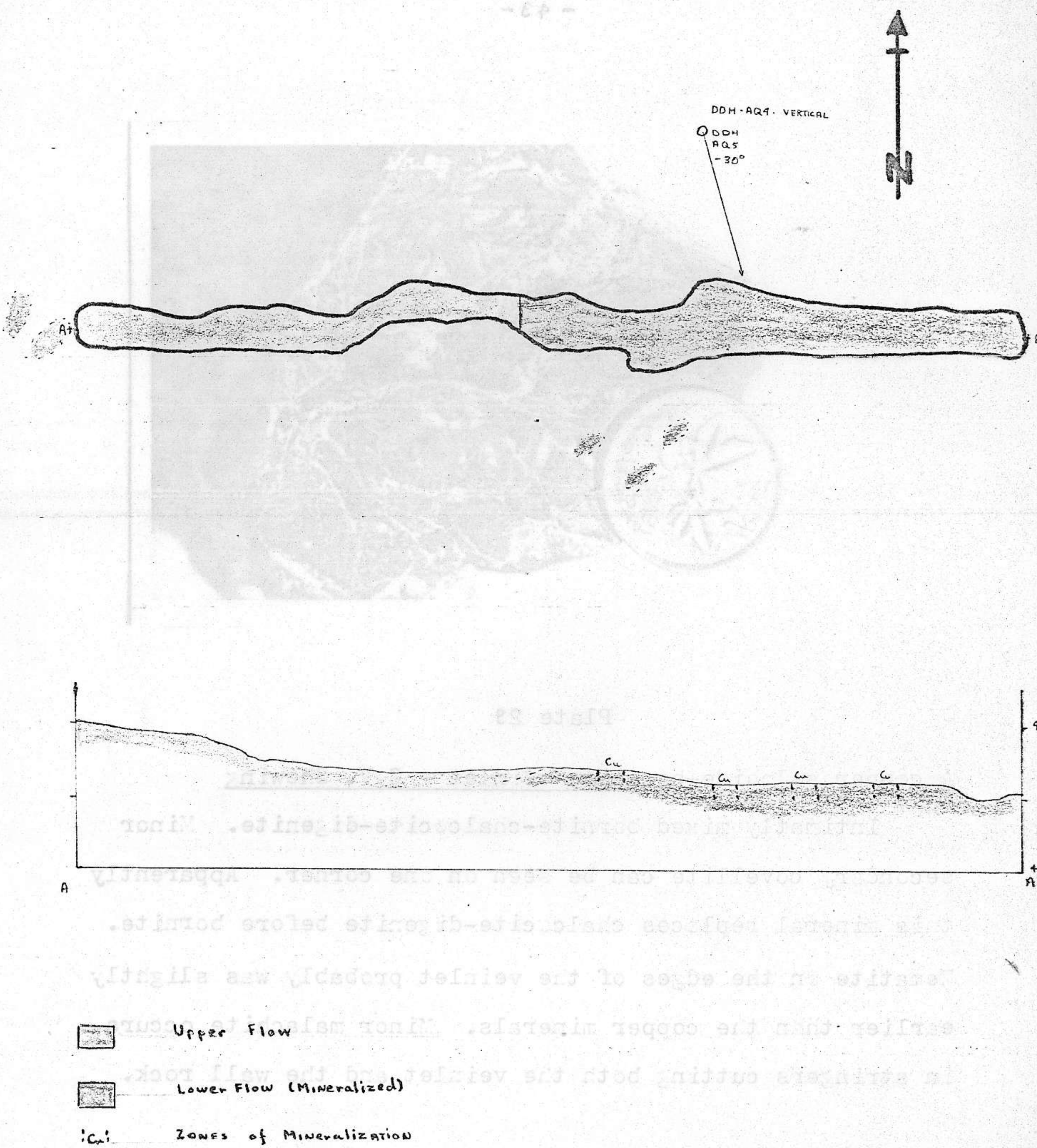
Mineralization occurs as veinlets and vesicle fillings in irregular zones over a distance of 30 feet. Secondary alteration is heavy with much malachite, minor azurite, and covellite occurring both in vesicles and along fractures. Primary minerals include chalcocite, digenite, and hematite

Figure 7



C.V. SHOWING
TRENCH PLAN
AND
IDEALIZED SECTION
Scale 1" = 10 ft.
N
A +
+A'
E 46
155
52E
010
87W
115
75N
005
57E
140
40S
FORMER SURFACE
FORMER SURFACE
4580
4570
4560
(Cu)

Figure 8



C.v.H. SHOWING
TRENCH PLAN
AND
IDEALIZED SECTION
Scale 1" = 10 ft.

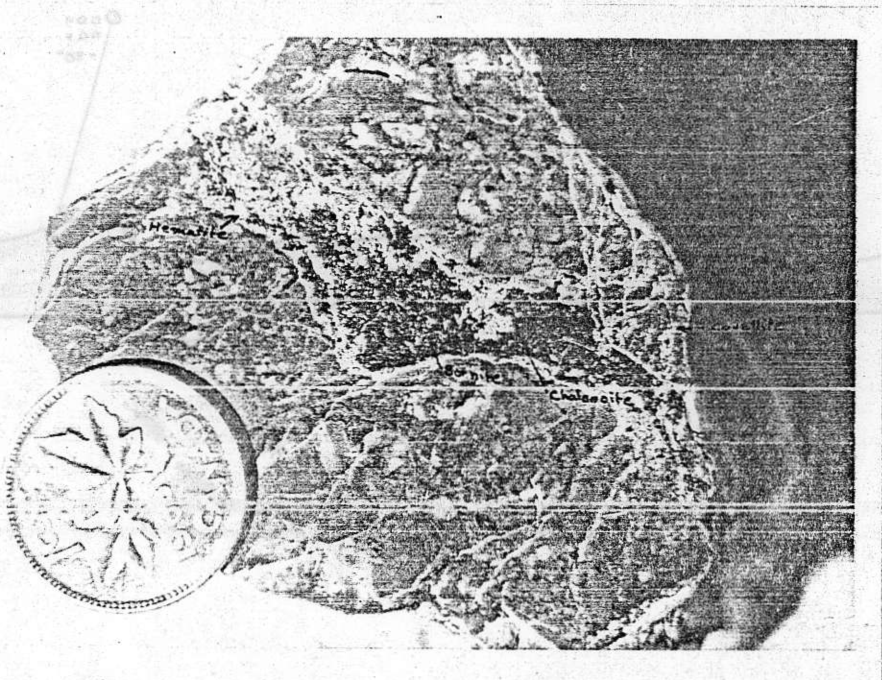
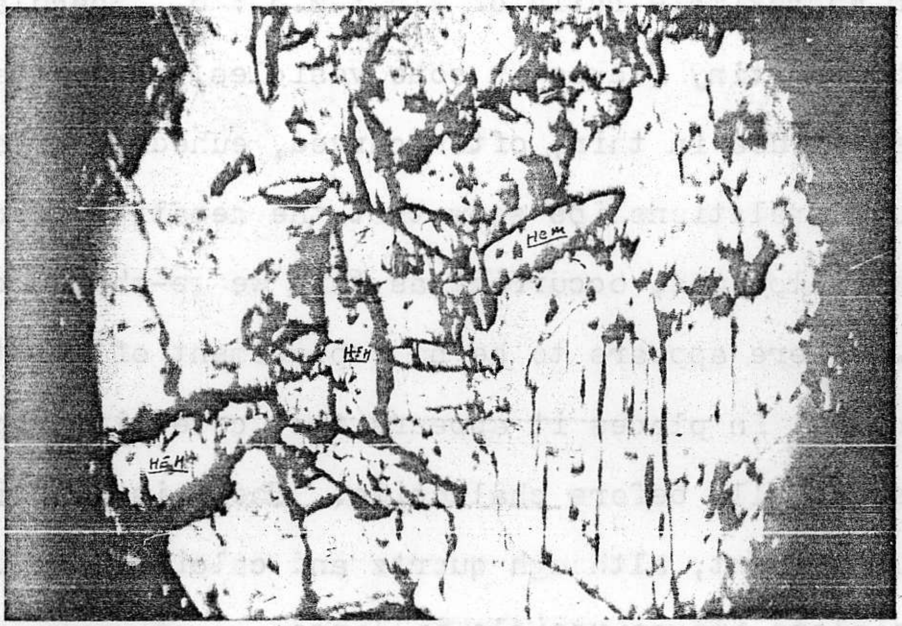


Plate 29

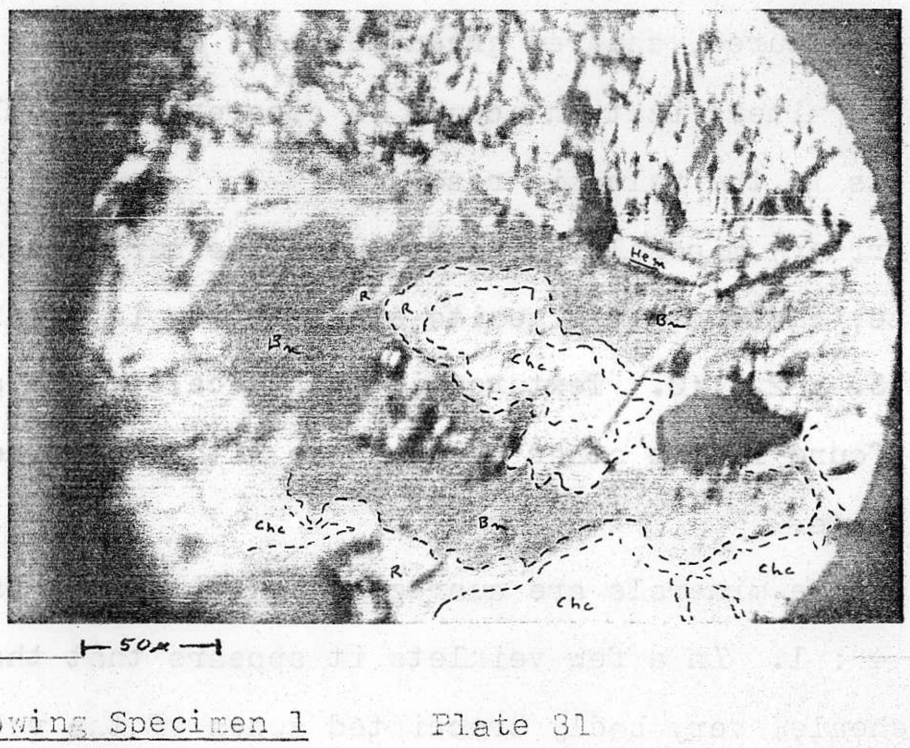
A copper sulphide-hematite veinlet - C.V. Showing

Intimatly mixed bornite-chalcocite-digenite. Minor secondary covellite can be seen on one corner. Apparently this mineral replaces chalcocite-digenite before bornite. Hematite on the edges of the veinlet probably was slightly earlier than the copper minerals. Minor malachite occurs in stringers cutting both the veinlet and the wall rock.



C.V. Showing Specimen   Plate 30

Euhedral hematite crystals in copper sulphides. The hematite appears to be essentially uncorroded.



B.C. Showing Specimen 1   Plate 31

Reaction rim (R) between chalcocite-digenite (Chc) and bornite (Bn). This apparently caused by heating during preparation of bakelite mounts.

in an approximate ratio of 2.5 : 2.5 : 5. Specular hematite is visible as tiny flakes in some vesicles, or scattered through the sulphides in thin, often curved, euhedral crystals. Textural relationships show that the hematite preceded the copper sulphides, occurring as thin wedge-shaped crystals in them. There appears to be no replacement of hematite by copper minerals. In places it appears that covellite replaces digenite preferentially before chalcocite. There is practically no gangue present, although quartz and calcite have been found, in veinlets and as vesicle fillings.

C.V. Showing

The C.V. showing is located some 150 feet south of the C.v.H. showing at an elevation of 4575 feet. The host rock is badly fractured, sheared green porphyry spillite. Primary sulphide mineralization occurs in apparenty randomly oriented veinlets in the volcanic rock.

Primary mineralization includes the normal assemblage of bornite, chalcocite, digenite and hematite in a ration of about 2 : 2.5. : 2.5 :3. Textures in this locality are similar to those found in the other occurrences with this mineral assemblage.

Gangue minerals are quartz and calcite in a ratio of about 4 : 1. In a few veinlets it appears that the gangue has rehealed very badly brecciated zones of the volcanic rock. The ratio of gangue: metallic minerals is about 2 : 1 on average, but some veinlets are barren while others consist of nearly 100% metallic minerals.

Secondary minerals include malachite, minor azurite, and covellite. All are found along or near fractures in the volcanic rocks, or directly on the parent mineral. Trenching exposed several strong shears along whichmalachite had concentrated. In particular, a nearly flat lying shear in the lower trench was very rich in copper carbonate (figure 7). Earthy hematite and limonite are common along these shears and many fractures.

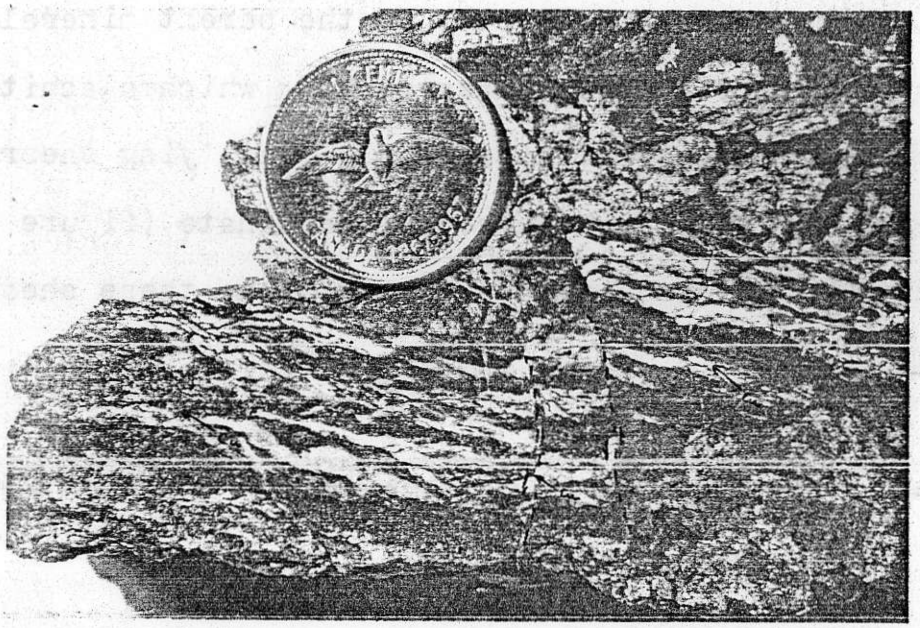


Plate 32

Talus in Landslide Scar.

Native copper with earthy hematite and calcite in porphyry spillites. The presence of fine grained calcite indicates that the native coper may have formed by dissociation of malachite. The hematite is intimatly mixed with the native copper and is probably all copper-rich. The displacement of the veins indicated minor tectonism after disposition of the copper mixture. Minor malachite has formed as an alteration product of copper.

Diamond Drill Cores - Lithology and Mineralogy

Nine diamond drill holes, a total of 2121 feet, were drilled on the Northstar Copper Prospect in 1967. Examination of the drill core did not fully explain the structural problems, but some correlation between the drill core and surface outcrop was possible.

Lithology

Holes 1 and 2 were drilled to clarify the stratigraphy and structure of the landslide scar area. They showed that the fault contact between the porphyry spillites and the underlying volcanic sediments maintained its dip and strike of 000/45°E. Beyond this it was not possible to extrapolate any contacts. The volcanic sediments of Unit I either resemble the sediments of Unit II so much in fresh core that they could not be distinguished, or the upper unit was not intersected.

Hole 3 passes through porphyry spillites, and breccias of similar rock, for 208 feet. At this point there is a pronounced gouge zone, and the hole cuts Unit I pyroclastic rocks to the end. A few flow contacts can be distinguished, but the hole is so far removed from any other holes that no correlation can be made.

Hole 4 passed through two, possibly three spillite flows. The rocks are all badly brecciated, and the hole was faced to stop at 88 feet because of caving of the sides. The top flow was slightly mineralized by chalcocite and bornite.

Hole 5 was inclined 30° to the previous hole. It passed underneath both the C.V. and the C.v.H. showings. The first two spillite flows in holes 4 and 5 can be correlated; they appear to be quite flat lying. Beyond this correlation in the volcanics is not ossible, except that a zone of fairly heavy mineralization between 100 and 140 feet is possibly an extension of the C.V. showing (figure 11).

At 340 feet the hole enters limestone. Correlation with surface exposure 5 (sect A-A' map I - Figure 11) indicates a contact dipping between 25° and 60° towards N15°E. An exact measurment cannot be made, as the surface exposures are too limited.

At 446 feet the hole encounters a 2 foot wide section of gouge, and then passes into fragmental rocks of Unit I. The contact between Unit I and Unit II rocks can be fairly accuratly estimated on the surface. It deposit about 30° toward N15°E.

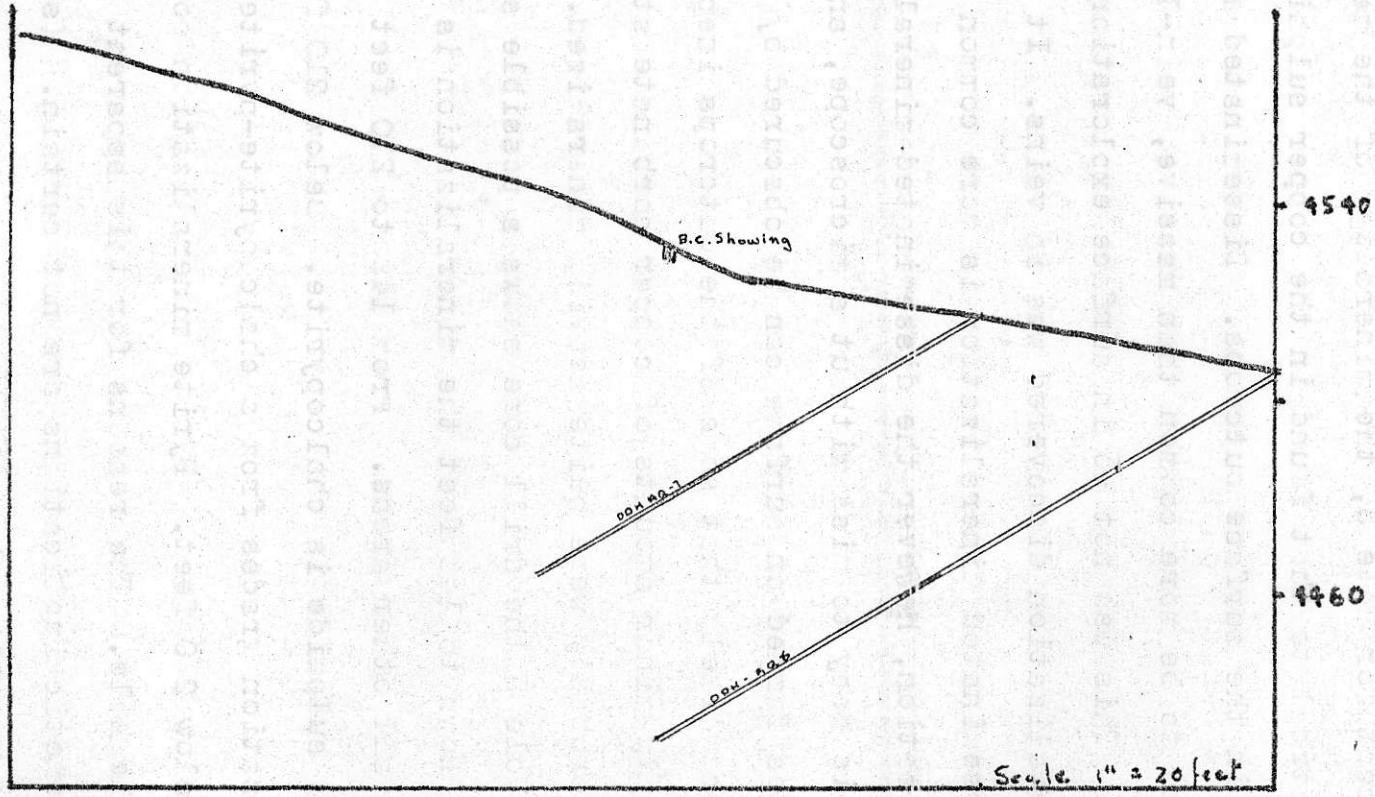
Holes 6 to 8 were drilled in a fan below the B.C. showing to establish the continuity of the high grade vein. All holes contained mineralized sections (see figures 9, 10) but in no case was it possible to correlate any section in the core with the rocks of the B.C. showing. Mineralization in the holes occured both in quartz-calcite stringers and disseminated in the porphyry spillites. It was not found possible to correlate flows from one hole to the next.

Mineralogy

Except for Hole 5, the mineralogy of the metallic minerals was identical to that found in the copper sulphide veins exposed in the surface outcrops. Disseminated mineralization was found to be more common than massive, vein-like, mineralization. This was not so in surface exploration, where nearly all mineralization discovered was in veins. It must be assumed that disseminated mineralization is more common than vein mineralization, however the disseminated mineral is so fine that it is easy to miss without a microscope, and any secondary carbonates formed on surface can be obscured by hematite. Thus it appears likely that some of the outcrops inspectes, which sh showed only minor amounts of copper carbonate stain, or none at all, probably were quite heavily mineralized.

In Hole 5 the drill core shows a possible sulphide mineral zoning. Down to 148 feet the mineralization is similar to that found in all other areas. From 148 to 210 feet the major, if not only, sulphide is chalcopyrite. Below 210 feet the mineralization grades from a chalcopyrite-pyrite mixture into pyrite below 2 0 feet. Pyrite mineralization continues to the end of the hole. The reasons for this apparent zoning as well as the genetic implications are not certain. (see section on Origin of Metallic Minerals.) Perhaps it is not zoning at all, chalcopyrite and pyrite may be unevenly disseminated through all the porphyry volcanics, and local concentrations have given an apparent zoning.

Figure 9

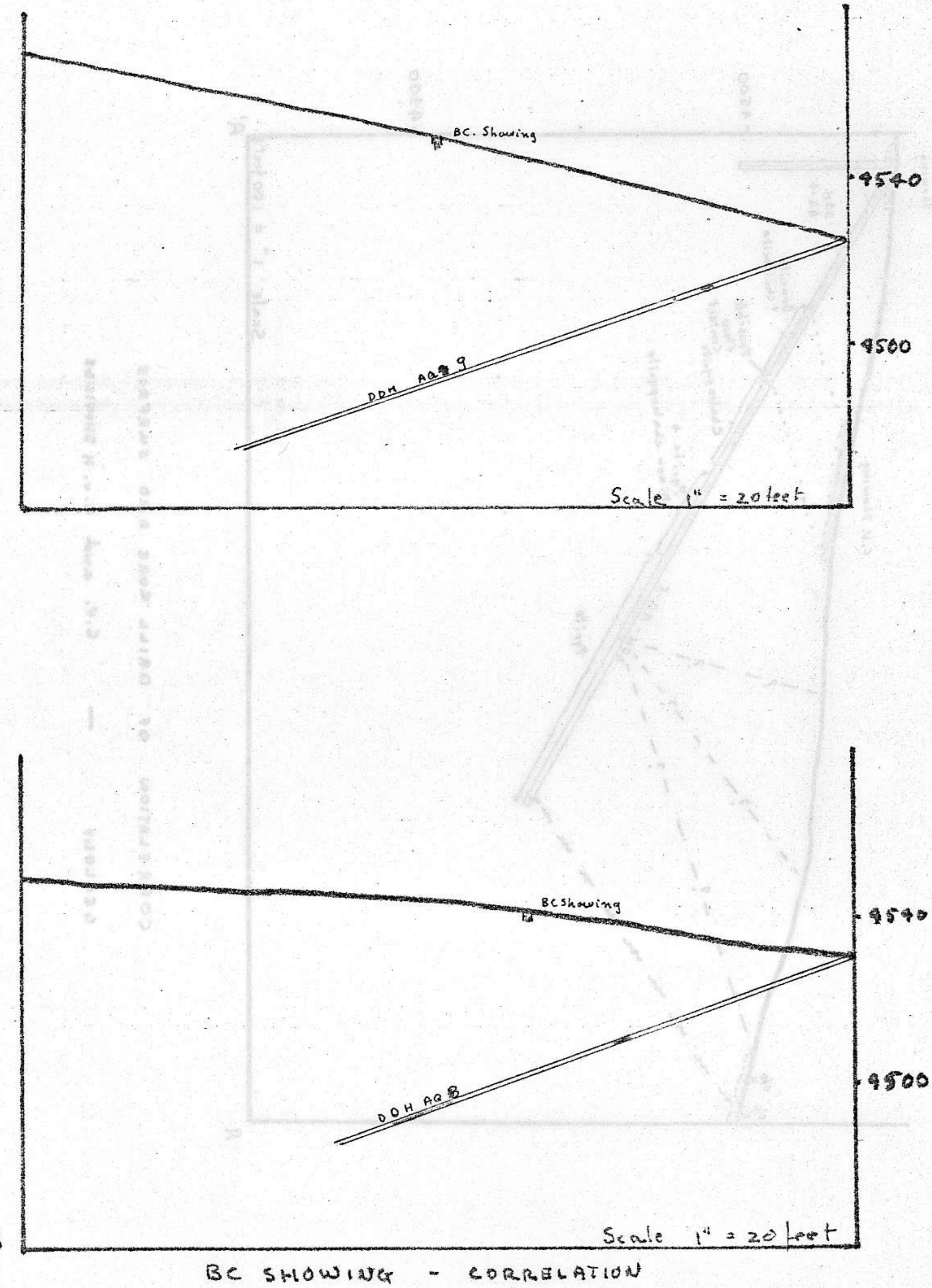


BC SHOWING

CORRELATION OF DRILL CORE AND SURFACE MINERALIZATION

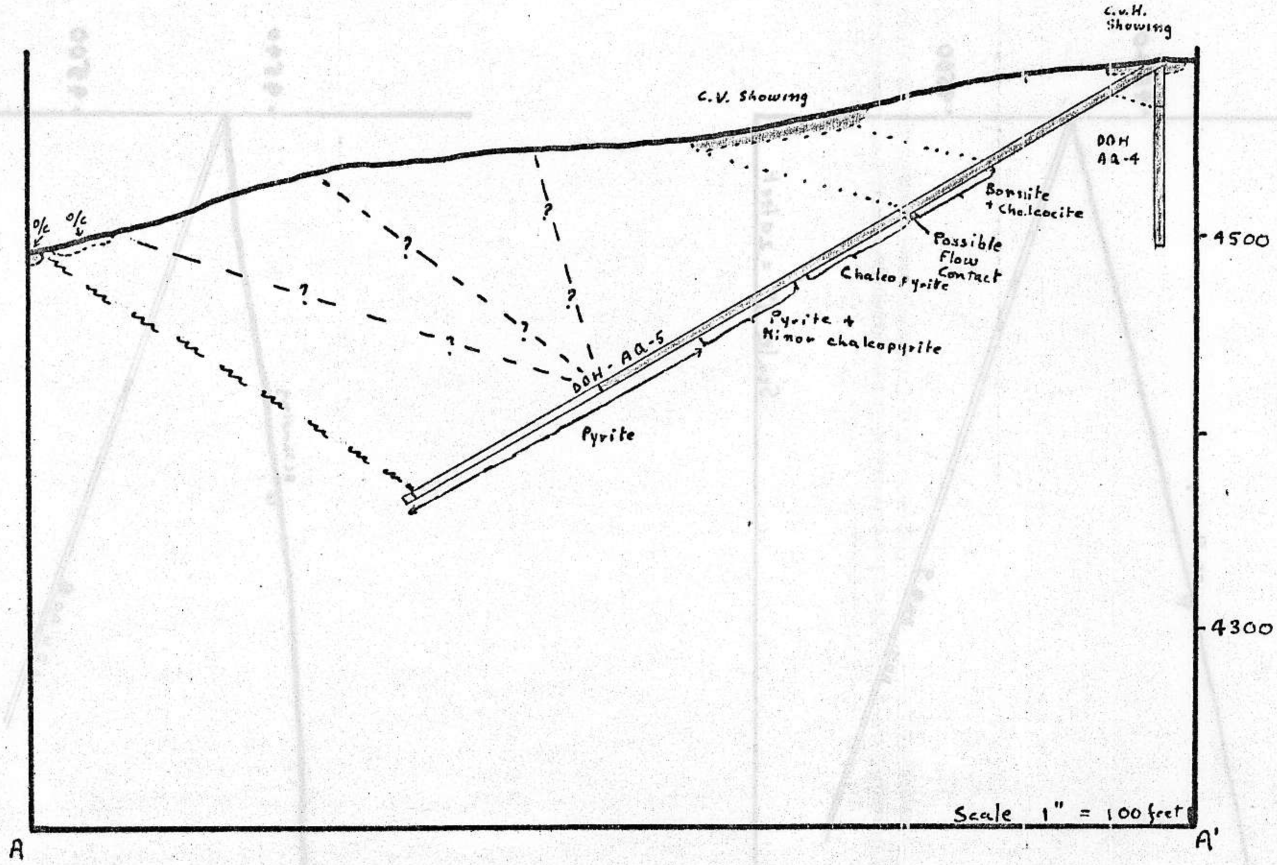
= MINERALIZED SECTION

Figure 10



BC SHOWING - CORRELATION OF DRILL CORE AND SURFACE MINERALIZATION

MINERALIZED SECTION

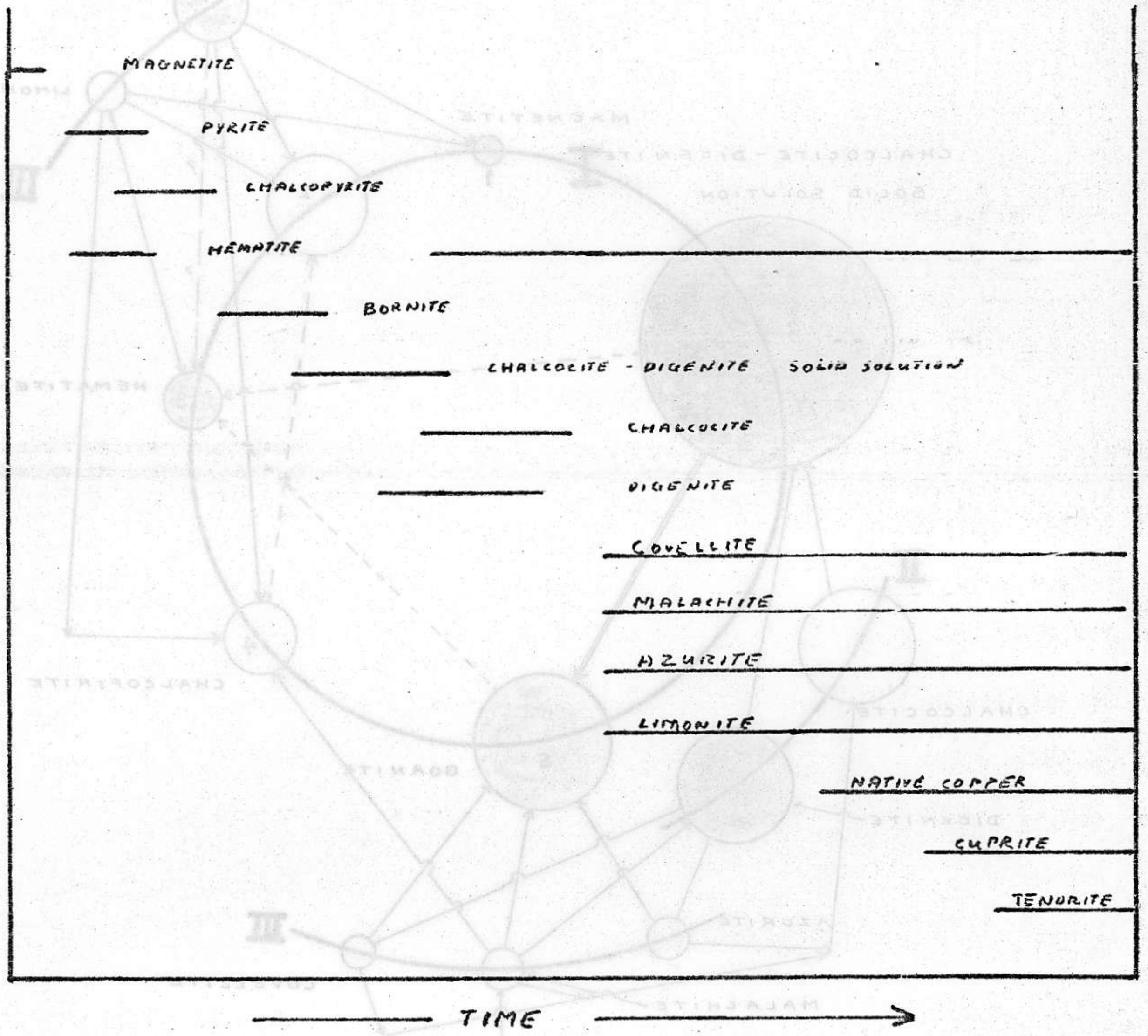


CORRELATION OF DRILL CORE AND SURFACE

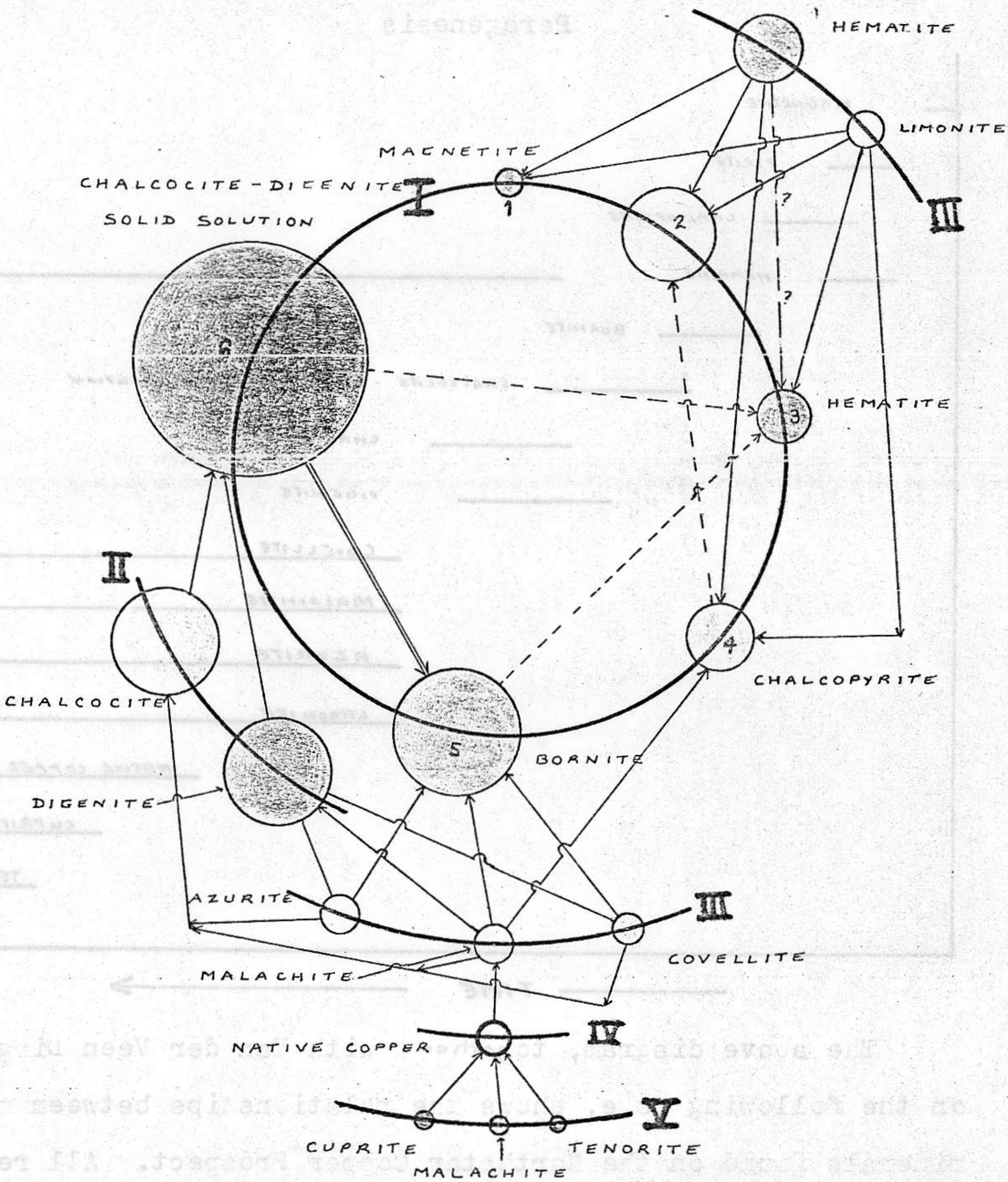
GEOLOGY — C.V. and C.V. H SHOWINGS

Figure 11

Paragenesis



The above diagram, together with Van der Veen Diagram on the following page, shows the relationships between metallic minerals found on the Northstar Copper Prospect. All relationships shown have been observed except the core of the Magnitite, Primary Hematite, Chalcopyrite and Pyrite. Here relationships were not observed, (except in the case of the last two minerals where the relationship was unclear). In these cases the normal order of deposition was used as the proper one.



Van der Veen Paragenesis Diagram
for Metallic Minerals - Northstar Copper Prospect

Circle I - Primary Minerals.
Circle II - Exsolution products of Circle I Minerals.
Circle III - Alteration products of Primary Minerals.
Circle IV - Alteration products of Circle III. Minerals.
Circle V - Alteration products of Circle IV Minerals.

Environment of Deposition of Metallic Minerals

The metallic minerals found in the porphyry spillite of the Northstar Copper Prospect were deposited in a hydrothermal environment. They are associated with the typical alteration products (chlorite) and gangue minerals (quartz and calcite) found in such associations. The disseminated mineralization found in the volcanic sediments was originally postulated to be syngenetic. Although this origin is possible, it appears unlikely. It cannot be proven or disproven, as regional metasomatism has subjected the rocks to temperatures which would destroy any definitly sygenetic textures (see description of R.M.T. showing.)

The temperature at which deposition took place is not certain as none of the mineral associations can be used to give more than limiting temperatures. The highest temperatures were reached during regional metamorphism in which albitization and chloritization took place. The presence of chlorite, though far from definitive indicates that maximum temperatures were probably between 300°C and 550°C and P_{H_2O} less than 8000 atm. These are the highest limits and actual conditions were probably less extreme. Prehnite in some of the rocks indicates temperatures between 200°C and 300°C. The only sulphides useful for temperature determination are chalcocite and digenite, which indicate temperatures of more than 105°C. This is obviously too low as the presence of hydrothermal chlorite indicates much higher temperatures. It is most probable that hydrothermal deposition started around 450°C at which time hematite and chlorite were deposited. Cooling of the solutions made the copper minerals stable. These were probably deposited near the lower limits of mesothermal conditions, possibly near the higher limits of epithermal conditions.

The gangue minerals apparently came in quite continuously starting after the deposition of hematite, and continuing until after the copper sulphides had all been deposited.

Source of Metallic Minerals

Although the environment in which the metallic minerals were ultimately deposited can be estimated fairly accuratly; no definite sourc for them has been discovered. There are several possibilities:

I) All the heavily mineralized rocks lie in what is probably a thrust fault plate, originating east of the area. It is possible that the rocks were originally mineralized by hydrothermal solutions from some igneous source. Later tectonism thrust the already mineralized rocks over the greenstone basement, and left them in their present position. This would explain the zoning from low to high temperature mineral found in one drill hole. Also it would explain the apparent lack of high grade copper mineralization in the basement rocks.

II) Small, high grade, copper deposits have been reported in many of the Mesozoic basic volcanic rocks of the Canadian Cordillera. Attempts have been made to mine some, as at Quadra Island, but generally these have been unsuccessful. Studies of the mineralization has indicated that copper may have originated as a primary mineral in the volcanics (Ref: C.S. Ney CIMM Special Volume #8, 1966). It is possible that the copper minerals in the porphyry spillite are of this origin, however it is difficult to explain why the mineralization is zoned, why it is concentrated in veins in some places and disseminated in others, and how it found its way into the volcanic sediments. It is conceivable that the rocks were metamorphosed enough to produce hydrothermal solutions, but this would imply higher grades of metamorphism.

III) It is also possible that the younger rocks form a spillite association, that they were extruded subaqeously and subjected to deuteric alteration. The albite and chlorite would all be formed at the same time as the sulphides were deposited. The hydrothermal solutions would be formed by sudden heating of sea water, and would move through the rocks during the time they were cooling, thus deposition would take place at a fairly high temperature. This origin does not account for the presence of copper minerals in the volcanic sediments, nor is there any definite indication that the volcanics were deposited subaqueously.

IV) Another possibility is that the volcanics were laid down on top of the water bearing sediments containing syngenetically precipitated copper minerals. The sediments were heated, and connate water formed copper-bearing hydrothermal solutions. This origin dows not give any reason for the possible zoning of minerals, nor is there any proof that the volcanic rocks were extruded on to sediments. The only sediments close at hand are the volcanics sediments, and these probably overlye the porphyry spillites.

V) It is possible that the both rock units have been altered by hydrothermal solutions from a buried igneous source. This could account for the apparent zoning of minerals and the fact that pyrite mineralization extends into the basement rocks. The porphyry dykes could originate from such a source.

At present exact knowledge of the minerology is not complete enough to say which, if any, of these theories is correct.

Geological History

1) Extrusion of basic lavas, and interbedded pyroclastic sediments of similar composition.

2) Diagenesis of sedimentary rocks. (Unit I)

3) Intrusion of Biotite-Quartz-Plagioclase Dykes possibly accompanied by some deformation.

4) Extrusion of porphyry spillites - originally probably as basalts.

5) Sinking of land or raising of sea level.

6) Deposition of limestones accompanied by some volcanic activity. Rate of deposition varies from quite rapid to extremely slow (where glauconite appears.)

7) Deposition of volcanic sediments probably in fairly shallow basin. Sea level is rising and size of sediments decreases upwards.

8) Intrusion of some igneous body. Metallic minerals are deposited from Hydrothermal solutions.

9) Regional tectonic activity disrupts the strata; thrust faulting moves Unit II rocks over Unit I. This is accompanied by deformation of Unit I rocks.

10) Further regional tectonism, accompanied by low grade metasomatism, alters the rocks to their present composition.

11) Pleistocene glaciation covers the area.

12) Recent erosion changes geomorphology to present state.