82FNE052 Sullivan 07

PROPERTY FILE

Box 1566
Yellowknife
N.W.T
March 1971

Dear Jim,

I can't locate your letter at the moment, anyway thanks very much. I'm sending you my copy of my thesis which isn't the best copy but my only one. There should be micro film copies available somewhere. At least I was requested to allow it to be microfilmed for some central library, I don't recall offhand where.

Thank you for your information re jobs with B.C. govt. I'd like to know more about them if you don't mind forwarding info.

Young Bob Warshing is up here in Yk. He was reminiscing about days at Salmo when he had known you.

Best regards. Ted Jardine

82FNE052
Sullivan Mine

PROPERTY FILE

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AN INVESTIGATION OF BRECCIATION ASSOCIATED WITH THE SULLIVAN MINE OREBODY AT KIMBERLEY B.C.

A Thesis
Presented In Partial Fulfillment
of the Requirements for the Degree
Master of Science
to
The Department of Geology
University of Manitoba
Winnipeg Manitoba Canada

by

Donald Edwin Jardine

1965

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CHAPTER I

INTRODUCTION

Brecciation has recently been recognized to be extensive in certain areas below, within, and above the Sullivan ore body, affecting large volumes of rock. Studies of the brecciation show that it is intimately related with the metasomatic processes that have altered the rocks adjacent to the ore body. Certain igneous rocks have been found to be intrusive into the breccia, and brecciated by later movement.

This thesis consists of a report on investigations of this occurrence which have been carried on at the Sullivan Mine, and at the University of Manitoba. Research has been concerned with

1. Determining the location and extent of the breccia.
2. Establishing the relationships of brecciated areas with the stratigraphy and structure of the surrounding rocks.
3. Deducing a chronology of events related to the brecciation process.
4. Forming an hypothesis of the cause of brecciation.

Thanks are due to the Consolidated Mining and Smelting Company for making information available for this study, to the Geological Survey of Canada, for a grant to aid in financing the University research program, and to the professors of the Geology Department at the University of Manitoba for their help and encouragement. To these persons and to many of my colleagues who have discussed the project and made valuable suggestions, I gratefully offer my thanks.

GENERAL DISCUSSION

Breccias are relatively unusual rock formations in the total volume of the earth's crust. They are indicative of important processes in the tectonic history of the rocks in which they occur. Many and various origins have been deduced for occurrences which have been studied, with a resulting significant contribution to understanding the mobility of the earth's crust. Breccias are also rather commonly associated with ore bodies and have often been found to have played a part in localizing the deposits.

From the viewpoint of an economic geologist, the information to be derived regarding the regional "tectonic framework" and the local "ground preparation" may be of great practical importance. Where brecciation occurs in connection with an ore deposit, as at the Sullivan, it may contribute to understanding the provenance, mode of transportation, and method of fixation of the metals in the body. An attempt is made in the accompanying chart to relate the present study to the other investigations so as to show some of the ramifications involved. (See Chart # 1)

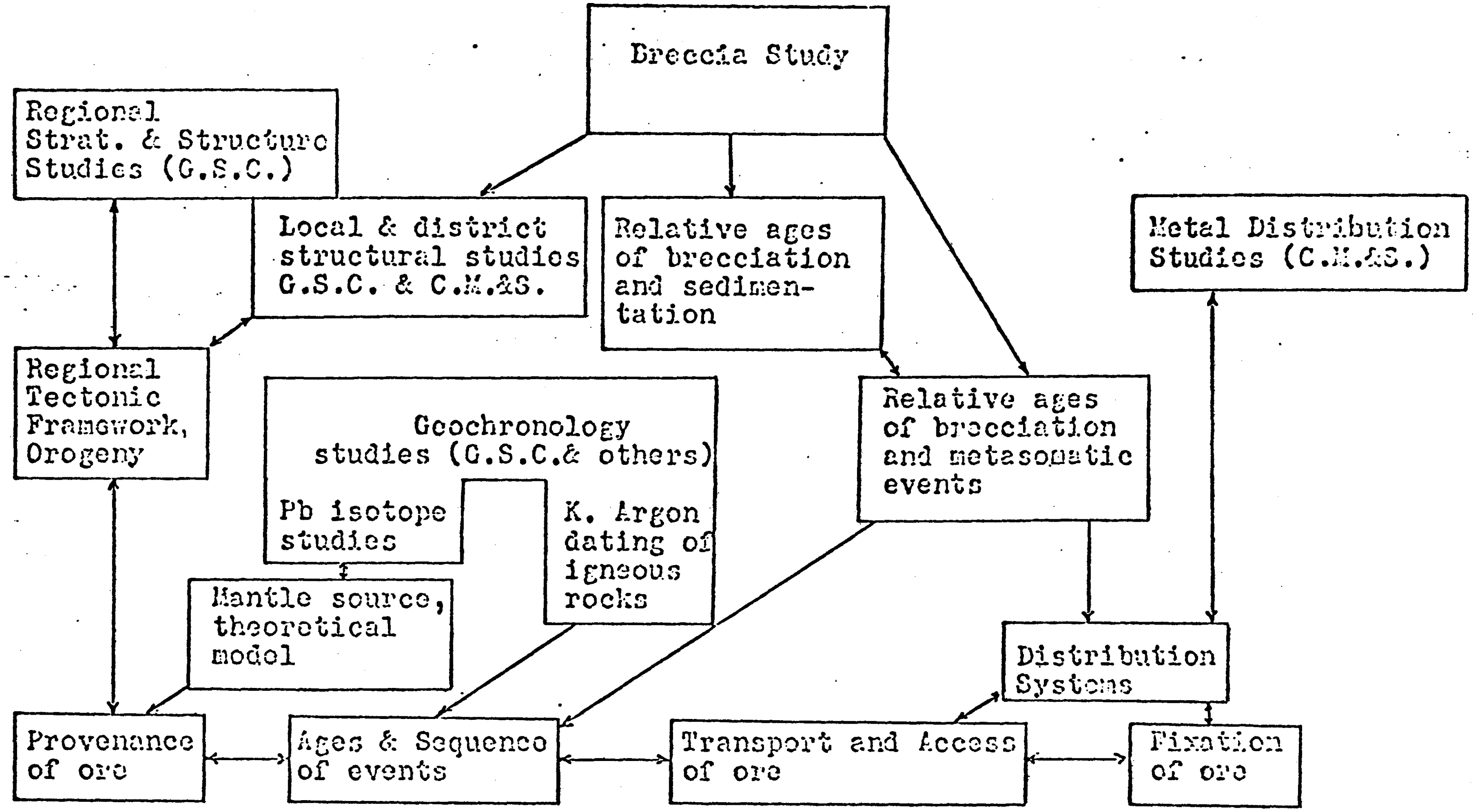


CHART 1 To indicate how the breccia study contributes to understanding the economic geology of the Sullivan orebody.

The relationships indicated are not explored fully in this thesis, but are called upon at such times as they help to understand the brecciation process.

PLAN OF PRESENTATION

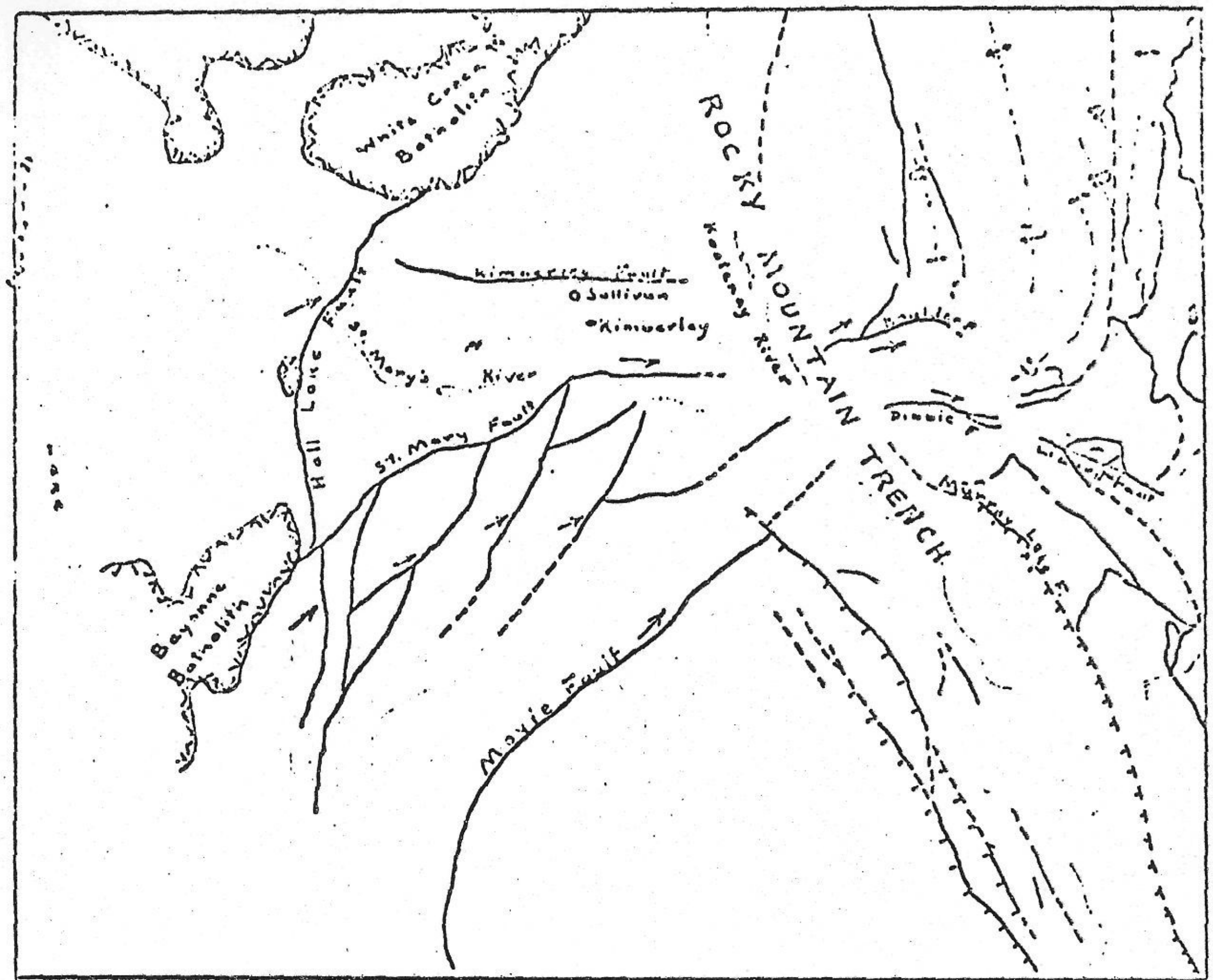
Discussion of the topic will proceed in the following manner

1. The regional setting
   (a) location, topography
   (b) stratigraphic position and the inferred sedimentary environment
   (c) structure
2. The local geologic setting
   (a) stratigraphic sequence of the mine series and it's position in the Purcell formation
   (b) structural features in the area of the orebody
   (c) metasomatic alteration
3. Description of the footwall conglomerate fabric and distribution. It is fundamental to the discussion to show that conglomerate and breccia are distinct entities, formed by different processes.
4. Description of the footwall breccias
   (a) pre conglomerate (collapse breccia)
   (b) post conglomerate (chaotic breccia)
      (i) pre tourmalinization
      (ii) post tourmalinization

5. Description of ore zone and hanging wall breccias
6. Discussion of the origin of brecciation

Location of Kimberley — Fig. 1

Note
1. Contrasting drainage patterns East & West of Rocky Mountain Trench
2. Curve in trend of Rocky Mts outlined by Kootenay, Lussier, Bull & Elk Rivers



Tectonic Setting (after Leech)

Fig. 2

CHAPTER II

LOCATION OF THE SULLIVAN MINE

The Sullivan Mine is located adjacent to the city of Kimberley in South Eastern British Columbia. Kimberley is about 50 miles north of the international boundary and 50 miles west of the Alberta boundary.

The Crows Nest, Kettle Valley line of the Canadian Pacific Railway passes 20 miles south of Kimberley through the city of Cranbrook. The southern transprovincial highway follows the same route, and a branch of the highway passes through Kimberley leading North through Banff National park to Calgary.

Kimberley is situated on the eastern flank of the Purcell range of mountains, overlooking the broad valley of the Rocky Mountain Trench, which is about twenty miles wide at this point. On the opposite, eastern side of the valley, the Rocky Mountains rise abruptly forming a precipitous wall contrasting with the more gradual slope of the Purcells. The Kootenay River flows southward through the Trench at an elevation between 2500 and 2600 feet. Kimberley is at an elevation of 3,700 feet, and the highest mountains in the vicinity attain altitudes of between nine and ten thousand feet above sea level.

The discovery area of the Sullivan Mine lies northwesterly from Kimberley on Sullivan Hill at an elevation of about 4600 feet, and is presently the sight of an open pit operation. The main entrance to the mine is an adit driven at 3900 elevation from the valley of the Mark Creek, some 7,000 feet south of the mine.

Regarding the topographic texture of the area around Kimberley (see Plate 1), it is obvious that the Rocky Mountain Trench separates two contrasting areas. The trellis drainage pattern of the Rockies reflects the folding, overthrusting and erosion of anisotropic rocks which vary from gypsum to limestone and quartzite.

The Purcell Mountain drainage on the other hand is very irregular due in part to the relative homogeneity of the Purcell system of rocks which form most of the range. Also, a notably greater proportion of igneous rocks buttress the sedimentary assemblage in this area than in the Rockies. The igneous intrusives include Pre Cambrian diorite sills and granite stocks, and Mesozoic granitic batholiths.

J.T. Wilson (1953) in his postulated system of island arc, mountain chain development, considers that the Rocky Mountain Trench marks the site of the boundary between the medianland (West of the Trench) and the secondary arc (East of the Trench). By this he implies a fundamental difference in the two areas during the time of sedimentary deposition. The secondary arcs (in this case the Rocky Mountains) are characterized by "normal" sediments and little recent igneous activity. They represent an uplifted and folded inland sea bottom, formed on the continental shelf and analogous to the present sea of Japan. The medianland is a complex of igneous and metamorphic rocks, which was involved from early times in the making of offshore island chains. Observations of workers in the region tend to confirm some of these generalizations and are presented following, as background to the thesis. Some emphasis is placed on evidence for Pre Cambrian tectonic activity because it is directly related to the breccia problem.

The Sullivan orebody occurs in the Aldridge formation of the Proterozoic Purcell system. J.E. Reesor (1956) describes this system of rocks as follows -- "The rocks comprise a series, not less than 30,000 feet thick of conformable, very fine grained thin bedded quartzites, argillaceous quartzites and argillites, with limy and dolomitic equivalents in the upper part of the section."

Elsewhere (Reesor J.E. 1957) he notes that in the Purcell Mountains, primary structures such as ripple marks, cross bedding and mud cracks are common to plentiful at some locality in every formation, with the exception of the Upper Aldridge. The coarsest rocks in the entire Purcell system (with the exception of local intraformational conglomerates in the Aldridge) were found in the upper part of the Creston formation. These comprise beds of medium to coarse quartzite and intraformational conglomerate located near the Rocky Mountain Trench on the East flank of the Purcell Mountains.

Correlation of strata is good from one hundred miles south of the forty ninth parallel to Findlay Creek, a total of 200 miles in a South-North direction. However, many uncertainties in correlation occur from East to West across the Trench due to changes in sedimentary characteristics. There is a higher proportion of quartzites in the Aldridge of the Purcell Mountains than in the Rockies.

Reesor concludes that deposition was rapid, in a basin of relatively great tectonic stability, possibly the flood plane of a large subsiding delta.

> Only rarely as shown by the Upper Aldridge sediments, has the rate of downwarp exceeded the rate of sedimentation so that shallow water features are not abundant. Yet even with this exception the series could only have been deposited in a region of relative tectonic stability over a long period. (Reesor J.E. 1956)

Price R.A. (1964) in a study of the Purcell system in the Rocky Mountains of Southern Alberta and British Columbia, found it possible to correlate formations equivalent to those in the Purcell Mountains, across the Rockies to exposures in Waterton Park. He states (pp 399)

> All current data concerning the character and regional relationships of the Purcell rocks are consistent with the hypothesis that the Purcell sediments were deposited on and adjacent to the western margin of the craton, under conditions analogous to those in the Gulf Coast geosyncline. This implies that the large volume of fine terrigenous clastic sediment that

constitutes the bulk of the Purcell succession was derived from the older Precambrian rocks which occur in the interior of the continent, far from the site of deposition; and that none of it need have originated in some supposed western landmass.

Perhaps the first departure from relative stability is indicated by unconformity at the base of the Sheppard formation, and it's equivalent (Price 1964 pp 419) the lower part of the Gateway formation. Price (ibid pp 416 Fig. 5 & pp 419) found that in the Galton Range the Sheppard lies unconformably upon the Purcell lavas. Schofield (1915 pp36) reports finding pebbles of lava in the basal conglomaratic beds of the Gateway where it overlies the Siyeh in the McGillivary Range south of Cranbrook. Areas of uplift and erosion of the Purcell lavas existed prior to and during the deposition of the Gateway. Price tentatively correlates the Sheppard with the lower part of the Dutch Creek formation, Upper Purcell system, therefore instability and uplift of areas of the Purcell sea bottom appear to have become important early in Upper Purcell time, probably not much later than the extrusion of the Purcell lavas.

Above this lowest evidence of unconformity there are numerous unconformable relationships shown where rocks of Windermere, Cambrian and Devonian ages lie upon Purcell rocks at a number of places in the area. Localized areas of erosion, and deposition are indicative of islands having been uplifted, perhaps the island arcs postulated by Wilson.

TABLE OF FORMATIONS

Era	Period	Rock Unit (Thickness in feet)	Lithology
Cenozoic	Recent and Pleistocene		Stream and glacier deposits; felsenmeer and talus
		Fry Creek Batholith	Leuco-quartz monzonite, pegmatite, aplite.
Mesozoic and/or Cenozoic	Jurassic or later		Relations not known
		White Creek Batholith	Pegmatite and aplite
			Medium-grained quartz monzonite
			Leuco-quartz monzonite
			Porphyritic (microcline) quartz monzonite
			Hornblende-biotite granodiorite (monzotonalite)
			Biotite granodiorite (monzotonalite)
		Intrusive contact	
Palaeozoic(?) or Mesozoic(?)		Ultramafic stock	Serpentine; serpentinized clinopyroxenite
		Relations not known	
Late Proterozoic (?) or later		Moyie intrusions	Meta-diorite and meta-quartz diorite sills; rare dykes
		Intrusive contact	

TABLE OF FORMATIONS--Concluded

Era	Period	Rock Unit (Thickness in ft.)	Lithology
	Upper Purcell	Dutch Creek formation (1,000+)	Buff and reddish weathering silty dolomite, dolomitic quartzite, and much argillite; some grey weathering, very fine-grained, grey quartzite
Proterozoic		Conformable, gradational contact	
	Lower Purcell	Siyeh formation (2,000)	Purple, green, and grey argillite; light and dark green laminated argillite; some very fine-grained, green weathering, green quartzite
		Kitchener formation (4,200)	Buff weathering, dolomitic and calcareous quartzites, siltstones, and argillites; green argillite and black and grey bedded argillite; minor creamy to buff dolomite and black limestone
		Creston formation (4,100-6,500)	Green and grey weathering, green-grey, and purple argillaceous quartzites, metasiltstones and argillites. Lower member (0-1,500 feet): dark weathering, black to dark grey argillites, arenaceous argillites, recrystallized equivalents of siltstones.
		Aldridge formation (Upper division 11,000+)	Upper Argillite member (1,000-1,500+): very rusty weathering, evenly laminated, black and grey argillites and arenaceous argillites. Remainder, of light grey weathering, light to dark grey quartzite with minor partings of black argillite and thin-bedded argillaceous quartzite, and rusty phyllitic equivalents.
		Aldridge formation (Lower division 4,500+)	Very rusty weathering, thin-bedded, laminated, light coloured, very fine-grained quartzites and argillaceous quartzites; minor argillite; equivalent phyllites, phyllitic quartzites and schists.

FOLDING

Leech (1963 pp246) says -

> Although Precambrian and Paleozoic unconformities had long been known in the Purcell Mountains, the concensus was that the major structures date from a Mesozoic orogeny which culminated in the intrusion of the granitic rocks (...). Precambrian deformation (now known on stratigraphic evidence to be chiefly pre Windermere and perhaps entirely so) had been considered to involve important uplift and probably tilting but to have produced only gentle open folds. (...)
>
> The recongnition of the Precambrian age of granitic intrusions at Hellroaring Creek, and of Precambrian metamorphism and intrusion nearer Kimberley, sheds new light on the importance of Precambrian (possibly pre Windermere) orogeny and, together with the Precambrian age of lamprophyres in the Sullivan Mine (p 252), points to specific Precambrian structures. Precambrian folds were not all large gentle ones.

However it remains true that most of the major structural features were produced by the Mesozoic mountain building period. The Purcell geanticline lying between the Rocky Mountain Trench and the Kootenay Lake is related to the Cretaceous batholiths which cut it.

Leech believes that -

> minor north trending folds with steep east limbs and westward-dipping axial planes (that) characterize the segment of the 'Purcell geanticline' in and north of the Kimberley area (...) are Precambrian and are older than the 'geanticline' on whose flank they occur.
> (Leech Ibid pp 246 and 247)

FAULTING

Regional fault patterns are shown Fig. II as interpreted by Leech. (1962 b. pp 399.) A notable feature is a tendency for the Northerly trending faults to swing eastward in the Cranbrook Kimberley area. The readers attention is directed to Fig. I where it can be seen that the trend of the Rocky Mountains (as outlined by the Kootenay, Lussier, Bull and Elk Rivers) swings westerly into the Trench in the same area. There is apparently a regional reversed S bend in the major structures.

Leech correlates the Moyie fault on the West of the Trench with the Dibble Creek fault in the Rocky Mountains, and gives evidence for believing that it is the site of an ancient structure which has had renewed activity at various times in the tectonic history of the area.

The Kimberley fault which cuts just North of the Sullivan Mine, brings Creston rocks into fault contact with the Aldridge mine strata. Striking East-West and dipping 45-55 degrees north this normal fault lies across regional trends excepting the eastward swing of other major breaks. Although it fits into the reverse S pattern of the area, no southerly trending portion has been established, and no continuation has been recognized in the Rocky Mountains.

At present there are only rather vague indications that the Kimberley fault may be an ancient structure, and they are as follows.

1. Mine geologists at the Sullivan interpret the evidence available on the intersection of North

Easterly trending Sullivan type faults with the Kimberley break, as indicating that the Sullivan type faults displace the Kimberley fault. See Fig. . No direct observation of these relationships is possible.

2. There is some evidence that the Sullivan structures existed prior to ore deposition because of the changes in mineralization in the orebody that at times accompanies them. (Consolidated Mining & Smelting Co. of Canada Ltd. Staff 1954 p 153) However there has also definitely been post ore movement on these faults which has brecciated the ore.

3. Dating of the sulphides by lead isotope methods, and by their relationships to a cross cutting minette dike dated by the Potassium Argon method, gives Pre Cambrian age, at least 765 million years old. (Leech G.B. & Wanless R.K. 1963 p 252.)

Therefore the Kimberley fault may be older than the Sullivan type structures which probably had some pre ore expression, and it fits reasonably into a regional pattern of faults which includes a rejuvenated ancient structure.

However, complicated renewals of movement on old structures is clearly a common occurrence, so the inferred cutting of the Kimberley by the Sullivan type faults may well be due to a late stage of movement along those breaks. It is not possible as yet to put a minimum date on this structure other than it's probable activity in the Mesozoic orogeny. The earliest time of major activity would be upper Purcell because Kitchener - Siyeh formations have been displaced by the fault.

The geology of the Sullivan Mine has been described by Swanson C.O. & Gunning H.C. (1945), Swanson (1948), and the Consolidated Mining and Smelting Co. of Canada Ltd. Staff (1954). The Swanson and Gunning paper may be found in the Structural Geology of Canadian Ore Deposits 1948 pp published by the Canadian Institute of Mining and Metallurgy.

A summary of the geology of the mine as it relates to a study of lead isotope ratios carried out by the Geological Survey of Canada, is presented by Leech & Wanless (1963 pp 248-256).

The following brief account is based chiefly upon the sources mentioned, and the writers own acquaintance with the mine geology.

LOCAL GEOLOGICAL SETTING

(a) Structural

The Sullivan ore body occurs in a broad shallow domical warp on the east dipping eastern flank of the Mesozoic Purcell geanticline. Minor fold structures include northerly trending sharp folds with the steep east limbs similar to those believed by Leech to be of Pre Cambrian age. There are also a few easterly trending folds. The orebody is in the footwall of the Kimberley fault and is cut by Sullivan type faults which trend North Easterly, dip steeply west and have normal displacements measurable in tens of feet. They rarely exceed five feet in width, of unconsolidated gouge vugs, and calcite.

(b) Stratigraphic

Stratigraphically the ore zone occupies beds in the upper part of the Lower Aldridge which comprises some 4,500 feet of rusty weathering thin bedded, laminated, light coloured very fine grained quartzites, argillaceous quartzites and minor argillites. (Reesor 1958 p6) Included in this thickness are about 1,000 feet of Moyie meta diorite sills.

The upper division of the Aldridge is 11,000 + feet thick, composed mainly of light grey weathering, light to dark grey quartzite with minor partings of black argillite and thin bedded argillaceous quartzite. At the top, an

Upper argillite member 1,000 to 1,500 feet thick can be distinguished locally.

Conglomerate, having intraformational characteristics has been observed to occur locally in the Aldridge. Reesor (1958 p63) notes the presence of conglomerate similar to that associated with the Sullivan orebody in the mountains near the headwaters of White Creek and the Middle Fork of Findlay Creek. Other Aldridge conglomerate bodies have been noted by Schofield (1915 pp38) on Cameron Creek, a branch of the Goat River, and by Rice (1937 p7) on Kootenay King Mountain.

GENERAL GEOLOGICAL FEATURES OF THE ORE BODY

An outstanding feature of the orebody established by the work of Swanson & Gunning is it's general conformability to stratigraphic boundaries. It occurs within a single stratigraphic zone 200 feet - 300 feet thick and has been mined for about 6,000 feet along strike and 4,500 feet down dip.

Certain aspects of the geology of the orebody change near the intersection of the 3900 foot elevation and it is convenient to think of the mine as divided into a western section where the orebody is above 3900 elevation and an eastern where it is below. The eastern section is characterized by strictly conformable ore bands dipping @ 30 to 40 degrees east. with little metasomatic alteration of the metasedimentary rocks. In contrast to this, the western orebody shows numerous departures from stratigraphic control; the dip is variable with flat areas separated by steep pitches, thicknesses of the ore zone are highly variable over short distances and in general the area shows a much greater degree of disturbance than the eastern part. In addition the western area is characterized by massive alteration of footwall rocks to a tourmaline chert, and chlorite, and of the hanging wall rocks to albitite and chlorite.

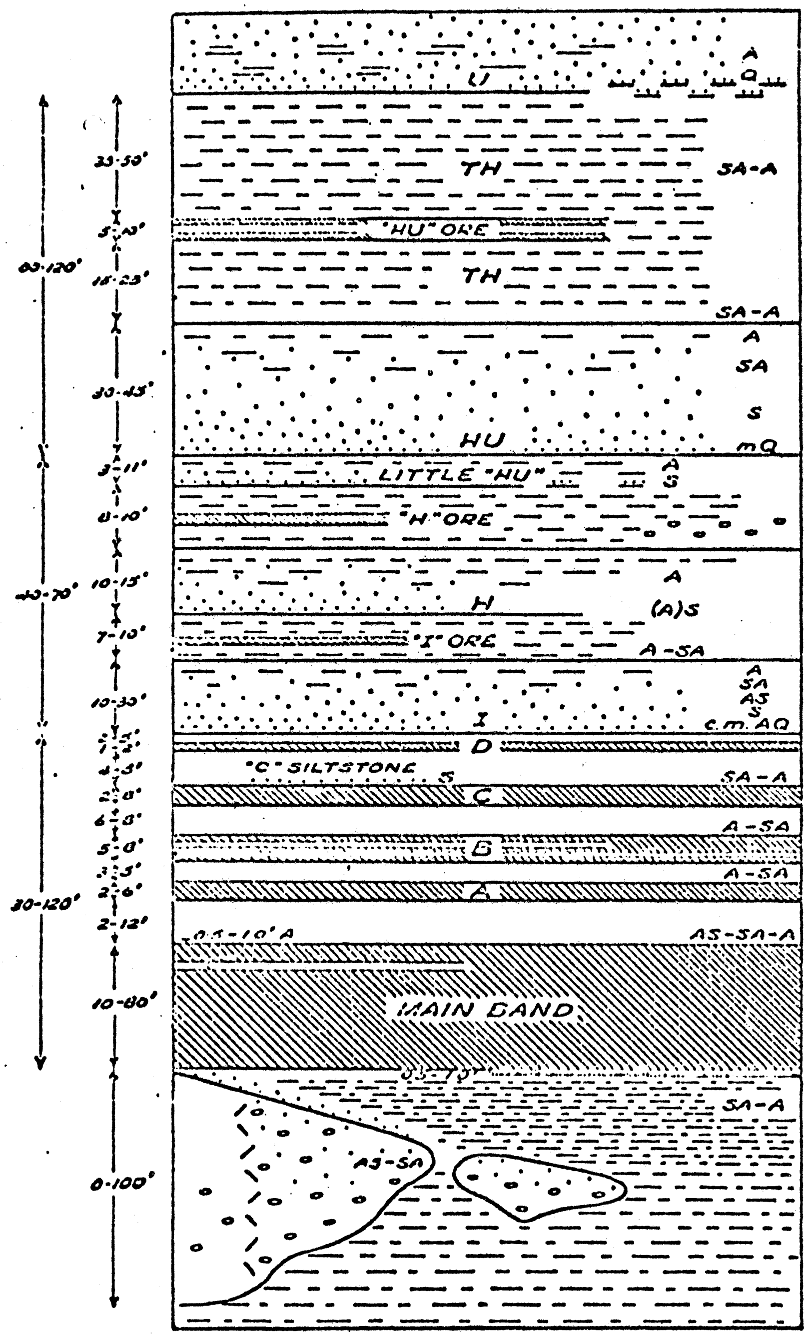
EASTERN SECTION

In a large area of the eastern section, the ore is strictly confined to certain definite layers separated by argillaceous beds. (See Fig 2 Ideal section). The hanging wall is formed by a graded argillaceous quartzite designated the "I" (intermediate) siltstone, which provides a marker throughout the area. Above "I" two other graded quartzites are recognized, which are designated "H" and "HU" respectively. Each of these beds has a moderately fine massive quartzite base which grades upward through siltstone and silty argillite to a thin bedded laminated argillite below the succeeding quartzite base. The laminated zones are locally mineralized sufficiently to become ore in the region where the orebody passes above the 3900 foot level.

THE CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED

SULLIVAN MINE

IDEAL GEOLOGICAL SECTION



UPPER QUARTZITE
Quartzite with argillite partings
Base not recognized as definite horizon.

THIN BEDDED HANGINGWALL
Beds, fraction of inch to several feet.

HANGINGWALL UPPER ORE ZONE
Laminated sulphide horizon.

HANGINGWALL UPPER SILTSTONE
Prominent Q or AQ base with Q grains for several feet.

LITTLE "HU" SILTSTONE

HANGINGWALL CONGLOMERATE
Recog. south and east of mine.

HANGINGWALL SILTSTONE
Q grains rarely concentrated at base.

INTERMEDIATE SILTSTONE
Q grains usually prominent.

Color zone D to I - fine P and Zn lams.

"B" Band triplets - two 2-12" Arg. bands separating three narrow sulphide bands.

MAIN BAND ORE
Massive to laminated sulphides.

FOOTWALL "SLATES"

FOOTWALL LAMINATED ZONE

FOOTWALL CONGLOMERATE

FOOTWALL THIN BEDDED SERIES

LEGEND

Q	Quartzite.	[dotted]	Quartzite.
S	Siltstone.	[dotted]	Siltstone.
A	Argillite.	[hatched]	Sulphide Ore.
AQ	Argillaceous quartzite.	[dashed]	Thin bedded.
AS	Argillaceous siltstone.	[dashed]	Laminated.
SA	Silty argillite.	[circles]	Conglomerate.

Fig. 3

Stratigraphic relationships of the sulphide footwall are not as clear as those of the hangingwall because no well defined marker horizon has been traced throughout the area. The hangingwall of the footwall conglomerate makes the best reference plane, but is available only under the northern half to two thirds of the orebody. The conglomerate will be discussed in detail later in the thesis.

The metamorphic grade of the sedimentary rocks is generally low in the greenschist facies. Original clay material has largely been converted to very fine sericite, and there has been some recrystallization of quartz grains. Biotite is not a prominent constituent. Within the orebody, local development of high temperature minerals has occurred. Biotite, garnet, scapolite, actinolite and cordeirite have been observed, the first two mentioned are occasionally quite abundant. Sedimentary textures are well preserved in all but the most severely metamorphosed rocks.

WESTERN SECTION

The brecciation, which is the subject of this thesis, is mostly found in the Western section of the mine area, closely associated with the characteristic features of disturbance, metasomatic alteration, discordant ore features, and high metal concentrations that distinguish this area. The ore in general loses the excellent banded features that it exhibits in the eastern section, and becomes a continuous sulphide deposit from footwall to hangingwall. Banding within the ore is marked by layers of sphalerite and galena in pyrrhotite. This banding is often quite lensy and discontinuous compared to that of the eastern section, but is thought to represent bedding features. The mineralization of the laminated zones above "I" "H" and "HU" has produced important ore bodies in this section. In some cases ore is continuous through the hanging wall marker beds. Towards the south of the western area, most of the ore is found in these upper beds and comparatively little below "I".

Tourmalinization has altered great volumes of rocks in the footwall of the ore zone into dense, dark coloured, very hard cherty rock. Tourmaline occurs as extremely fine needles replacing the sericite of argillite and silty argillite. The quartz grains remain unaltered excepting around the edges where they are penetrated for short distances by the tourmaline needles and knit tightly into the matrix. Sedimentary structures and textures are preserved. Individual beds can readily be identified. A small amount of tourmalinization has occurred in the hanging wall rocks.

Chloritic alteration occurs prominently in the footwall and hangingwall rocks adjacent to the orebody. Probably the greatest development is connected with the pyritic portion of the iron zone, a centrally located area which has a very low content of lead and zinc. Large volumes of chloritized rocks occur in the hangingwall associated with albitite.

Albitite is found extensively in the hangingwall, and to a much lesser extent in the footwall. Albite and chlorite often obliterate original bedding features making it impossible to trace hanging wall markers over considerable areas in the western section. Stratigraphic relations of the hanging wall are often in doubt where they would be most useful in elucidating structure.

A body of Moyie diorite underlies the strata beneath the orebody. In the central part of the mine area and to the east it is apparently sill like and at a depth some 500 feet below the sulphide footwall.

To the west it becomes dike like and rises across the strata, approaching within a few tens of feet of the orebody, then turns down forming an elongated dome west of the orebody.

Dikes given off by the diorite body have cut through the ore zone in places, but are no longer continuous in the ore. On the contrary, fragments of diorite are found scattered in the sulphides in the areas where the dikes cut the footwall and hangingwall rocks. In general the dikes are extremely variable in attitude and thickness so that it has only been possible to correlate three of them for any distance in the footwall, and none at all in the hangingwall. One younger, 2 foot lamprophyne dike known as the Lindsay dike has been traced for several thousand feet in the northern part of the east section. It has been seen to cross cut a dike of Moyie diorite. In the ore zone the Lindsay dike is disrupted and it's continuation in the hanging wall is offset.

Leech (Leech & Wanless 1963 p251) describes in detail an occurrence of a lamprophyre dike intersecting the D ore layer on which the hanging wall segment is displaced seven feet out of alignment from the footwall segment. Fragments of the dike appear in the 2½ foot thick ore layer, cross cutting the banding in the ore which lies parallel to the ore contacts. This is very similar to the observation noted by Swanson & Gunning (1945 p63). (Swanson 1948 p5)

> At one place in the mine, structure shows that a lamprophyre dike was intruded during the period of mineralization. This dike distinctly cuts heavily mineralized sediments in which pyrrhotite and sphalerite are the main sulphides, and is itself cut by a layer of galena a few inches wide that follows a minor fault.

The age assigned to the dike by Leech & Wanless, based on Potassium Argon dating, is not less than 765 million years.

PLATE I

Typical Footwall Conglomerate

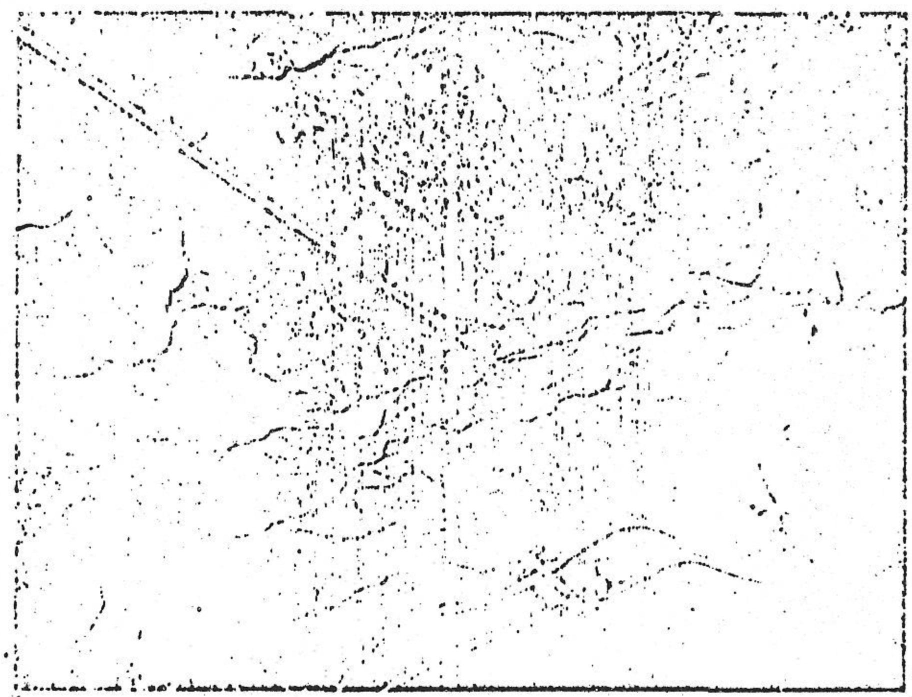


PLATE II

Boulder Conglomerate

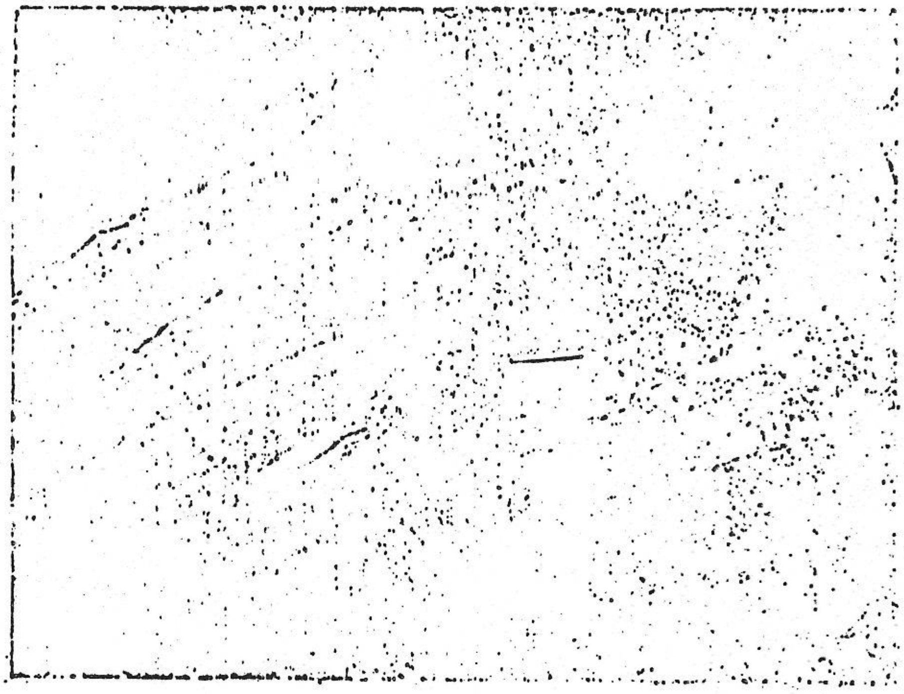


PLATE III

Discordant contact at the base of the footwall conglomerate.

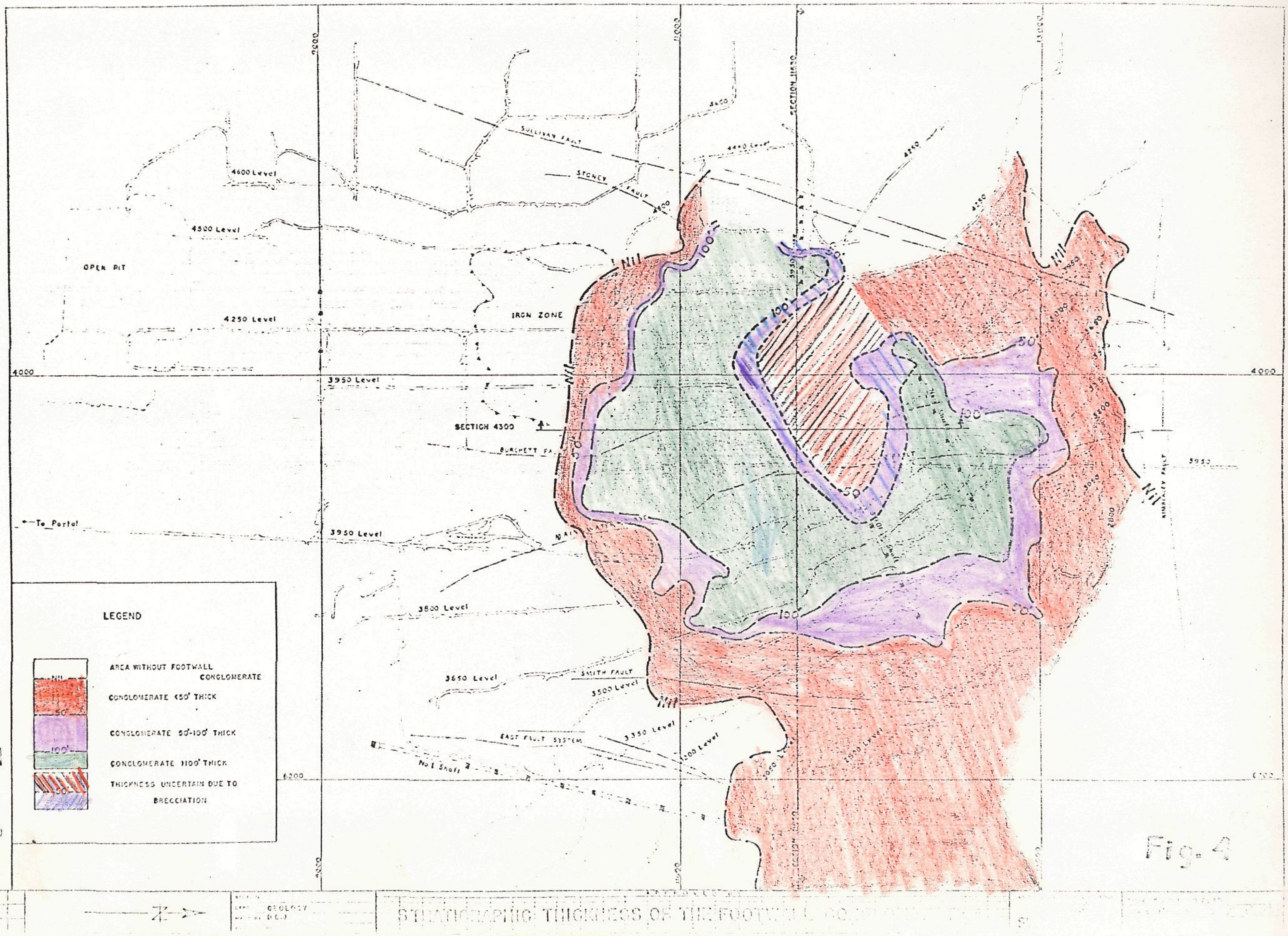
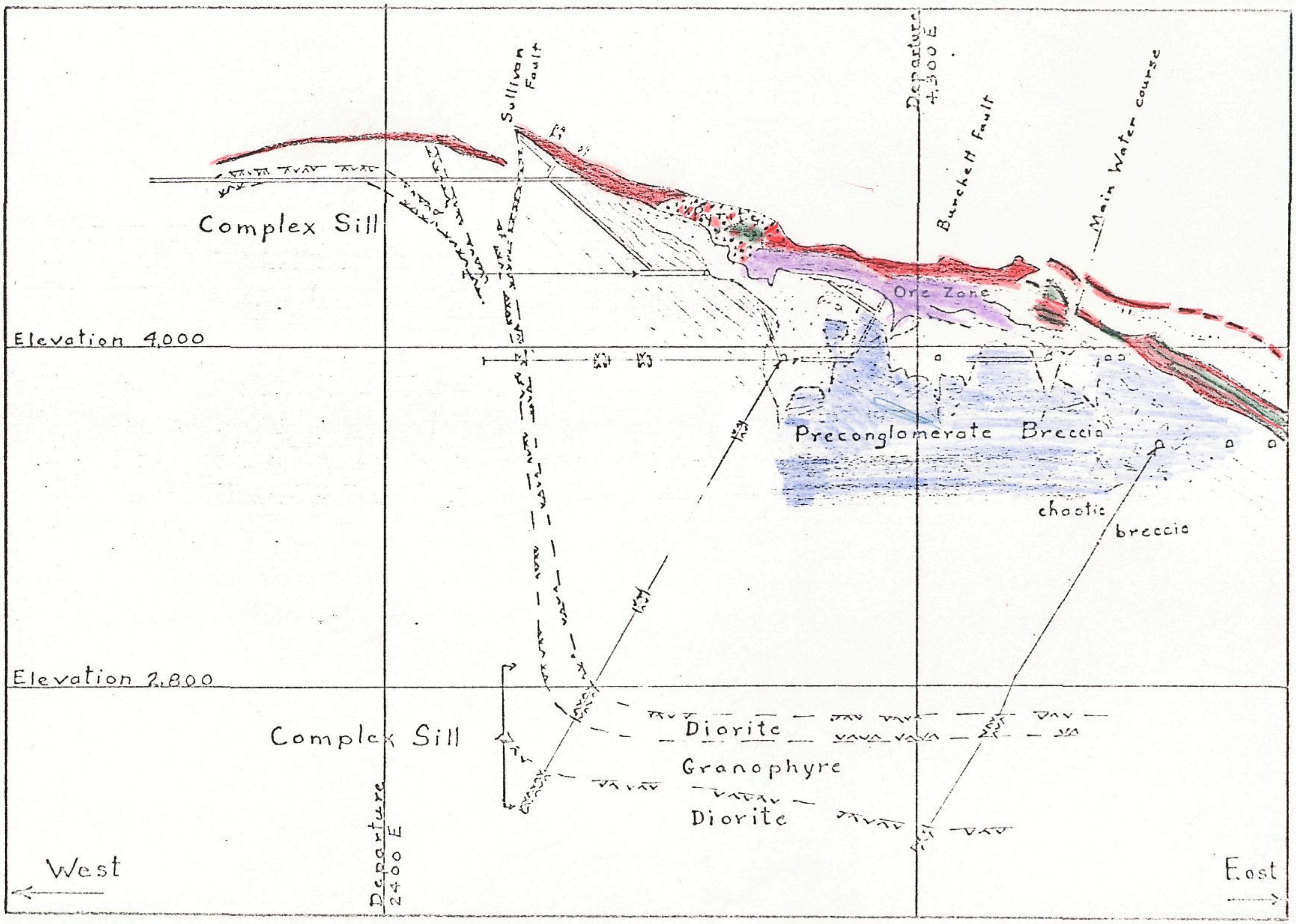
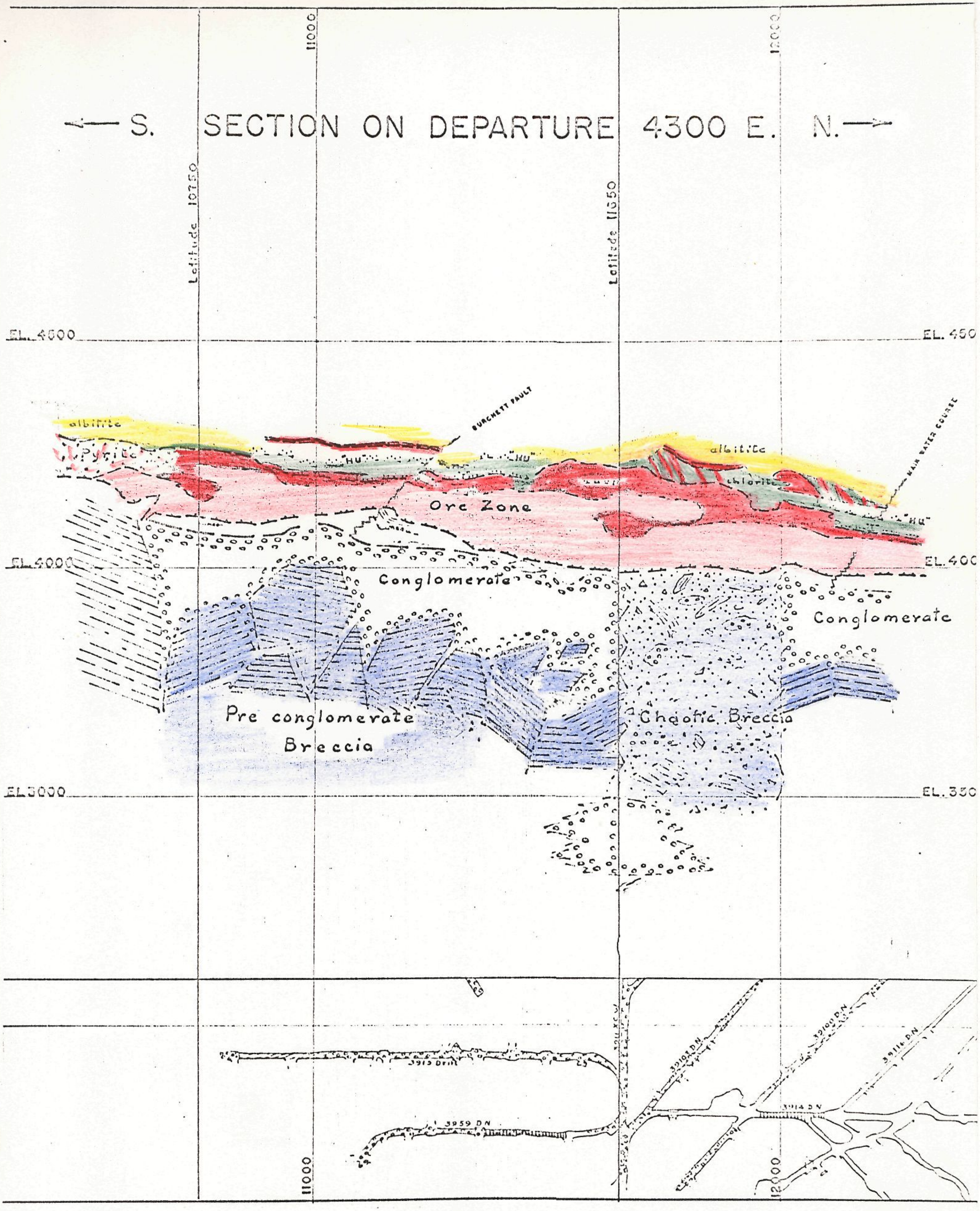

OPEN PIT
4600 Level
4500 Level
4250 Level
IRON ZONE
3950 Level
SECTION 4300
SULLIVAN FAULT
STONEY FAULT
BURCHETT FA
To Portal
3950 Level
3800 Level
3650 Level
SMITH FAULT
3500 Level
3350 Level
EAST FAULT SYSTEM
No 1 Shaft
KIMBERLEY FAULT
Nil
50'
100'
LEGEND
AREA WITHOUT FOOTWALL CONGLOMERATE
CONGLOMERATE <50' THICK
CONGLOMERATE 50'-100' THICK
CONGLOMERATE >100' THICK
THICKNESS UNCERTAIN DUE TO BRECCIATION
GEOLOGY
STRATIGRAPHIC THICKNESS OF THE FOOTWALL CO

Fig. 4



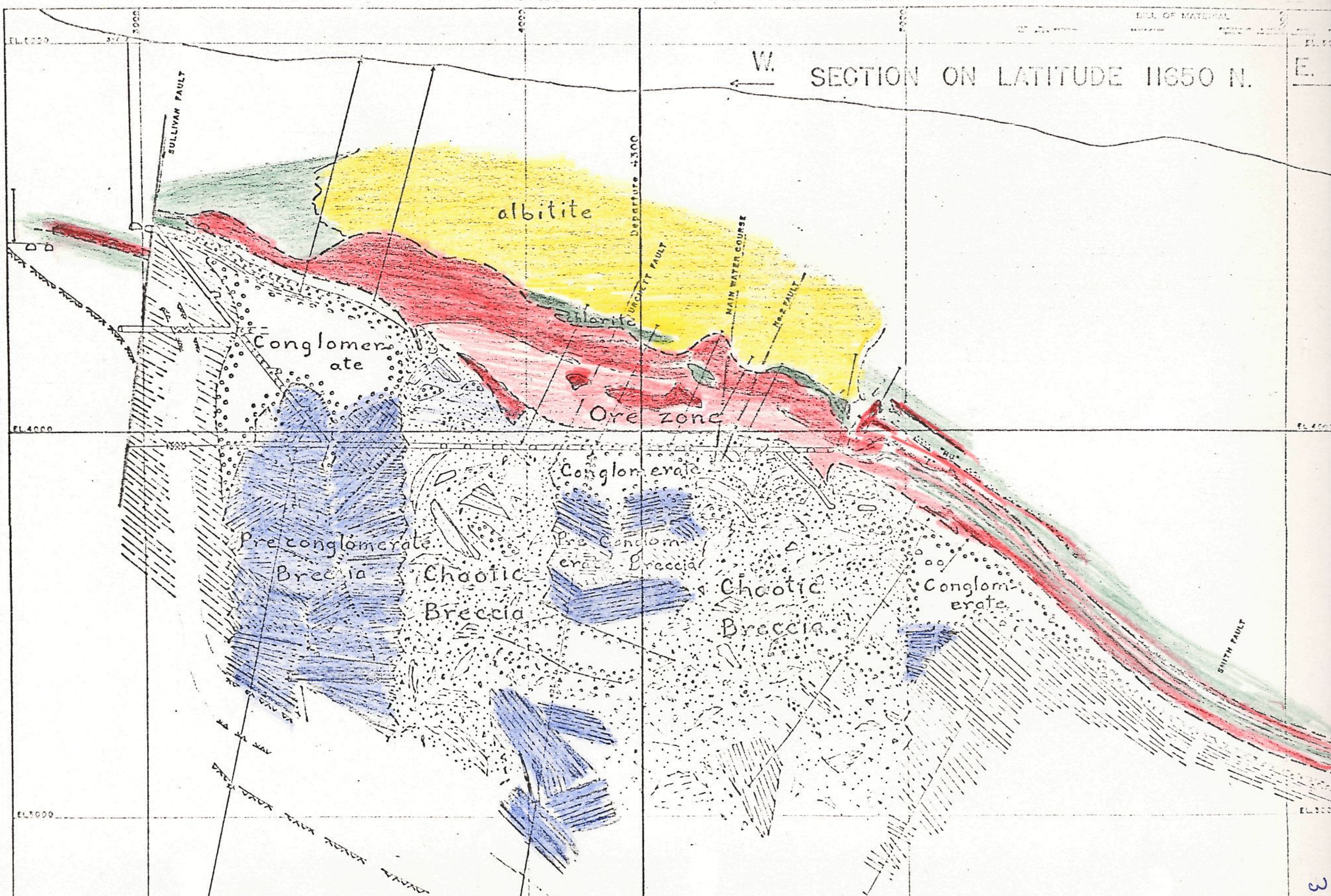
Vertical Section through the Sullivan Orebody on Latitude 10750 N. looking North

Fig. 5



← S. SECTION ON DEPARTURE 4300 E. N. →
11000
12000
Latitude 10750
Latitude 11650
EL. 4500
EL. 450
EL. 4000
EL. 400
EL. 3000
EL. 350
BURCHETT FAULT
MAIN WATER COURSE
albitite
Pyrite
HU
albitite
chlorite
Ore Zone
Conglomerate
Conglomerate
Pre conglomerate
Breccia
Chaotic Breccia
3959 DN
3914 DN
11000
12000

Fig. 6



Vertical Section through the Sullivan Orebody on Latitude 11650 N.
looking North

Fig. 7

CHAPTER III

It is fundamental to the discussion of the conglomerate and breccia to show that they are distinct entities, therefore a description of the conglomerate fabric will be given in the first part of the report.

The footwall conglomerate has been a familiar rock type to geologists at the Sullivan Mine for many years. Description of it are included in the papers on Sullivan geology, but since new data has accumulated regarding it's distribution and relationships, it will be reviewed in this paper.

Pebbles

The conglomerate is composed of fragments of argillite, silty argillite, siltstone and quartzite. No foreign pebbles, differing from the Aldridge rock types have been observed.

Matrix

The pebbles are set in a matrix that varies from argillaceous to locally quartzitic. A mixture of various sized quartz grains and grit sized particles, very similar to that found in breccia has been observed. Pebble to matrix ratio varies from closely packed pebbles with little matrix, to scattered pebbles with up to 60% matrix. It is likely that the amount of matrix is often overestimated because the pebbles do not show up well unless outlined by pyrrhotite or bleaching. Generally, in the writers experience, a high pebble-to-matrix ratio prevails.

Shape of Pebbles

There is a fair correlation between the composition and the shape of pebbles. Argillite and silty argillite pebbles are often laminated, tabular, and sub-angular, whereas the siltstones and quartzites are more massive, spherical and sub rounded to rounded. In comparison with Pettijohn's illustrations of roundness (p59 2nd Ed'n Sed. Rocks) they range from sub angular to rounded with perhaps the average shape being sub rounded.

Lithification

The rocks from which the pebbles were derived likely were quite well indurated because they are rarely bent or mashed. Also it is improbable that the siltstone and quartzite pebbles could have been derived from unconsolidated sand beds.

Size

Most of the pebbles in the conglomerate are less than an inch and one half in diameter, but occasional individuals up to three inches are not uncommon. Large boulders are unusual, the only accumulation exposed is at the base of the conglomerate in 3917 Drift near 3911 cross cut. These boulders have well rounded outlines although they have been fractured. See Plate II. Some large tabular pebbles nine inches or so long by 1-1½ inches thick have been observed, but are rare occurrences.

Sorting

Most of the conglomerate is a massive body (Pettijohn 1956 p159) without bedding. It presents a uniform appearance in which there are no outstandingly large components. In 3917 Drift there is a gradation from the boulder sized components at the base, to normal sized conglomerate at higher stratigraphic levels. Sorting of pebbles into lenses of coarser and finer sizes is not uncommon near the top where there are also intercalated lensy beds of grit and silty argillite.

Summarizing briefly, the conglomerate components are derived from rocks similar to the underlying sediments which had probably reached the stage of lithification of sandstones and mudstones. The pebbles have not likely been transported far, but have received a certain degree of rounding and sorting. This relatively orderly fabric stands in contrast to the unsorted chaotic fabric of the breccia.

Sulphides

Pyrrhotite is the most abundant sulphide present in the conglomerate. In certain localities galena and sphalerite are present in quantities sufficient to make ore. Arsenopyrite and chalcopyrite are present in small amounts.

The sulphides occur in a variety of ways. In places pyrrhotite appears mainly to be disseminated in the matrix, in others pebbles may be rimmed, or laminated, or composed entirely of pyrrhotite. Occasionally sphalerite and arsenopyrite pebbles are observed.

Distribution of sulphides throughout the conglomerate is variable. High concentrations occur usually with numerous pyrrhotite veins which are commonly associated with quartz and carbonate.

It has been suggested that some pyrrhotite laminated pebbles may have been derived directly from pyrrhotite laminated beds where the base of the conglomerate cuts unconformably across them. Similarly, certain isolated pyrrhotite pebbles with no visible connection to veinlets have been thought to be fragments of pre-existing pyrrhotite, although no source is known. On the whole though, the evidence suggests that the sulphides have been introduced into the conglomerate replacing some matrix and some pebbles.

Conglomerate

Location and Shape

Location

The position of the conglomerate body has been outlined by isophachous lines. See Fig. 3. It underlies the northern two thirds of the mine at varying distances below the sulphide footwall. At one time a continuous body, it has been disrupted in places by brecciation and later faulting.

Thickness

The fifty and one hundred foot isopach lines outline a thick portion of the conglomerate body. There are thicknesses greater than 200 feet within this area, but intersections to the base are few, so no detailed contouring has been attempted.

Contacts

"McEachern (1944) noted that the base of the conglomerate marks a disconformity" (Swanson & Gunning 1945). Studies and observations made since that time confirm and amplify this observation.

At its south and west boundaries the body increases in thickness rapidly from zero to over 200 feet. From several intersections it is known that the conglomerate is in contact with sharply truncated thin beds of argillite, siltstone and quartzite. Sections along latitude 11650 and departure 4300 show this contact cutting steeply down across some 200 feet of beds. (See Figs. 4, 5, & 6) The north and east contacts have not been seen, but the isopachs indicate thickening of the conglomerate which would require truncation of beds for its accommodation. Such information as can be found, indicates an eastern contact cutting 90 feet or so of beds at 40 degree to the bedding. It appears, therefore, that the thick part of the conglomerate is contained in a basin with steep south and west walls and a less steep east wall.

Base

The base on which the conglomerate rests is exposed in some of the 3950 level drifts and footwall development, and is seen to be very irregular. Masses of thin bedded sediments protrude upwards at least 100 feet into the conglomerate. The edges of some of the thin bedded blocks appear cracked and broken with fragments falling into the conglomerate, in other places the bedded rocks have sharp straight contacts. Bedding in the thin bedded blocks is often inclined at different angles on either side of conglomerate filled fissures. Many of these blocks of thin bedded rocks measure in tens of feet and are not entirely exposed.

The impression given is that the bottom of the steep walled conglomerate basin was strewn with huge blocks of thin bedded rocks and that a muddy gravel was more or less poured over them.

To the north and east of the thick part, the conglomerate body extends over the edge of the basin onto the surrounding terrain forming a pseudo conformable bed. The base of this bed has been observed to have a disconformable contact. The bed has a lense like cross section from north to south. The boundaries show an east-west elongation of the conglomerate body.

Relation of Conglomerate hanging wall to Sulphide footwall

Around the perimeter of the conglomerate body excepting stretches at the south east and north east, the sulphide footwall is in contact with the hanging wall of the conglomerate. Centrally however, there are thirty to forty feet of bedded sediments separating the two. The reason for the convergence of the two contacts away from the centre area is not clear. It cannot all be accounted for by crosscutting of beds by a discordant sulphide footwall, although this is known to occur, because convergence takes place in the eastern section of the mine where the footwall conforms most strictly to stratigraphic control. Furthermore, there is a convergence between the conglomerate and the base of "I", particularly out towards the North West fringe.

The hangingwall of the conglomerate may have been somewhat concave, allowing accumulation of thicker deposits in the central area.

BRECCIA

History

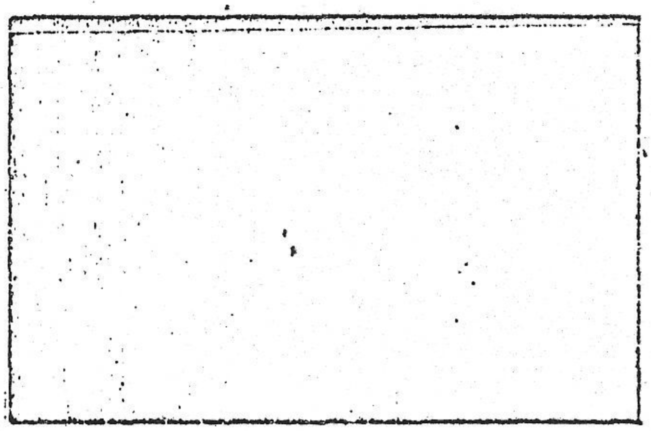
Breccia was not mapped as a distinct coherent unit of the Sullivan rocks until 1958. During the spring of that

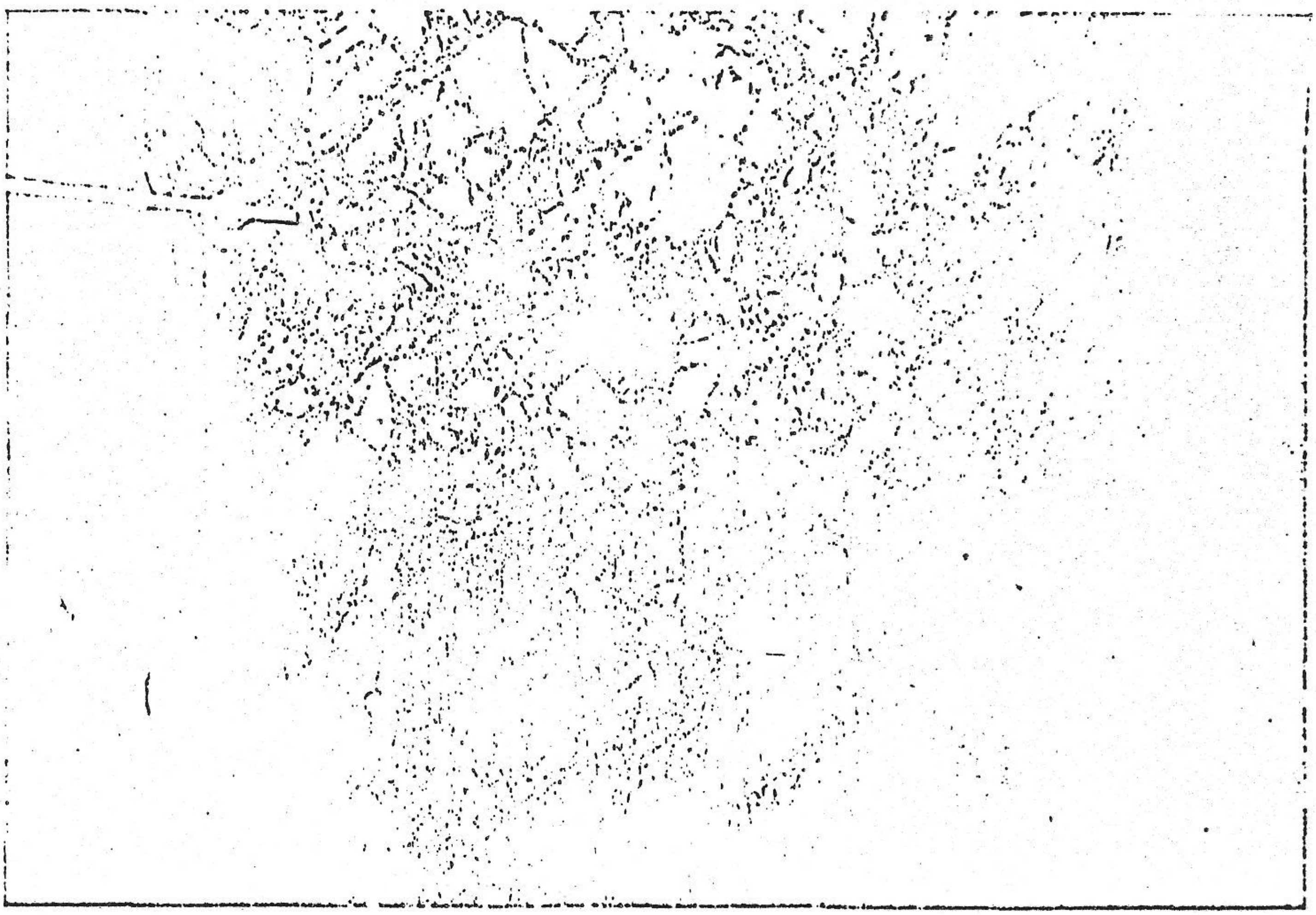
PLATE IV

Typical post conglomerate breccia in the footwall in the central area of the mine.

PLATE V

Breccia in the footwall towards the western fringe of the mine.





Post Tourmaline Breccia

adjacent to the 4800 E Keel structure

Light colored fragments are tourmalinized argillite;- "chert"

Dark colored matrix is oxidized Pyrrhotite

Central area of mine 38515 subB, R-14

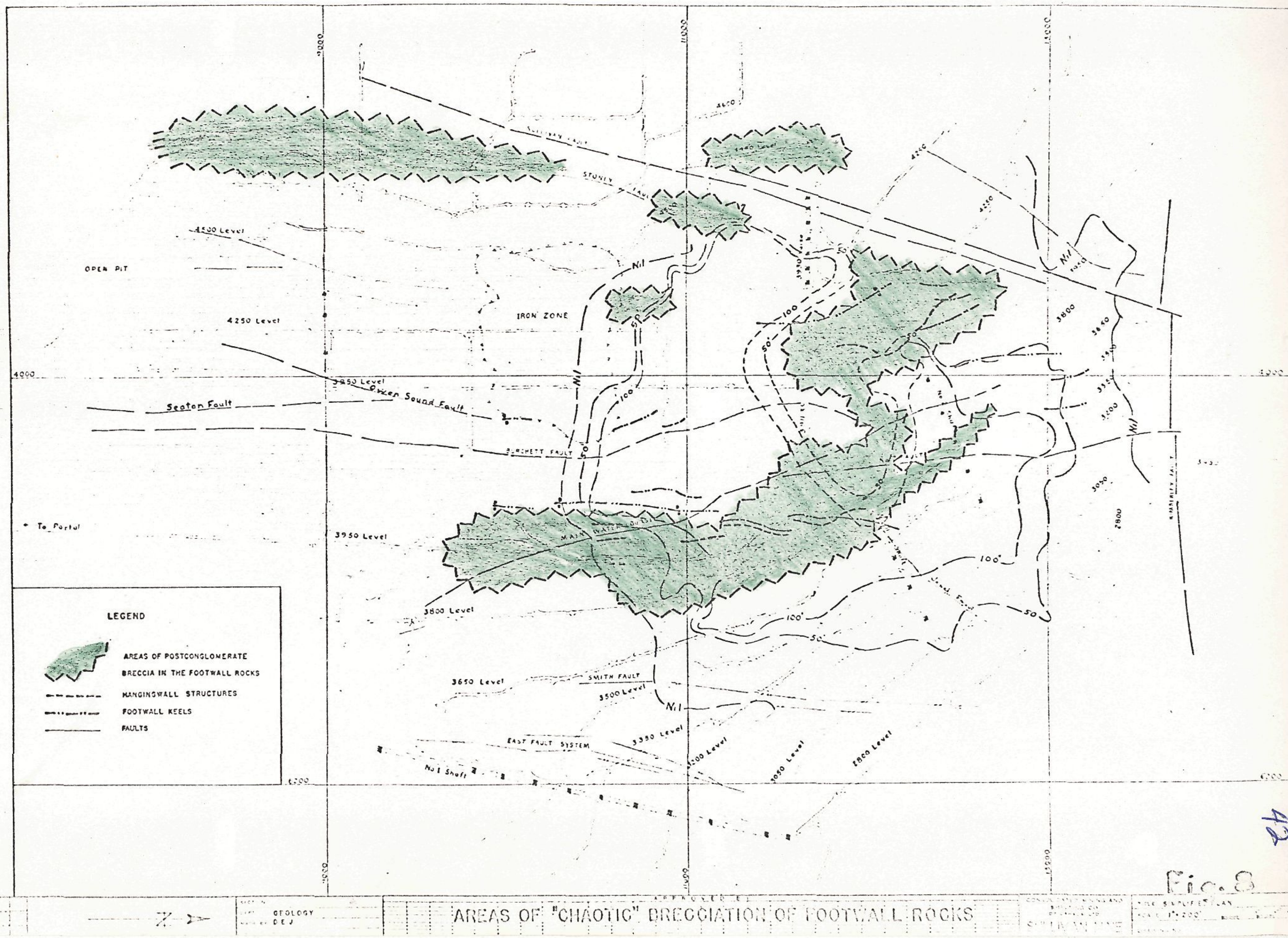

SULLIVAN FAULT
STONEY FAULT
4500 Level
OPEN PIT
IRON ZONE
4250 Level
Seaton Fault
Owen Sound Fault
BURCHETT FAULT
To Portal
3950 Level
3800 Level
3650 Level
SMITH FAULT
3500 Level
3350 Level
EAST FAULT SYSTEM
No 1 Shaft
3200 Level
3050 Level
2800 Level
LEGEND
AREAS OF POSTCONGLOMERATE BRECCIA IN THE FOOTWALL ROCKS
HANGINGWALL STRUCTURES
FOOTWALL KEELS
FAULTS
GEOLOGY
DEJ
AREAS OF "CHAOTIC" BRECCIATION OF FOOTWALL ROCKS

Fig. 8

47

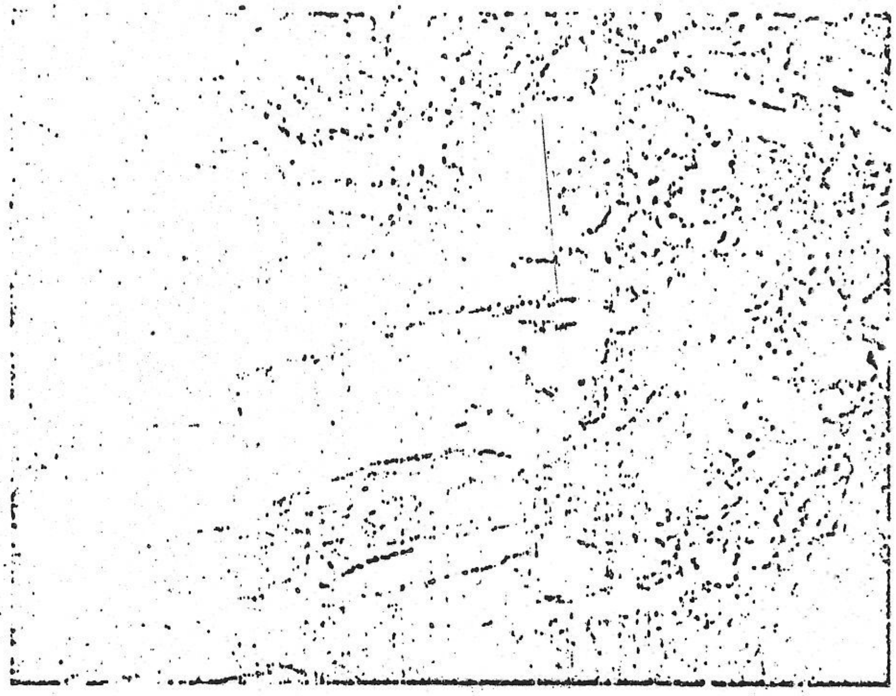


PLATE VI

Thin bedded block in breccia

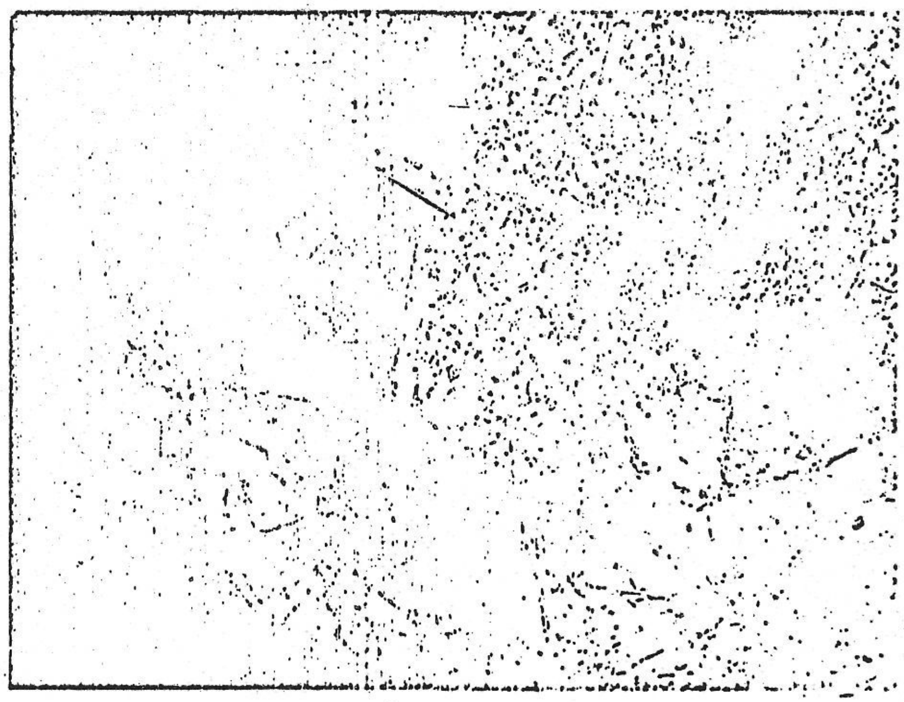


PLATE VII

Conglomerate block in breccia

PLATE VII A

Note torn and twisted end of a thin bedded block

PLATE VIII

Note bending of beds

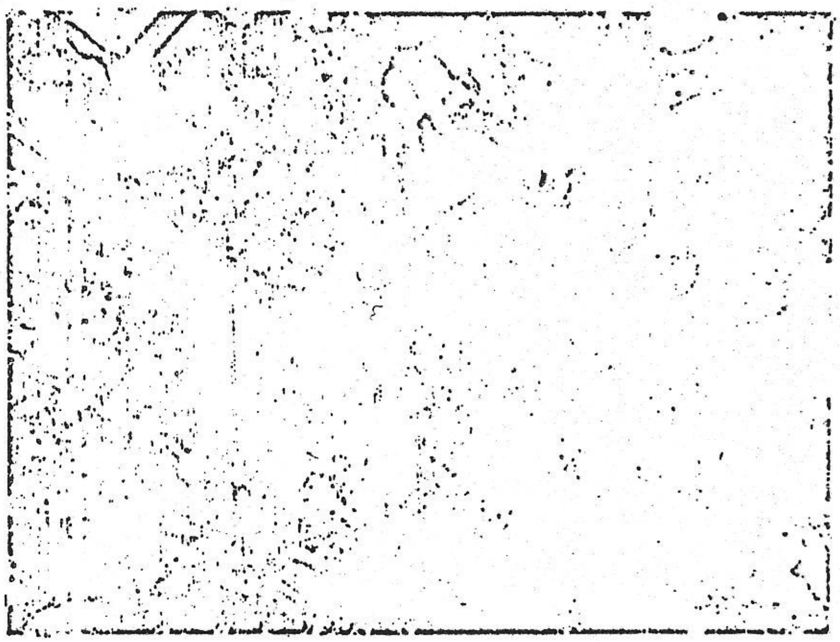
JU - 65 - 15 15 X

PLATE IX

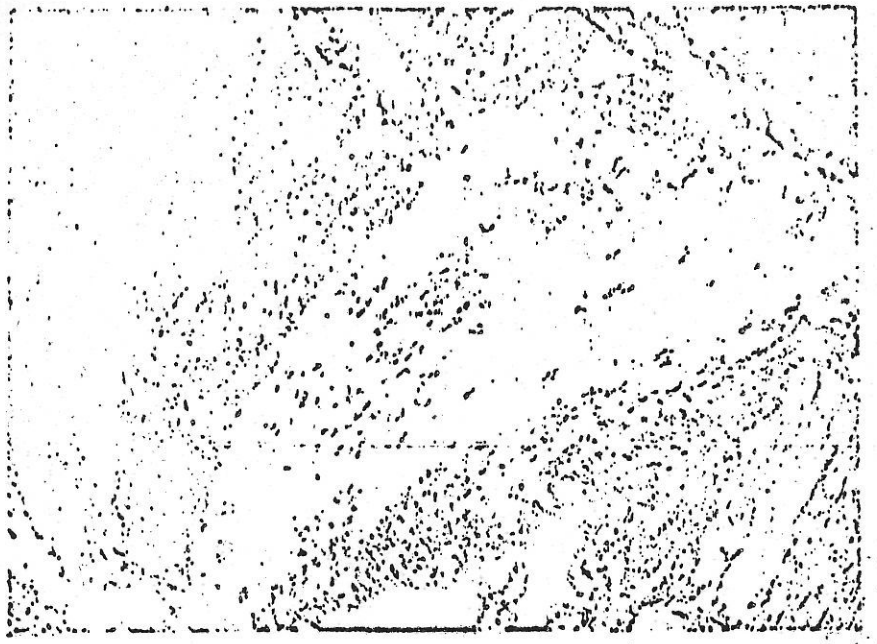
General view of matrix showing poorly sorted quartz and scattered fragments

PLATE X

Note tourmaline needles penetrating quartz grains, Pyrrhotite in fractured grains.



JU - 65 - 14 76 X



JU - 64 - 6(b) 11 X

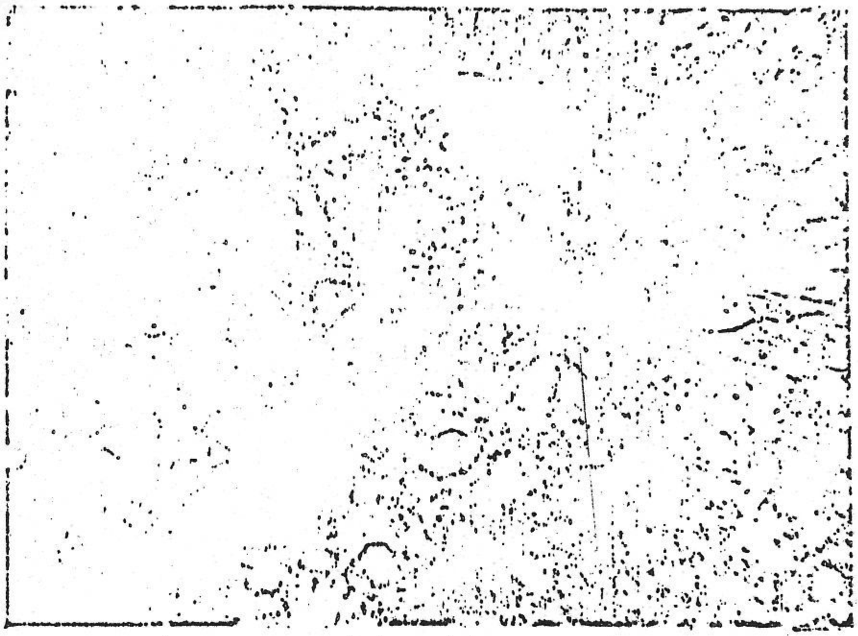
PLATE XI

twisted and torn fragments in breccia

JU - 64 - 6 (a)

PLATE XII

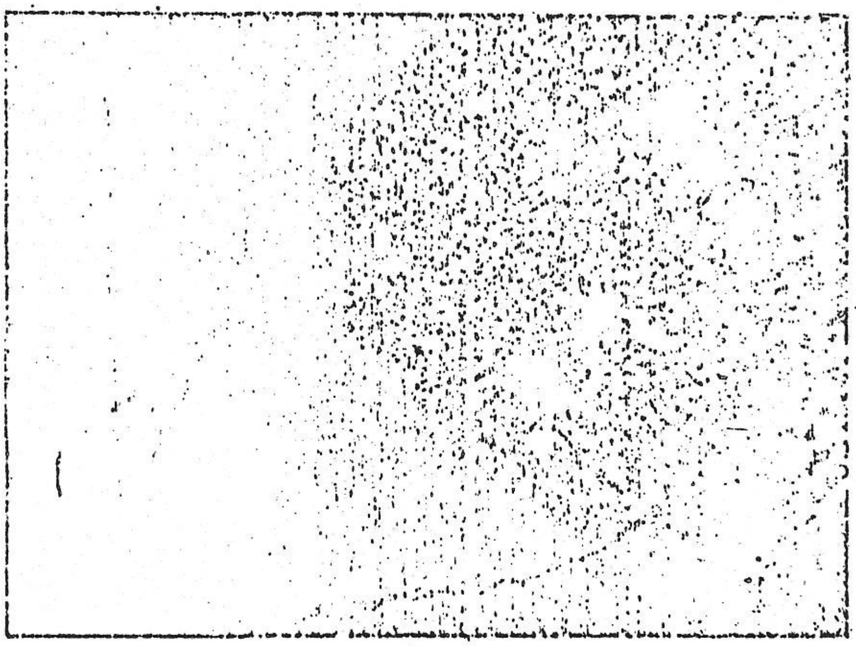
Pyrrhotite filling a quartz lined vug



JU - 65 - 16 73 X

PLATE XIII

Pyrrhotite veinlet cutting breccia matrix



JU - 65 - 1 A 20 X

PLATE XIV

Pyrrhotite distribution in matrix (right) and in fine grained fragment (left)

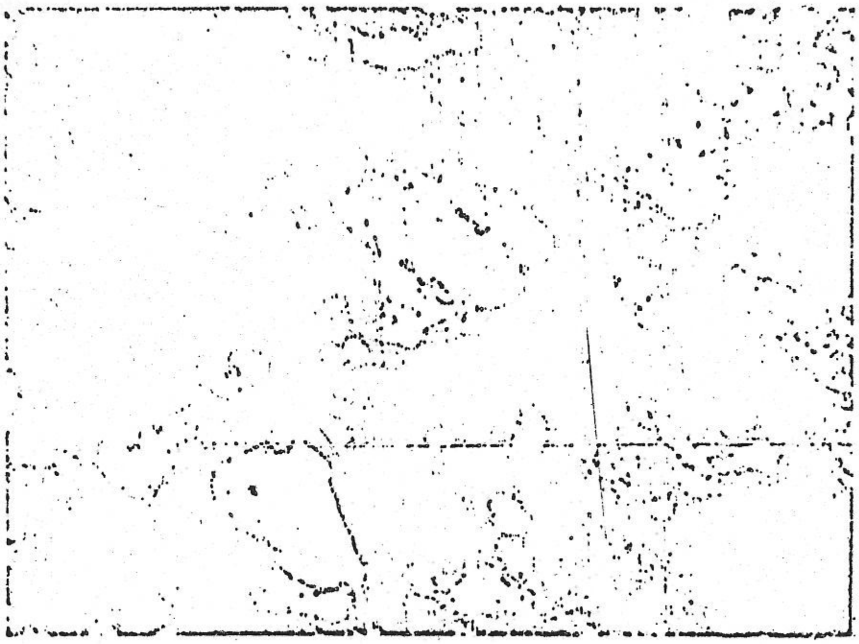


PLATE XV

Orthoclase (centre) altering to muscovite

JU - 64 - 4 120 X

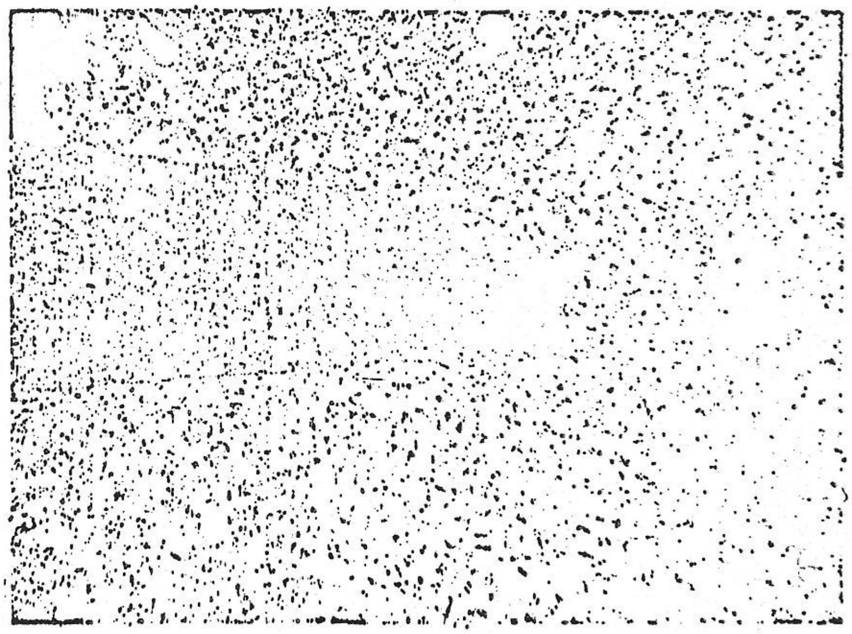


PLATE XVI

Orthoclase altering to muscovite (wedge shape) note included tourmaline needles

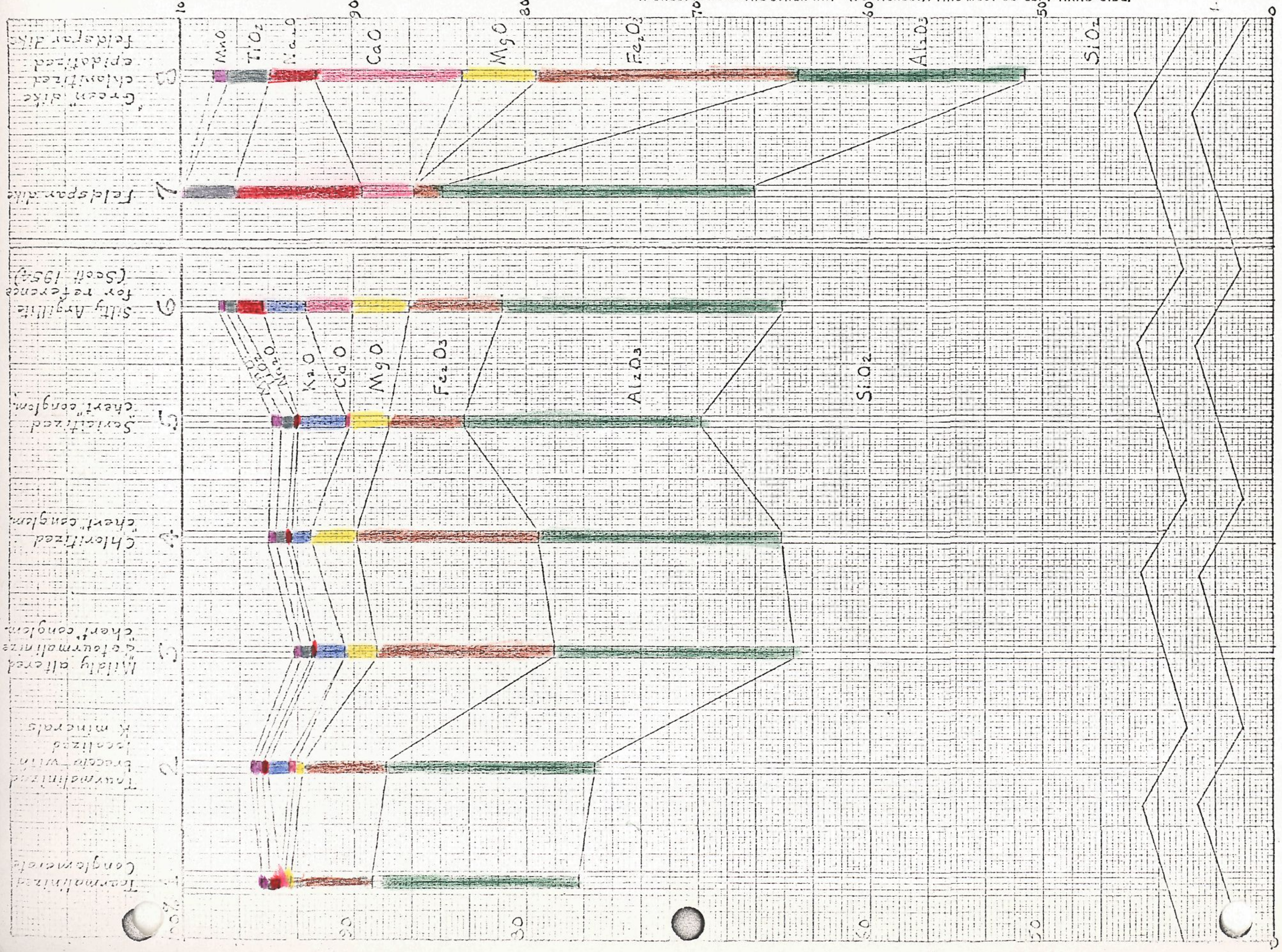
JU - 65 - 13 (a) 192 X

X nicols

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.

IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.



FORM 100

Analysis No.

	1*	2*	3*	4*	5*	6	7*	8*
B_2O_3						N.D.		
MnO	Tr.	0.09	0.66	0.44	0.23	0.19	0.03	1.03
TiO_2	0.50	0.46	0.65	0.66	0.68	0.59	2.72	2.40
Na_2O	0.70	0.30	0.20	0.23	0.19	1.55	7.60	2.65
K_2O	Nil	1.33	1.72	1.25	2.92	2.41	Nil	Nil
CaO	0.10	0.36	Tr.	Tr.	0.10	2.84	3.05	8.50
MgO	0.25	0.40	1.90	2.60	2.40	3.18	Tr.	3.90
Fe_2O_3	5.00	4.86	10.34	10.60	4.36	5.45	1.62	15.60
Al_2O_3	11.90	12.20	13.85	14.05	13.80	16.07	18.10	13.10
SiO_2	77.0	76.0	64.5	65.2	69.75	65.26	66.7	51.0

* Analyses by X-ray fluorescence and flame photometer. U. of Manitoba Geology Dept. K. Ramlal analyst.

Description of samples

(a) Tourmalinized rocks and rocks altered subsequent to tourmalinization

1. "Chert" conglomerate, dense, dark and hard. No visible alteration. Minor amounts of sulphide minerals

   JU - 65 - 27 3930 A Rse 8.8% sulphide

2. Tourmalinized breccia, dense dark hard "chert" K feldspar and some mica present, concentrated along fractures.

   JU - 64 - 4 39120 D.N. 19.9% sulphide

3. Detourmalinized "chert" conglomerate fairly soft with a few "chert" pebble remnants.

   Rock resembles slightly altered silty argillite.

   JU - 65 - 24 D-3 38331 SA 9.4% sulphide

4. Chloritized "chert" conglomerate. Soft greenish grey rocks. Occasional chert remnant.

   JU - 65 - 44 D-4 38331 SA 17.5% sulphide

5. Sericitized conglomerate, soft light grey rocks. Strongly mineralized with sphalerite and pyrrhotite.

JU - 65 - 26   B-4   39-P-19 Rsc   37.7% sulphide

(B) Reference specimen, normal sediments.

6. Silty Argillite collected by Scott.

(Scott 1954 Table II)

From below the sulphide footwall

D.D.H. 4728

(C) Feldspar and "green" dikes

7. The feldspar dike is a white fine grained rock intruded into brecciated chert and found with included fragments. It contains considerable amounts of pyrite. Rutile and leucoxene are plentiful in the fine grained matrix surrounding feldspar crystallites

JU - 64 - 3   16.3% sulphide

8. The "green"dike is a fine grained green colored rock intruded into brecciated chert and found as fragments broken in the ore zone. It has a texture similar to the feldspar dike but the feldspars have largely been altered to chlorite and epidote. Textures have been preserved by the rutile and leucoxene which mark the original fine grained matrix. Feldspar crystallites remain as clear areas with occasional remnants of feldspar.

J - 937 - 64   7.6% sulphide

year, the heading 3920 Drift was driven through rocks which appeared to be composed of a chaotic jumble of different sized rock fragments. A proposal that breccia or "chaotic" breccia be recognized as a mappable rock unit was made at that time, and subsequently large areas of breccia have been recognized and mapped. The following description is of the chaotic breccia as observed in the footwall rocks.

Fragments

The rock is composed of fragments of Aldridge type sediments varying from grit size to pieces measured in tens of feet. Bedded fragments are often wispy, twisted, and rotated with ends that appear to have torn rather than broken. Blocks of conglomerate are mixed in with bedded and massive pieces, and the whole appearance is heterogeneous and chaotic. Apparently much of the broken rock was in a relatively soft state at the time of breaking.

Matrix

The blocks are now completely consolidated in a matrix of silty argillite with a plentiful sprinkling of fine grained quartz. Pyrrhotite is disseminated through the matrix, and is also present in irregular veinlets that lace through the rock. Much of the breccia, both matrix and fragments, is now tourmalinized.

DISTRIBUTION OF POST CONGLOMERATE BRECCIA

In the footwall

Areas in which breccia occurs are indicated in Fig 8 Boundaries are approximate for the following reasons,

1. the breccia commonly grades outward from highly disturbed and mixed zones through cracked rocks into relatively undisturbed rocks.

2. in some places the boundary zone occurs against pre conglomerate breccia and cannot be distinguished.

3. the breccia may be exposed in conglomerate areas where it can be distinguished when mixing has brought thin bedded blocks into the conglomerate, but is otherwise vague.

The method used to place the outlines was to plot all clearly brecciated areas first, and then to plot all clearly non brecciated areas. The indefinite area between was taken as outlining the breccia zone. Benefit of any doubt was generally given to unbrecciated areas, so the outlines are considered to be minimal.

The outlines are quite irregular and do not show any sharply defined trends. There are two areas elongated in a north south direction, and another with an irregular east west elongation. More clearly defined are certain "keel" structures which are closely associated with brecciation. These structures are discordant downward projections of the sulphide footwall trending north or northwesterly, and frequently are paralleled by hanging wall folds with steep to over-turned east limbs. (See Fig. 8)

Strata affected

Brecciation has been traced from the rocks below the conglomerate through to the sulphide footwall. Brecciation of the conglomerate is certain where blocks of conglomerate are mixed with fragments of bedded rocks and vice versa. See Plate VII. Below the area of footwall development, breccia is found in three diamond drill core holes shown on section Latitude 11650 N (Fig. 7) This breccia is a cross cutting feature, extending more or less vertically below the orebody, and cutting the earlier breccia at the base of the conglomerate. The vertical attitude is well illustrated, in the south end breccia channels which are relatively narrow with sharp contacts.

The interpretation of breccia extending downward to considerable depth (Figs 5 & 6) is based on a projection of information mapped in development headings, and the information available from diamond drill core from holes, four of which are indicated in Fig. 6. It should be realized that the outlines shown are quite highly interpretative, increasingly so with depth, but breccia is found in the core down to the hangingwall of the diorite sill.

Microscopic examination

When examined in thin sections, the breccia matrix is seen to be a poorly sorted aggregate of sand and silt grains ranging from 0.01 m.m. to 0.5 m.m., each surrounded by a thin coating of tourmalinized argillite. The very fine tourmaline needles penetrate the edges of the quartz grains for a short distance, leaving the centres clear. The quartz grains are sub angular to sub rounded, and although occasionally fractured they do not exhibit signs of crushing, shearing or mylonitization. Scattered through the sand grains are tourmalinized chips of fine grained argillite and coarser, laminated silty argillite. Quartz forms upward of 80% of the matrix in places. Views of typical matrix are shown in Plates IX and X.

It is clear from the way that the matrix has been tourmalinized that tourmaline was introduced after brecciation. The breccia is not merely a cemented accumulation of previously tourmalinized fragments. Furthermore, fragments of all sizes (See Plates VII, VIII and XI) show deformation that indicates they were relatively soft (untourmalinized) when broken. It is concluded therefore, that a great deal of the brecciation predates the tourmalinization process.

Sulphide Minerals

Although Pyrrhotite is by far the predominant sulphide mineral, it is not uncommon to find a few grains of chalcopyrite and arsenopyrite in pyrrhotite veins. Locally within the breccia area, galena and sphalerite are relatively abundant, to the extent of making sub ore to depths as much as 150 feet below the sulphide footwall.

Pyrrhotite is relatively much more plentiful in the matrix than in the fragments, so that oxidized surfaces show matrix areas dark and fragments light. In many places pyrrhotite is so abundant that it forms the entire matrix. In general however it is disseminated through the matrix in irregularly shaped blebs amongst the quartz grains and in thin veinlets in fine grained fragments. Plate XIV illustrates these relationships. Note in Plate XII that Pyrrhotite has filled a small quartz lined vug between breccia fragments, and in Plate XIII thin veinlets of Pyrrhotite cut straight through the various mineral grains of the matrix. Clearly the sulphide minerals have been introduced after brecciation of the rock. It is also apparent that sulphide minerals are partly if not entirely later than tourmaline. The evidence for this is

1. Veins of sulphide minerals cut through tourmalinized rock.

2. Inclusions of tourmalinized rocks within the sulphide veinlets are common.

3. Sulphide grains cut across tourmalinized quartz grain contacts.

4. Sulphide minerals have textural relationships that indicate they formed later than muscovite and chlorite alteration of tourmaline "chert".

5. Rarely, larger tourmaline grains are seen which have been broken and the cracks filled with sulphide minerals. See Plates XX - XXIII.

K Feldspar and Muscovite

The presence of feldspar in tourmalinized breccia was first noted in very thin veinlets of microperthite. Elsewhere grains similar in appearance to detrital quartz but partly altered to muscovite were suspected of being feldspar. Subsequently staining techniques using Hydrofluoric acid etch and sodium cobaltinitrite stain confirmed the presence of potassium feldspars in several specimens. Presence of plagioclase feldspar is indicated by positive reaction to the rhodizonate test, but this cannot be considered to be specific for the reasons outlined in Appendix A where the staining procedures (Bailey & Stevens 1960) are given.

Distribution of K minerals

The specimens that reacted positively to the K feldspar stain showed two types of distribution. On one fine grained specimen, very small grains of feldspar were abundantly sprinkled all over the etched surface. On others the stain was concentrated along certain fractures, with decreasing numbers of disseminated grains away from the cracks. There is a definite close association of feldspars with sulphide minerals. Where muscovite is in contact with sulphide minerals it always shows well developed straight crystal outlines to which the sulphides conform. Sulphide minerals often penetrate along the cleavage planes of the muscovite books. Although K feldspar and muscovite are always closely associated with sulphide minerals, the reverse is not true:- most of the breccia does not contain feldspar.

The distribution of the feldspars shows that they are not detrital although they resemble the quartz grains in size and shape. In addition they do not show the alteration due to weathering that might be expected in detrital grains. Their presence would seem to be due to a potassium metasomatism.

POST TOURMALINE BRECCIATION

Keel structures

Keel structure is a term applied by geologists at the Sullivan Mine to downward projections of the sulphide footwall below the general contact surface. In some cases this keel has the aspect of a rather thin vertical fin of ore passing downward into a vein, in others the keel is a broad trough like depression. One type may change to the other along strike. Cross sections through some of these structures are illustrated in Figs. 9 & 10 and in more detail in Fig. 11 They are shown in Plan on Fig. 8

Some of the keels are continuous for hundreds of feet, though they may be offset en echelon. Their strike is northerly with considerable variation.

A definite displacement of footwall strata accompanies the keel structures. On the two longest ones the strata west of the keel are down some forty feet with respect to the east. On some of the smaller keels displacement is in the reverse direction. Severe brecciation of the rocks adjacent to the keel is commonly observed.

Figs. 9 & 11 show a keel which has been observed in some detail. The following facts seem pertinent.

1. All sulphide contacts tightly adhere to the footwall rocks, on the discordant east contact as well as on the more conformable west side.

2. Pyrrhotite veinlets anastomose through the breccia, and where they join the massive sulphides of the orebody no line of contact can be discerned. The vein pyrrhotite and the orebody pyrrhotite are continuous.

3. Galena laminations are found to parallel both the discordant and the conformable contacts. The laminations which are of the type usually thought to represent relics of

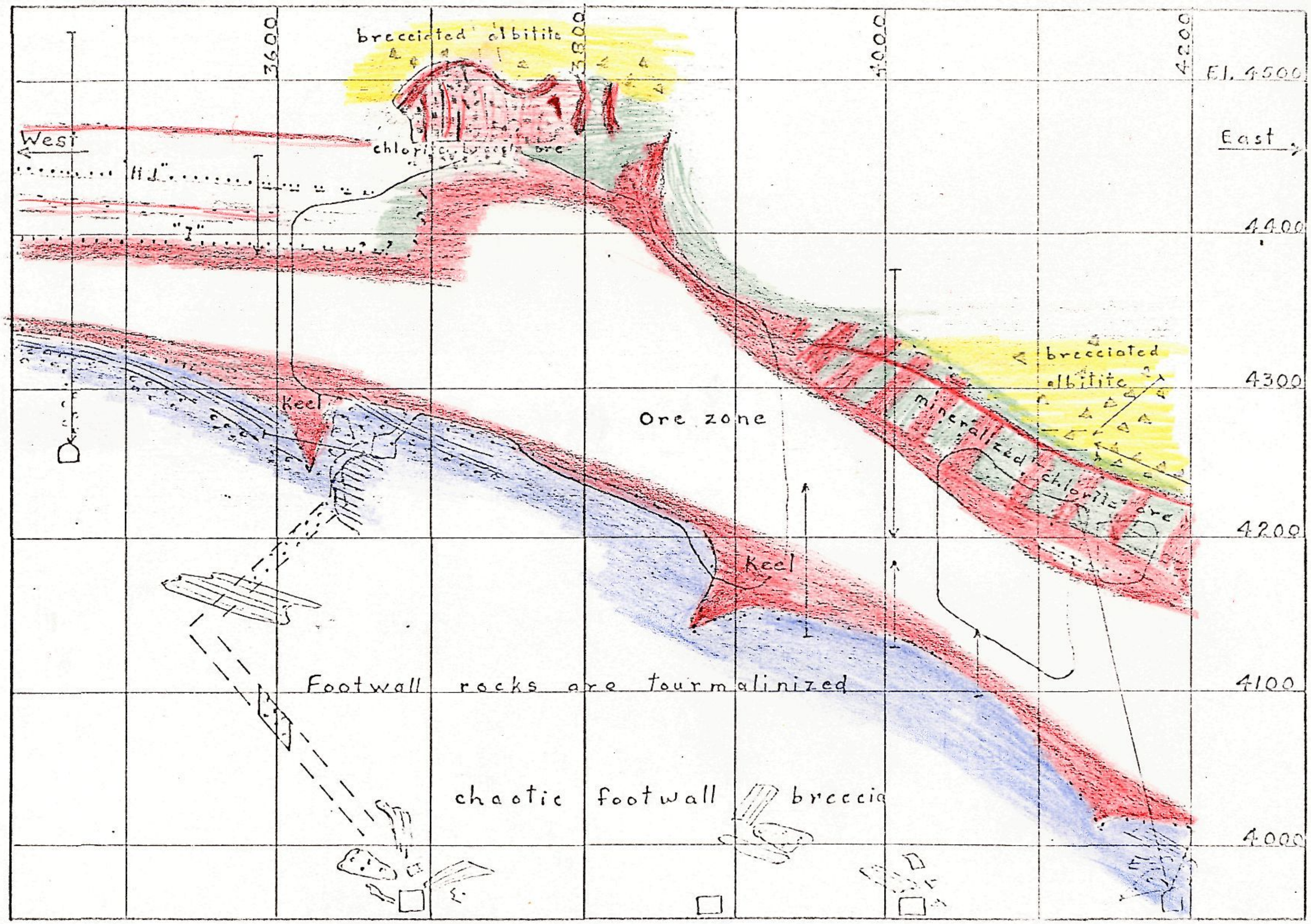
sedimentary bedding, are very nearly continuous around the sharp corner at the base of the keel. Similar banding has been seen in the keel where it is quite narrow and veinlike.

4. "Chert" fragments are found in the main sulphide body.

5. A green fine grained chloritized epidotized feldspar dike occurs in the breccia adjacent to the keel. The dike surrounds tourmalinized fragments, and is found as fragments in the sulphides. A relatively unaltered white fine grained feldspar dike of similar texture and feldspar composition is found intruding the breccia elsewhere in the vicinity. Plates XX & XXI illustrate the textures of the two dikes. The chemical compositions were determined by x ray fluorescence analysis as shown. Note that the fairly high titanium content (rutile & leucoxene) is common to both. It is thought that they represent different stages of alteration of the same dike.

6. A displaced portion of the green dike found some 110 feet above the sulphide footwall is illustrated in Fig. 13 & Plate XIX. Note that small fragments of the dike at the broken end are surrounded by ore much richer in galena than most of the adjacent pyrrhotite.

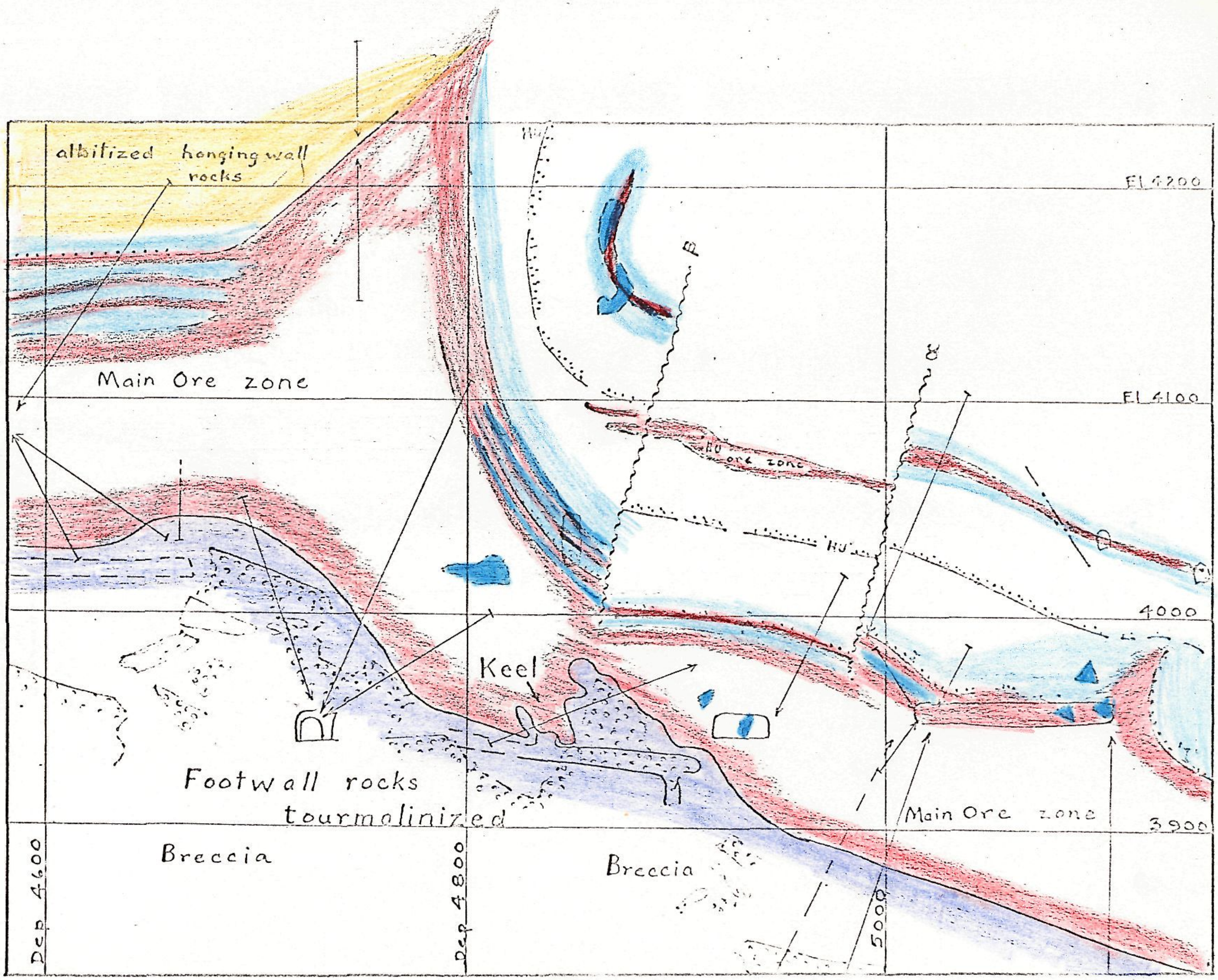
The points listed above indicate that the tourmalinized breccia was rebroken and intruded by the feldspar dike, which was in it's turn broken at a time when



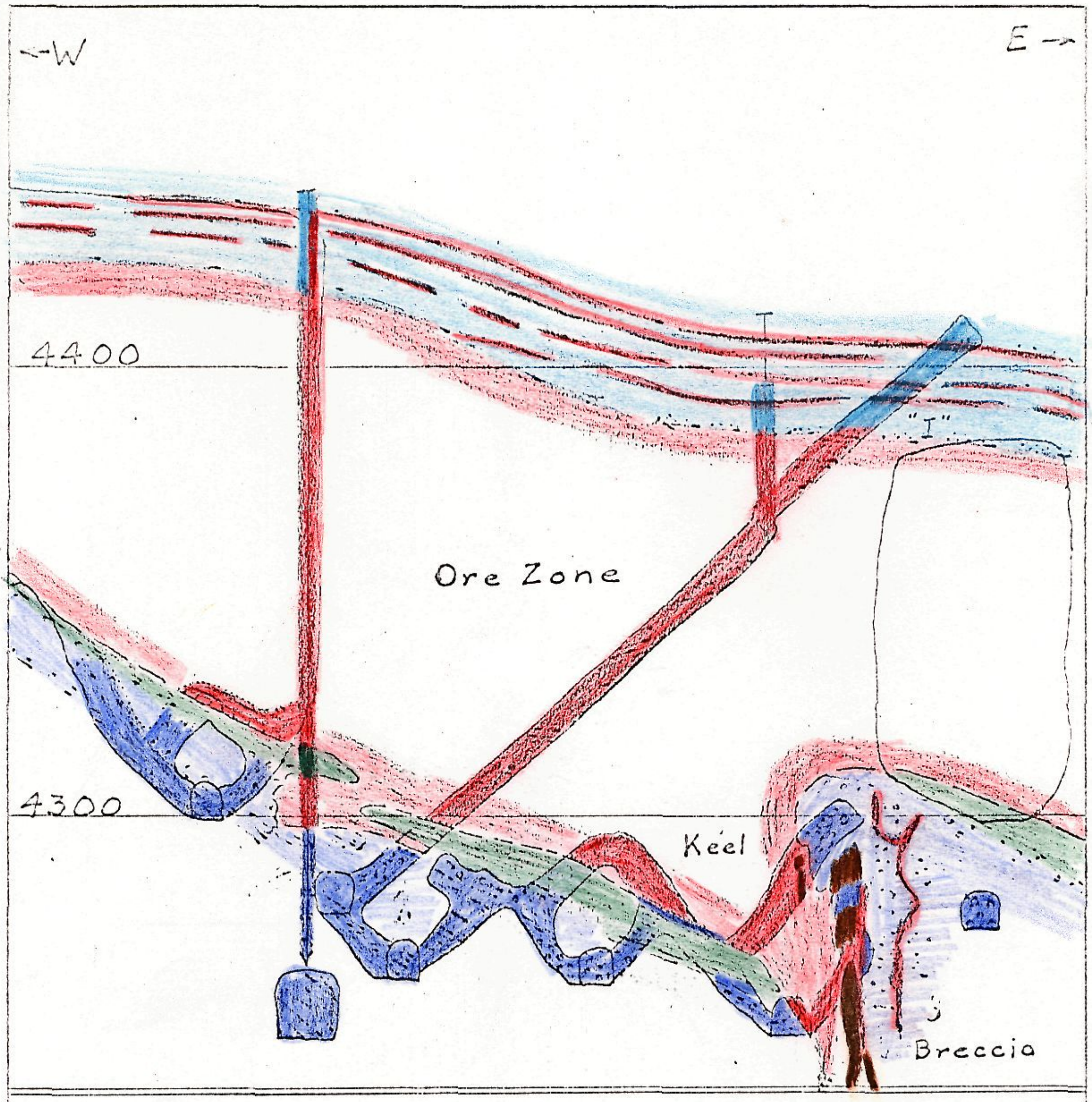
Vertical Section on Latitude 11900 N. to show keel, hanging wall structures, and brecciation

Fig. 9

Fig. 10



Vertical Section on Latitude 11300 N. to show ke[illegible] and hanging wall structures along 4800 Depart[illegible] Fig. 10



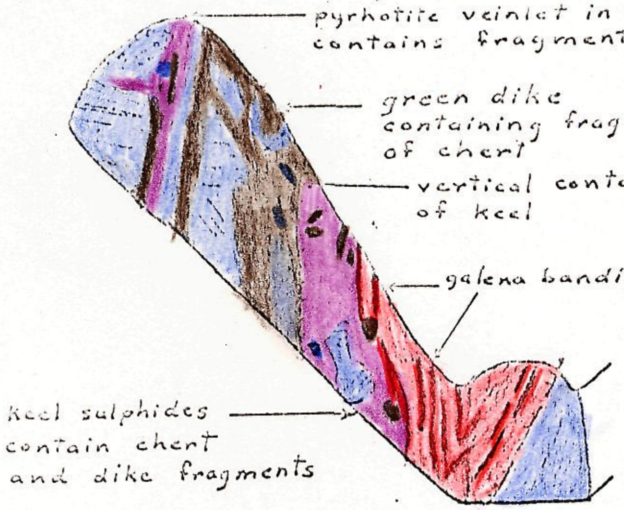
Scale 1" = 40'

Vertical Section looking North to show keel structure

Note — footwall structure has no counterpart in hangingwall

T-8-5 pillar

Fig. 11



Detail of keel as seen in a drawhole 39-T-18^{S}E D.H #2

Fig. 12

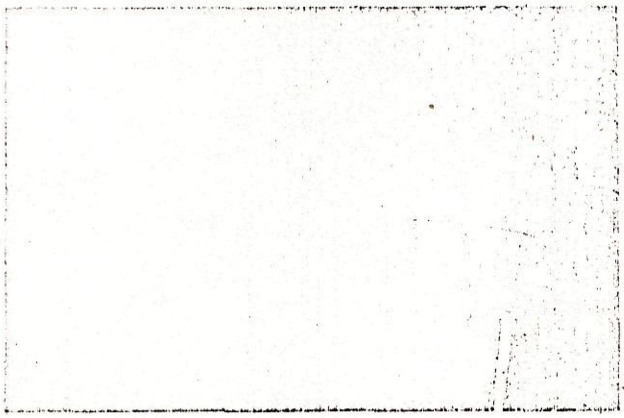
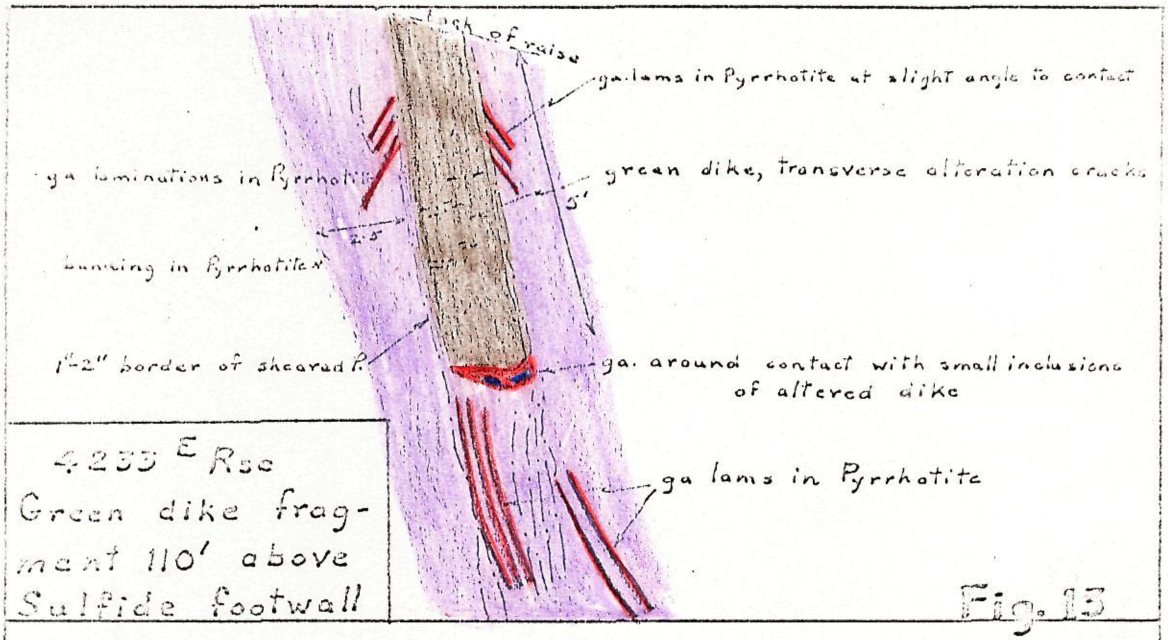


Plate XVII 17

contact of green dike with sulphide keel Note chert inclusions in dike

Plate XVIII 18

Fragment of green dike in sulphide of keel



4233 E Rse
Green dike fragment 110' above Sulfide footwall

Fig. 13

Plate XIX
19

Dike in 4233 E R
as in sketch above

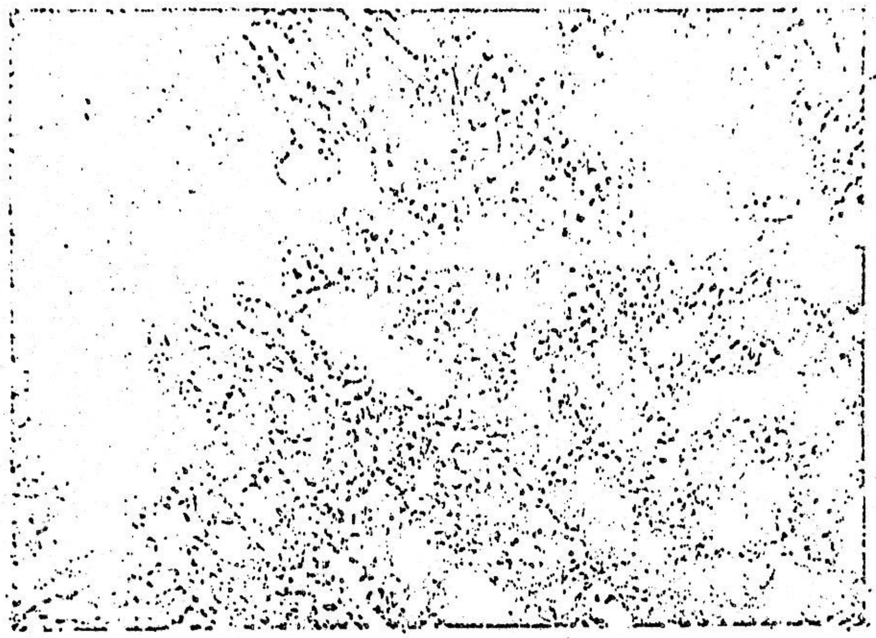


PLATE XX

Feldspar dike from breccia

JU - 64 - 3 42 X

Analysis	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO
	66.7	18.10	1.62	Tr.	3.05	--	7.60	2.72	0.03

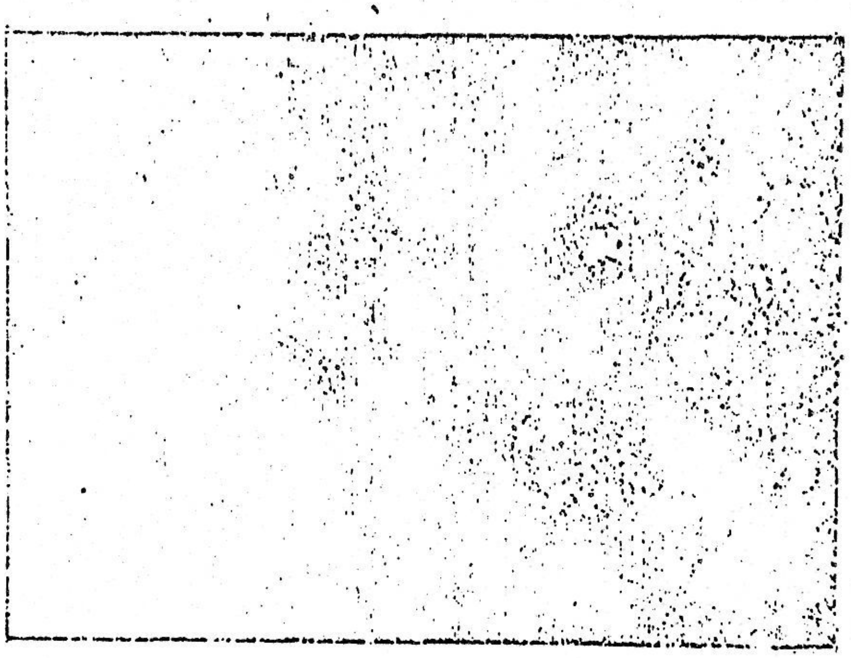


PLATE XXI

Green dike, chloritized epidotized feldspar dike

J - 937 - 64 23 X

Analysis	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO
	51.0	13.10	15.60	3.90	8.50	-	2.65	2.40	1.03

The breccia was laced with pyrrhotite veins. The main ore zone reacted in a contrasting plastic or fluid manner. This contrast in the rheologic properties of the sulphide zone will be discussed in more detail prior to considering brecciation in the ore zone.

Post Tourmaline alteration

Alteration zones cut through the tourmalinized foot-wall rocks in many places, the alteration effects varying in severity and in kind. Mild alteration is often observed spreading out to short distances on either side of fractures, removing the cherty characteristics of the rock and leaving it very similar in appearance to normal argillites and silty argillites. More extensive alteration usually grades from a sericitized or chloritized central zone to mildly altered edges. Frequently in conglomerate, the matrix has altered more rapidly than the pebbles, leaving what has appeared to be "chert" pebbles in slightly chloritic silty argillite.

In one broad alteration zone that cuts tourmalinized footwall conglomerate on the 4250 level, the main alteration has been to chlorite, but pebbles have been selectively albitized. Albitization of pebbles has been observed to occur into the tourmalinized rocks for a few inches beyond the contact of the main alteration zone.

Very severe alteration has locally decomposed the tourmalinized rocks to a brownish soft muddy material with disseminated calcite crystals through it.

Chlorite is the most abundant alteration. Large volumes of footwall rocks are chloritized at the west end of the iron zone. Remnants of tourmaline chert are commonly found enclosed in the chlorite. Chloritic alteration is also often found for a few feet below the sulphide footwall. It is a characteristic of much of the chlorite that it is associated with pyrite rather than pyrrhotite. Often the iron sulphide will be pyrrhotite in the tourmaline "chert" but will be pyrite in the chloritized portion of the same bed a few inches away. The chlorite is an iron rich variety with anomalous brownish and berlin blue interference colors.

Sericitic alteration produced a light grey colored rock that has a bleached appearance in comparison to the darker grey of normal silty argillites, and the green of the chloritized rocks. Strong alteration produced in places muscovite crystals much larger in size than the tiny sericite flakes. Associated with the muscovite in about equal amount is a chlorite mineral, characterized by a light greyish color with no pleochroism, and low birefringence with no anomalous coloring. An x ray powder photograph of the mineral showed a pattern closest to chlorite variety aphrosiderite

$Mg\ 1.0 \quad Fe^{2+}\ 3.2 \quad Fe^{3+}\ 0.4 \quad (Al\ 1.5 \quad Si\ 2.5)\ O10\ (OH)\ 8$

A.S.T.M 12-243

A series of 5 specimens were chosen to represent (1) tourmaline chert; (2) chert with minor development of orthoclase; (3) mild alteration; (4) chloritic alteration (5) strong sericitic alteration. The specimens were prepared for analysis by x-ray fluorescence and flame photometer method. The specimens were pulverized. Sulphide minerals were leached out by the chlorine methanol method described in Appendix B. The results of the analysis are presented in Fig. & Table .

The most notable changes accompanying increased alteration appears to be a decrease in silica accompanied by increased iron, magnesium, potassium and manganese. Titanium is constant but sodium shows a slight decrease. There is a markedly higher potassium content in the sericitized rocks than in the chloritic rocks and about half as much iron. The lower iron to magnesium ratio is probably because of a less iron rich variety of chlorite in the sericitic rock. Boron content has not yet been determined for these samples. A specimen of chloritized breccia fragment taken from a keel structure show micro-breccias of chlorite flakes into which sphalerite, pyrrhotite and quartz have been introduced. (see Plates XX & XXI) Tourmaline crystals are found in this chloritized rock which are much larger than usual (possibly recrystalized). Many of these have broken. Chlorite fills the cracks in some, sulphides in others (see Plates XXII & XXIII).

The evidence, both macroscopic and microscopic shows that a number of metasomatic minerals have formed after tourmalinization of the footwall rocks. Orthoclase, and muscovite have formed where potassium has been introduced. Chlorite has formed where iron, magnesium and water have been available, and albitization attests the local availability of sodium. Introduction of these materials into the tourmalinized rocks has ~~involved~~ followed rebreaking the breccias more or less severely. Minor amounts of igneous material, the feldspar dikes, have been found intruded into the breccia. Keel structures have formed where movement has been concentrated along linear zones, with resulting vertical displacements of forty or fifty feet. The relationships of sulphide minerals and quartz to chlorite and micas, indicates that the former pair were mobile after the latter had formed and had been bent and broken. The sulphide minerals were also mobile after the igneous dikes had been intruded. The nature of mobility in the sulphide zone will be discussed in the following chapter.

CHAPTER IV

Definition of sulphide zones

The term as used here refers principally to the various ore bands of the Sullivan ore body but includes mineralized zones that would be excluded by the term ore. It should be clearly understood that the term sulphide zone refers to their present composition and does not imply that they were necessarily sulphide zones in the same sense at the time they were mobile. Descriptions are phrased in terms of the mobility of sulphide minerals but with the idea in the background that the sulphides need not have existed at that time in their present mineral form.

1. Mobility of sulphide zones

Contrasting competence between ore bands and the surrounding silicate rocks is displayed in many relationships and on a variety of scales. Some of these have been mentioned previously in discussing brecciation of the footwall rocks.

Plates XXVI & XXVII show argillite beds near the hangingwall of the main band of ore which have fractured whilst the sulphides and thinner argillite bands have deformed plastically. Plate XVIII and Fig. show how displacement of hanging wall beds of the HU ore zone on small fractures has been accommodated by flow in the ore band. The faults do not cut through the ore zone. On a microscopic scale, (Plates XXIV & XXVI) sulphides show continuity around broken ends of chlorite flakes. Plastic flow seems a less likely explanation for mobility of sulphides in the microbreccias than in the macroscopic cases. The closely associated unbrecciated quartz which has penetrated the microbreccia to the same extent as the sulphides most likely was mobile in solution.

Regarding the state of the ore zone and the sulphides during the mobile period this opinion has been expressed (C.M.&S. staff pp148)

> Folding on a large or small scale is quite common, and apparently continued during and after the period of mineralization because in places, the sulphides follow tiny tensional fractures developed on minor anticlines while elsewhere they show slickensides produced by slipping between beds during folding."

One example of sulphides penetrating tensional cracks is found in the HU ore zone (see Fig.) where an argillite parting in the ore broke, and was thrust upward through the ore zone. Sulphides in the tension cracks were examined carefully and were found to change, in character from the fine grained pyrrhotite sphalerite mixture of the ore zone at the open end, to moderately coarse crystalline sphalerite and galena further in the crack then gradually becoming quartz carbonate veinlets with sparse sulphide minerals into the tail of the fracture. Clearly the filling is not simply a plastic flow of ore into the fractures.

Further to this point we should note that the sulphides have not always behaved plastically under stress, as is shown by some of the younger faults of the Sullivan type which have sheared through the ore zone and in which broken ore fragments have been found below the sulphide foot wall.

Diorite and other igneous dikes that are found broken up in ore zones, provide examples of sulphide mobility. Other than the dislocated fragments, there is no record within the sulphides themselves of where movement took place. There is no shearing and no obvious flow lineation. Fig. shows fragmentation of a diorite dike in the west central part of the main ore zone. Fig. just below it shows the fragmentation of the minette dike described by Leech (Leech and Wanless 1963 p251) and referred to previously on p. . Note the minor thrust faulting, with movement in the same sense as that shown by the dike displacement, found in a laminated zone above the D sulphide band. The laminations carry disseminated sulphide minerals. The planes of thrusting would be imperceptible were it not for the presence of the displaced laminations. Similar tightly healed, practically imperceptible fractures are fairly common in the argillaceous rocks in other locations.

A feature often observed in connection with ore which surrounds displaced fragments, or penetrates cracks in them, is that there is a segregation of minerals into bands paralleling the contacts. Thus the fragment of altered feld-spar dike shown in Fig. & Plate XIX has a concentration of galena around it's broken end, and the sulphide veinlets penetrating the quartz vein shown in Fig. & Plate XXX are banded with galena and sphalerite. Note also that mineralized conglomerate has flowed toward the crack in the quartz, and that mineralized sediments have flowed around the fragments of quartz vein Fig. & Plate XXIX.

It seems clear that the property of "flowing" was not confined entirely to sulphide bands but was also present where the ore zone consists of disseminated mineralization in silicate meta-sediments. Furthermore, whatever was the means of transportation of the sulphide minerals it was often capable of depositing them in banded concentrations.

In summary, the sulphide zones show many evidences of having been highly mobile compared to the silicate beds but it is doubtful that the mobility was due to properties of the sulphide minerals as they now exist.

2. Breccia in the ore zone

Breccia in the ore zone is most clearly apparent in certain fringe area stopes. A good deal of the ore in these locations is heavily disseminated rather than massive. In part it is made up of slightly mineralized fragments in a well mineralized matrix. Cut off grade may occur where fragments become very numerous.

Some of the ore zone breccias are simply waste bands pulled apart, in places as a result of folding. These can be readily reconstructed mentally. In other places compl dislocation and rotation of fragments occur. Frequently the fringe breccias are confined stratigraphically between fairly continuous hangingwall and footwall bands. One such occurrence is illustrated in W-7-30 stope (see Fig.).

Here a continuous sulphide band below the "I" marker bed, overlies a mineralized breccia zone, which in turn overlies the footwall conglomerate. A sill like quartz vein has been fragmented in the breccia zone and is now surrounded by mineralized breccia. Sulphides penetrate fractures in the quartz. In the same stope, brecciated sediments are found in a quartz matrix. Clearly, repeated brecciation has occurred, before and after the introduction of quartz.

Towards the central area of the mine, brecciation in the ore zone may be indicated by remnants of various types and sizes of silicate rocks. Some fragments of argillite or chloritized argillite bands near the hangingwall are likely pieces of the regular waste partings, possibly still in place. Other fragments are obviously displaced. Fragments of tourmalinized footwall rocks, including footwall conglomerate have been found well up in the ore.

Plate XXXII shows fragments of argillite (light brown) in massive pyrrhotite of the main ore zone as seen on an oxidized wall of 39109 Drift. Some of the fragments enclosed in massive sulphides remain as heavily mineralized ghostly remnants. Strong development of muscovite is noted in some. Garnets, (variety spessartine-pyrope) are fairly common, and actinolite and talc have been noted in places. A tendency for fragments to be rimmed by sphalerite and galena segregations has been mentioned before. The fragments in the ore zone have tended to react with the sulphides. Higher grades of metamorphism within the ore zone indicate it was hotter than the surrounding rocks.

3. Hanging wall breccia

Hanging wall breccia is most noticeable in the albitized rocks, particularly where white albitized fragments are found in green chloritized matrix. Most of the evidence of this breccia has been seen in diamond drill core, and is found to have a broad distribution in the albitized hanging wall rocks.

Direct observation of hanging wall rocks is limited by relative scarcity of development headings above the ore. However mining of hanging wall ore has exposed considerable areas particularly in the HU ore band. Normally this band is quite continuous and conformable, but it has been involved in brecciated hangingwall structures. Two of these structures are illustrated in Figs. 9 & 10.

Characteristically the hanging wall structures have a steeply dipping, to overturned east limb. West of this is an upward projection of ore, and immediately west of the ore an area of brecciation may be apparent. Beyond the brecciated area more or less normal hangingwall strata with low dips are found.

The hangingwall structures trend roughly parallel to the footwall keels, and in close association with them as shown in Fig. 8 . There is not however a direct coupling between them. In fact, the 4800 Departure structures (see fig. 10) are in opposition so that the hangingwall comes down where the footwall comes up, producing an attenuation of the ore zone, just east of where hanging wall and footwall diverge due to the keel, and hangingwall roll.

In one area this opposition of hangingwall and footwall structure produced an attenuated ore zone only three feet thick, some forty feet east of a portion thickened to 250 feet.

Figure shows mapping of the wall of a sub-level drift which was driven into an area of hangingwall breccia. The rocks here have not been albitized. A good deal of sulphide mineralization has occurred and shows as dark brown oxidized streaks and patches (see Plates XXXIII & XXXIV.) The breccia has entirely consolidated, and it will be noted that the fragmented nature of the rock is rather obscure where pieces are not outlined by sulphide minerals.

Mineralized chlorite breccia formed a portion of the ore mined in the hanging wall stopes shown in Fig. 9 . Large fragments of banded sulphides, apparently torn from a once continuous band, are surrounded by chlorite breccia. The matrix of the breccia contains disseminated pyrrhotite, sphalerite and galena sufficient to make ore. Above the ore is brecciated albitite with a chloritic matrix, similar to the specimens shown in Plate XXXV.

Hanging wall beds have translated towards the centre of the mine from the north, west and south. The evidence for this is found in the displacement of the hanging wall portions of igneous dikes. Fig. 16 shows the location of several of these dikes in the footwall of the orebody. The arrows show the direction of the component of displacement perpendicular to the strike of the dikes. The displacements are clear for dikes 3, 4 & 5, but due to the irregular nature of diorite dikes 1 & 2, their displacements are not as certain.

Diorite dikes have been found in surface exposures some 300 feet above the hangingwall which indicates that at least this thickness of rocks was involved in the translational movements. Furthermore, albitite extends about the same distance above the ore body and must also represent a minimum amount of rock present when brecciation took place.

<u>Summary</u>

It is not known whether the brecciation that affected the footwall ever penetrated through the ore horizon into the hangingwall directly. At least part of the brecciation of the ore zone has been stratigraphically confined and due to lateral movements. The sulphide zone shows evidence of having been mobile with an ability to flow when silicate rocks were breaking.

Formation of keel structures may have initiated slumping of ore zone material toward them, resulting in thinning of portions of the ore zone and synclinal buckling of the hangingwall. Hangingwall rocks gliding on the lubricated ore zone may then have pushed the west limbs of the synclines eastward and upward with final rupture and brecciation. Such structures would be somewhat analogous to the roof and wall structures formed by gravity tectonics, (Harrison J.V. & Falcon N.L. 1936) modified by diapyric intrusion of the slumping mobile sulfide zone into the fold crest.

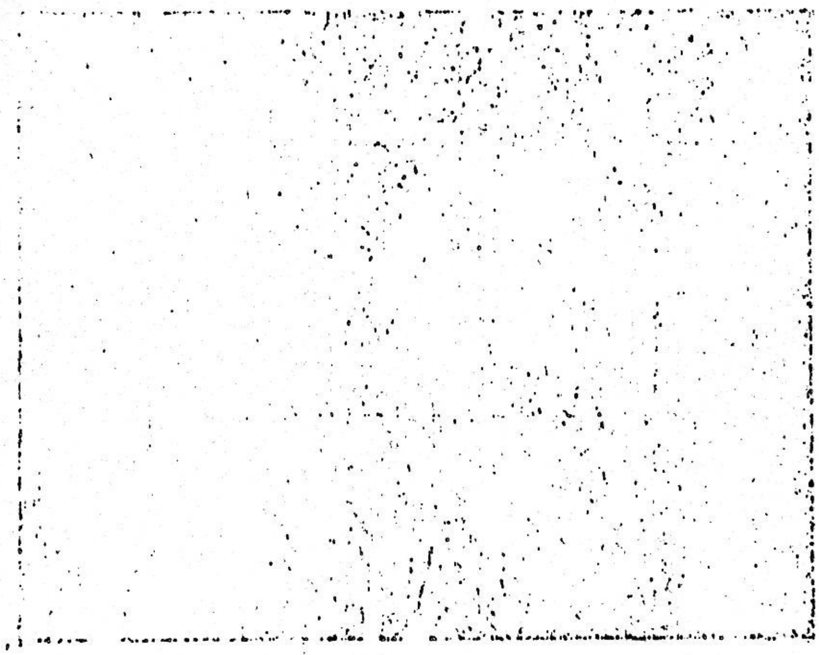


PLATE XXII

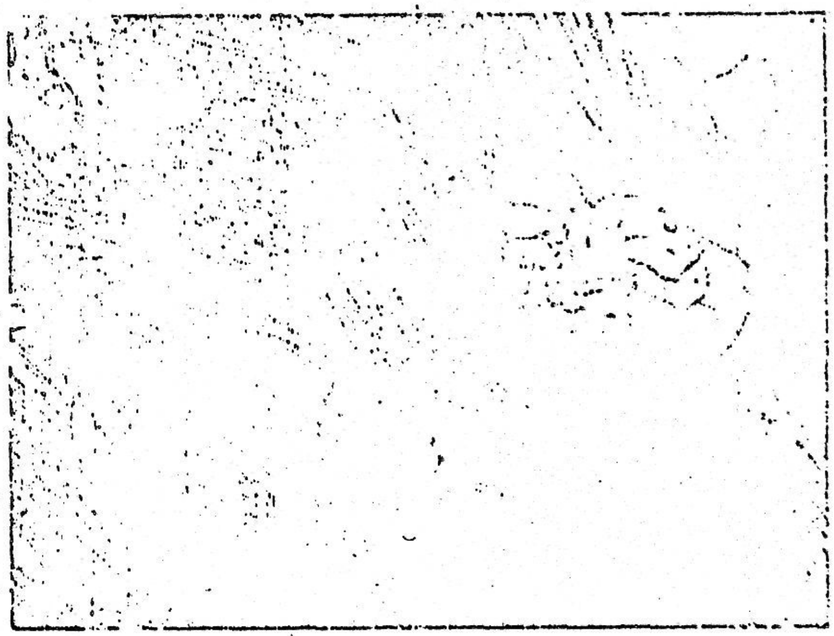
Sph[illegible], Pyr[illegible] and quartz in chloritized Argillite from kool breccia

J - 940 - 64 38 X

plane light

PLATE XXIII

Enlarged portion of photo above note brecciation of chlorite and filling of cracks with sulphide and quartz.



J - 940 - 64 95 X

X nicols

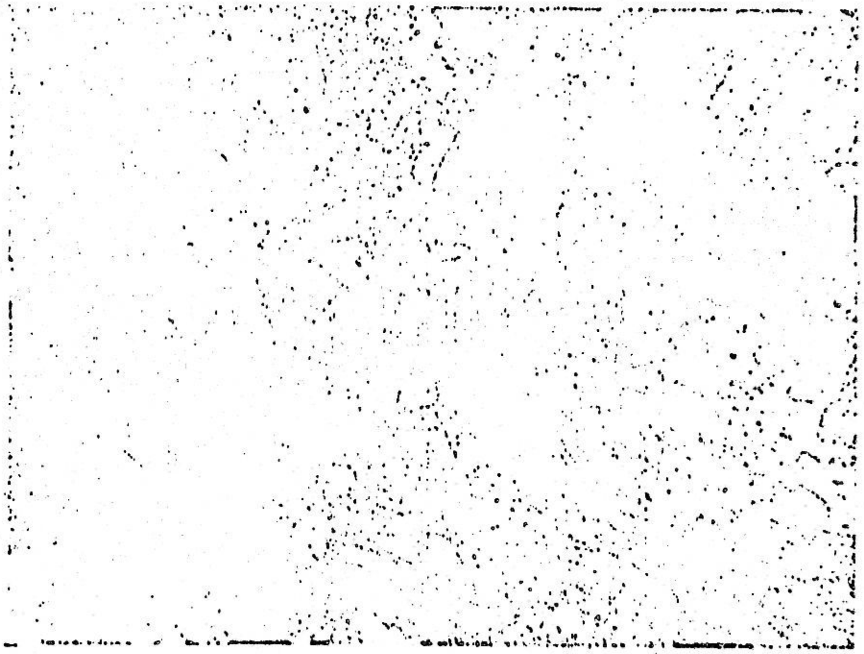


PLATE XXIV

Tourmaline chlorite, quartz and sulphides Note sulphide minerals in fractured tourmaline

JU - 939 - 64 76 X

PLATE XXV

Fractured tourmaline crystal chlorite fills fracture

J - 939 - 64 320 X

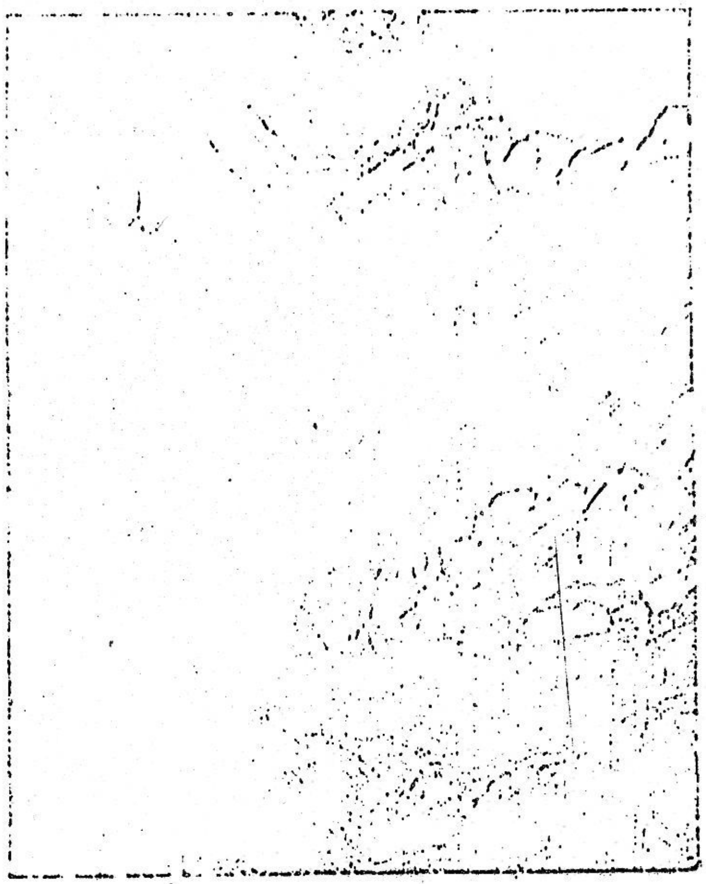


PLATE XXVI

to show mobility in sulphide bands.

Note that movement which fractured thicker argillite bands is taken up by crumpling in sulphide bands

PLATE XXVII

PLATE XVIII

Movement on small fault in hangingwall has been adjusted to by plastic flow in ore band.

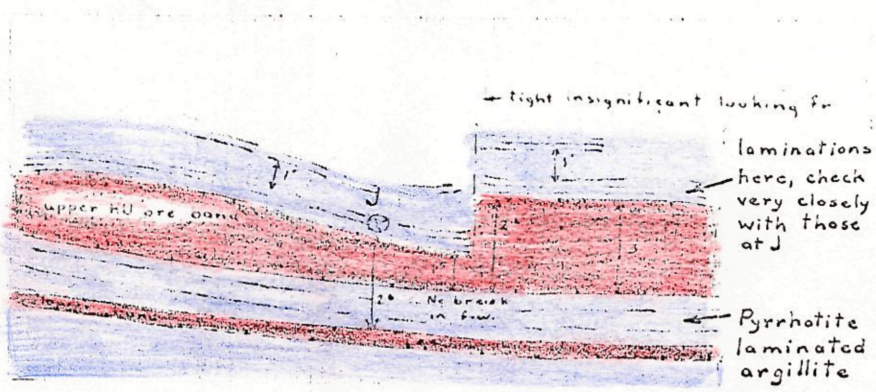


FIGURE 14

A similar occurrence mapped at a different location.

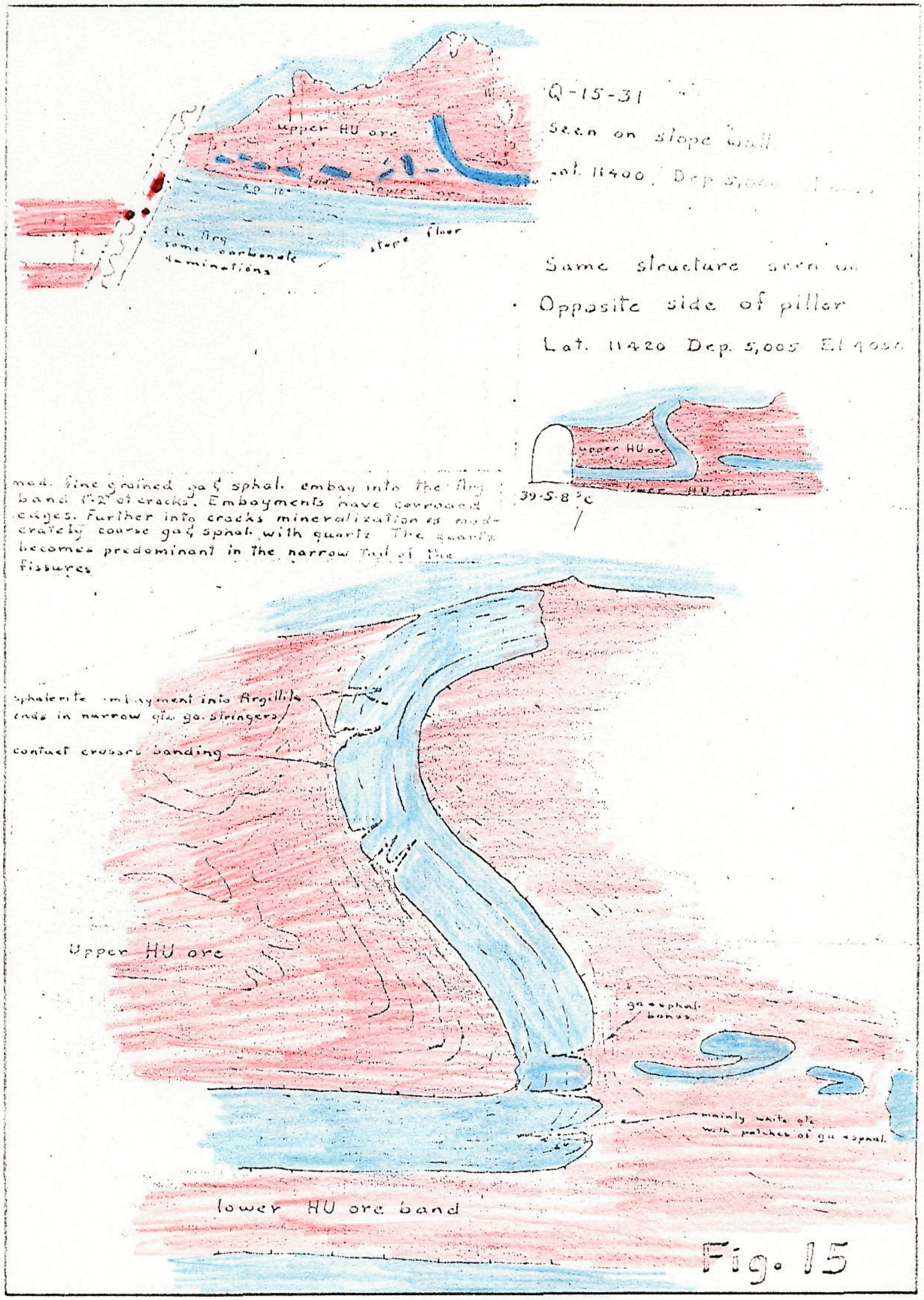


Fig. 15

Mapping of broken argillite parting in HU ore zone. Note tension fractures

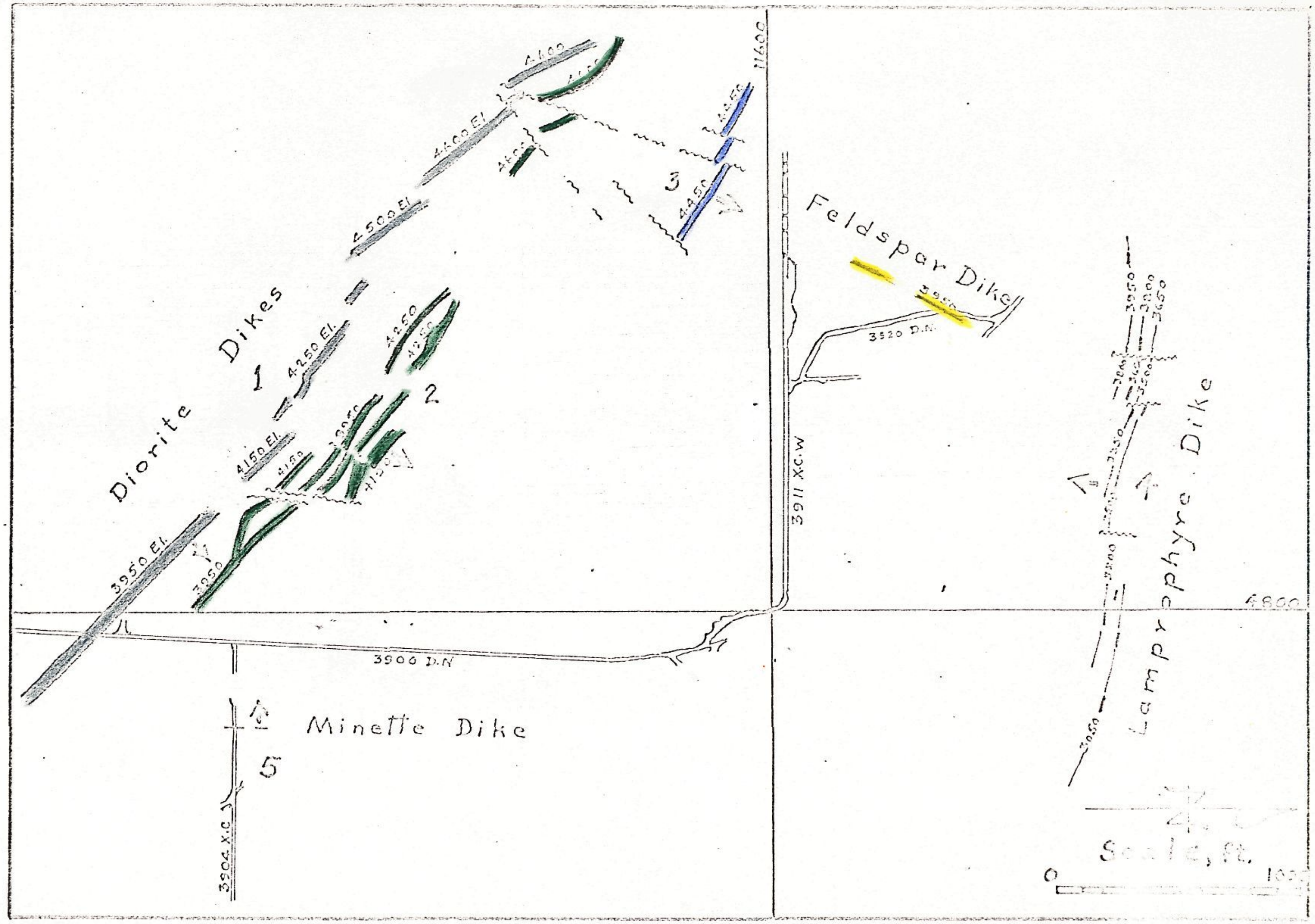
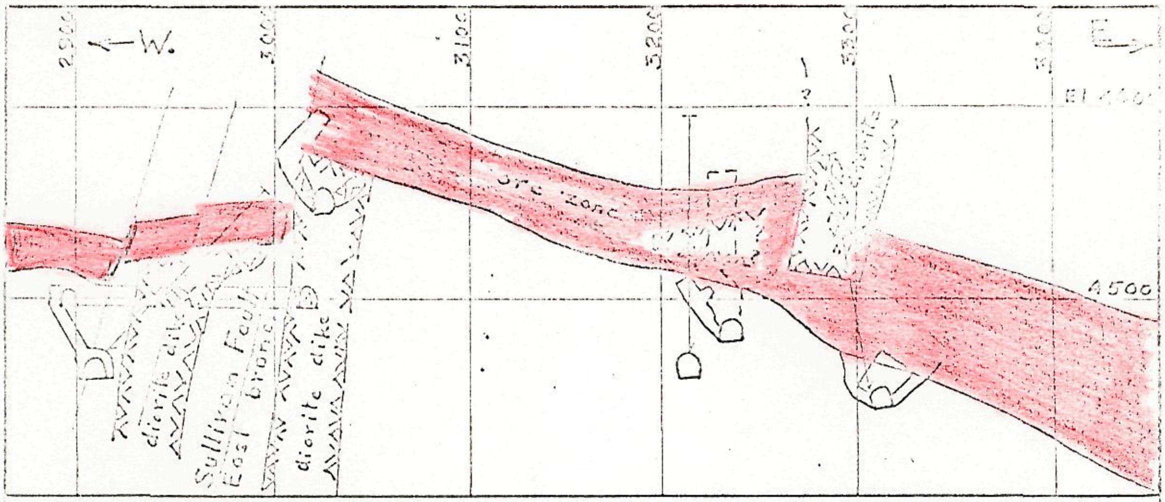


Fig. 16

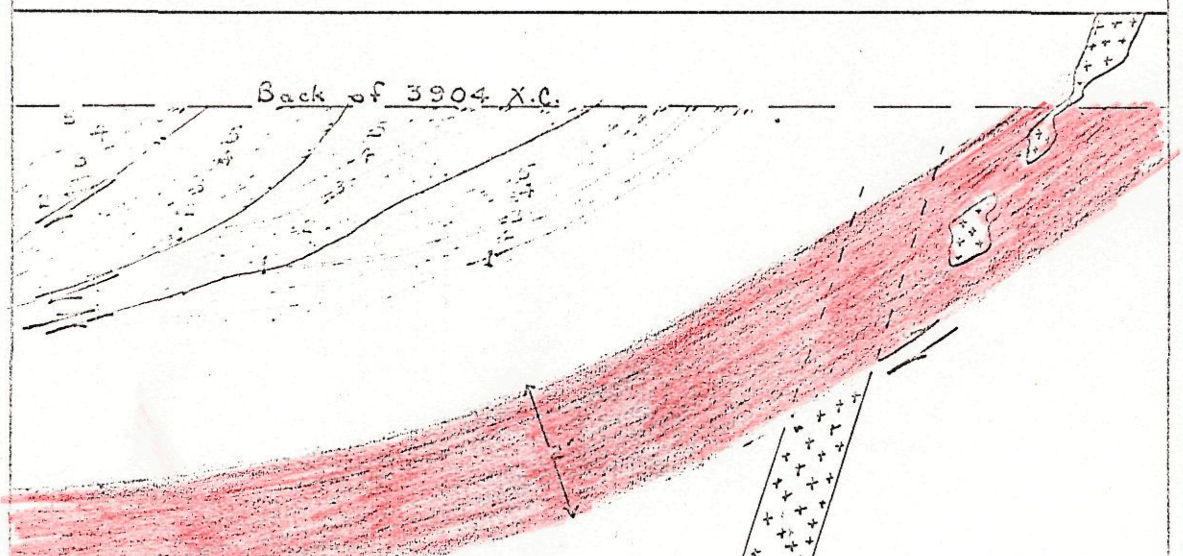
Dikes in the footwall of the Sullivan Orebody Fig. 16

Arrows show direction of displacement of dikes in the orebody and hangingwall



Sketch of a portion of geology from section on Latitude 11400 (X) North, showing diorite displaced in ore zone

Fig. 17



Sketch to show displacement of minette dike in an ore band, and overthrusting of laminated bands showing the same direction of displacement. 3904 X.C.
after drawing by S. B. Hamilton

Fig. 18

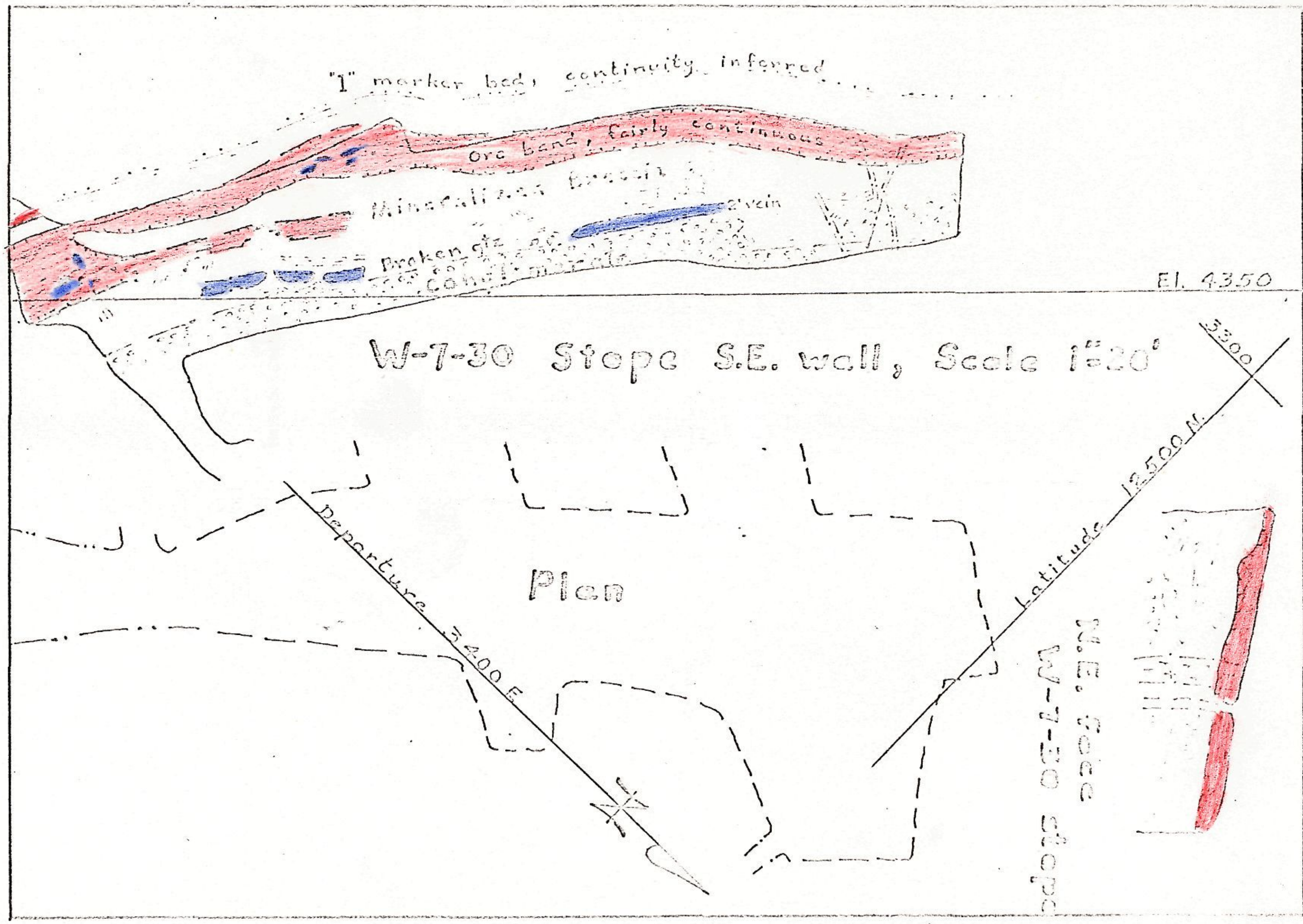


Fig. 13

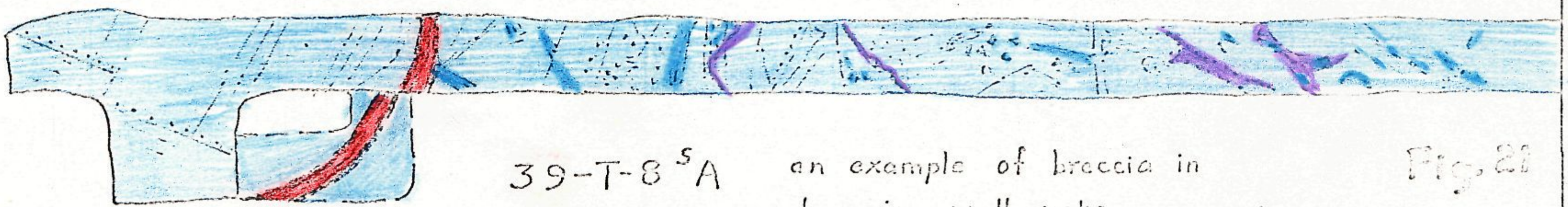
Ore Zone Breccia, Fringe Area, Stratigraphically controlled

PLATE XXXI

Mineralized breccia, Fringe ore W-7-30 stope.
Note - quartz forms matrix of part of the breccia

PLATE XXXII

Fragments of argillite in oxidized massive sulphides of the main ore zone



39-T-8 ^{s}A an example of breccia in hanging wall rocks

Fig. 21

Plates
XXIII and XXIV

oxidized breccia
in the hangingwall
39-T-18 ^{s}A

Plate
XXV

Albitite breccia,
specimens from
the hangingwall

Fig. 21

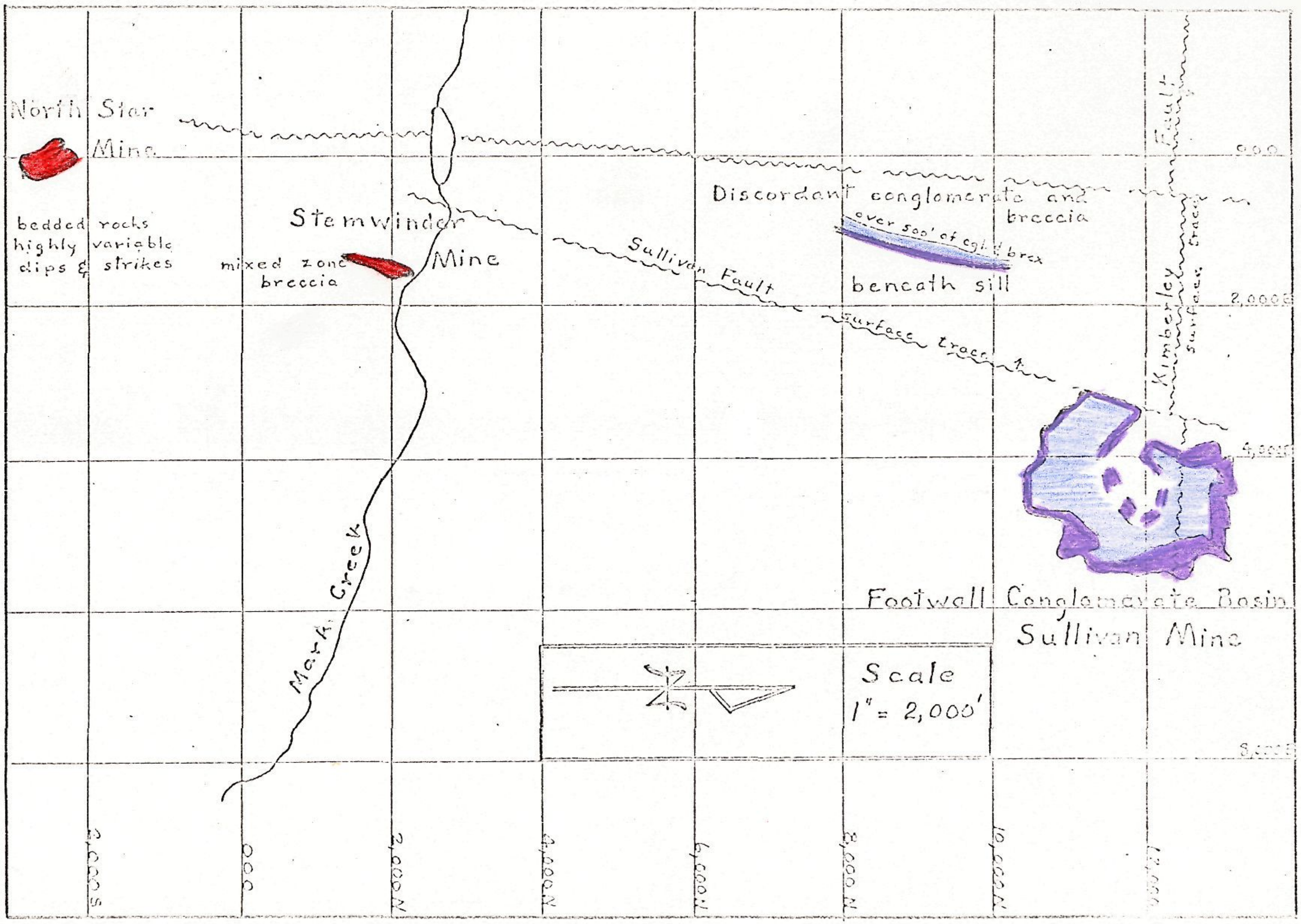


Fig. 22

Conglomerate and breccia zones and ore bodi
in the vicinity of the Sullivan Mine

Fig. 22

CHAPTER V

Discussion of the origin of the breccias

The conglomerate basin was formed during the latter part of Lower Aldridge time. It seems to have been steep walled, roughly circular and floored with large blocks of thin bedded rocks similar to those forming the walls.

The problem of the conglomerate basin resolves primarily into two questions.

(1) was the conglomerate basin excavated from above

or

(2) was it excavated from below

Four processes that have been considered capable of excavating the basin from the top are

1. (a) erosion, either sub aerial or submarine

1. (b) slumping and gravity gliding

1. (c) cryptovolcanic explosion

1. (d) meteor impact

Two have been considered capable of removal of material from below. These are

2. (a) solution caverning

2. (b) magmatic stoping

Considering these possible origins in turn the following criteria seem applicable.

1. (a) (i) Fluted waterworn surfaces are not observed at the conglomerate contacts.

(ii) Thin bedded blocks at the base are breccia fragments and not erosional remnants or stacks because they have been rotated.

(iii) The breccia has considerable vertical extent and is not merely a veneer on a solid rock base.

These criteria indicate that the conglomerate basin was not an erosional feature.

1. (b) Preconsolidation slumping and gliding are believed to be capable of producing steep walled depressions in both unconsolidated and consolidated sediments. They are essentially lateral movements, and would not be expected to form a pipelike breccia column. Breccias produced by gravity gliding are described by R.A. Baldry (1938) as thick zones along low angle slip planes at 7° to 10° to bedding, and extending for as much as several miles.

Kindle and Whittington (1958) describe intraformational breccia formed by penecontemporaneous slumping and sedimentation. Hugh blocks and boulders of shallow water sediments slid out over deep water sediments, at several different times. The resulting breccias attained thicknesses up to 200 feet thick, but extend parallel to the strata.

1. (c) & (d) Cryptovolcanic explosions or cryptoexplosions are described by Bucher (1935) as natural ex-

plosive structures related to maars and diatremes. They are attempted but abortive beginning of volcanism in a region. The structure is produced by explosion of gases under high pressure and without extrusion of any magmatic material. A cryptovolcanic explosion if shallow and strong is said to blow out an explosion basin filled with jumbled rocks and surrounded by a ring of debris. If deep-seated weak and muffled it produces a dome.

Dietz 1959 summarizes some of the features of "Cryptoexplosion Structures" as follows:-

(1) Circular outlines with radial or somewhat bilateral symmetry.

(2) A central dome shaped uplift with intense structural derangement, surrounded by a ring syncline and in some cases by other ring shaped uplifts and depressions of rapidly diminishing amplitude.

(3) Complex high angle and mostly normal faulting but with minor folding.

(4) Sheared, brecciated, powdered rock and sometimes shatter cones in the central uplift.

(5) A variation in diameter from less than one to greater than six miles. Dietz does not think that these structures are necessarily cryptovolcanic explosions, but favours meteoric impact as an alternative.

The Sullivan structure resembles the cryptoexplosion structures in some points, the outline is more or less circular, and there is a domical structure, tilted on the flank of the Purcell geanticline. The dome is not clearly related to the breccia column, but is closely associated in space.

However three aspects of the typical cryptoexplosion structure are missing.

(1) there is no known ring of debris. (This could have been eroded away during deposition of conglomerate.)

(2) severe crushing, shearing and powdering of rocks are not in evidence (see also Schrock & Malloth 1933).

(3) Complex high angle faulting is not a particularly notable feature.

Furthermore, both cryptovolcanic and meteorite explosions are single calastrophic events which would offer no explanation for subsequent brecciation.

2. (a) Proceeding now to consideration of the second alternative of excavation from below, we come to 2 (a) solution caverning. We find immediately a serious objection in that no soluble beds have been found in the Lower Aldridge. The nearest limy beds are found in the Upper Fort Steel formation under some 4,500 feet of Lower Aldridge. Creation of the conglomerate basin by collapse of the roof of a cavern does not seem probable.

(b) There has been considerable attention in recent literature to the formation of breccia pipes and pebble columns by a process of magmatic stoping. This process is thought to act in the following manner. Magma under pressure in a magma chamber, begins to invade it's cover rocks along lines of weakness, possibly the intersection of two faults. Pressures in the magma will vary, and at each point of advance there will be surges of pressure followed by relaxation. With each surge of pressure fracturing occurs, and with relaxation the fractured rock falls back. A column of breccia builds up in advance of the invading magma. Brecciation at the advance end of the column may consist merely of fractured rock, and gradually downward becomes more comminuted, rotated and mixed. Good reviews of Breccia and Pebble Columns and Mineralized Breccia Pipes are given by Leonid Bryner (1961) and Vincent D. Perry (1961).

Perry states that "repeated magma advances at various points, and resultant slumpage in the chimneys would eventually extend the breccias to or near the surface". He further suggests that collapse to surface would likely occur during a period of withdrawal of magma.

Leech (G.S.C. Paper 64-1 p30) reports diatreme breccia columns occurring in the Rocky Mountains. He has this to say (Leech personal communication)

> At the highest levels the rock is fractured but not displaced. At a lower level the rock is brecciated with some rotation of fragments, then brecciated and containing "foreign" but local sedimentary fragments, with an

> increase in the proportions of matrix and a range of fragment shapes from angular to partially rounded by abrasion. An important point is that over a considerable vertical range the fragmental rock looks like a cross between a tectonic breccia and an unsorted or poorly-sorted conglomerate, whose fragments correlate with the local stratigraphic succession. At still lower levels the conglomeratic aspect increases because matrix (silt, sand and pebbles) increases, more fragments are sub-rounded or subangular and because rounded pebbles or cobbles of igneous or metamorphic rocks appear. The latter are rounded by abrasion in their passage through the pulsating column of brecciated rock.

and elsewhere

> going deeper the igneous components increase and also dykes may appear. The point is that a great depth of breccia has no igneous material.

This process appears to be one capable of producing the conglomerate basin during withdrawal of magma from beneath a breccia column which had approached sufficiently close to the surface to permit collapse. It is also a recurrent process which can be called on as a cause for later periods of brecciation. Following the classification proposed by Bryner (1961 p491) the pre conglomerate breccia would be of the pre hydrothermal type.

Subsequent to the formation of the basin, it was filled with conglomerate. The pebbles originated from Aldridge type sediments similar to those forming the walls of the basin, but clearly if the basin existed as a hole in the rocks, it could not at the same time provide the material to fill the hole. The pebbles then, were derived from fairly well consolidated rocks outside of the depression but at no great distance. Other fragmental rocks were being formed at about the same time, and are now found in local accumulations at or near the Lower-Middle Aldridge contact at various places in the district.

The preconglomerate breccia blocks seem to have been fairly well consolidated, judging from rectilinear outlines and lack of folding in most of those observed. If the deduction is correct that the surface layers were relatively hard, and were suffering erosion in places, then the Lower-Middle Aldridge contact may mark a surface of relative uplift, lack of deposition and local erosion.

If in addition the preconglomerate basin is assumed to have formed by magmatic action, there is an implication that the generation of magma had begun while the area was still receiving sediments. Perhaps this indicates that the igneous activity of the island arc system began long before the formation of prominent islands. Conceivably igneous intrusion beneath the deltaic wedge had blocked subsidence of the area during the latter part of lower Aldridge time causing a period of non deposition. Relief of pressure in the magma chamber indicated by subsidence in the breccia pipe may have been of regional significance in promoting the subsidence interpreted from Upper Aldridge sedimentation.

A period of quiescence is probably indicated during the time of deposition of the mine series sediments, but downward adjustments may have made a concavity in the hanging wall of the conglomerate. This could account for the forty feet or so of sediments between the ore zone and the central part of the conglomerate, that are absent around the edges.

Post Conglomerate Breccia

Post conglomerate brecciation in the footwall is essentially a vertical disturbance. Conglomerate fragments have migrated downward in the chaotically mixed breccia. No great shearing stresses are indicated. Quartz grains in the matrix have not been crushed. Torn and twisted blocks and fragments suggest failure in tension rather than compression. The breccia matrix may have been rheomorphic in the sense used by Goodspeed G.E. (1953). It is certainly very pervasive through the breccia, and in places there are rather large volumes of matrix with only a scattering of small fragments.

One visualizes the brecciation process grinding up the rocks, especially friable sandstones, into a slurry which would have a mobility much greater than the whole mass, and yet would tend to float large blocks, and facilitate the mixing process. Some of the narrower sharp walled breccia zones that are observed, (particularly towards the south end of the mine) may be true rheomorphic breccia dikes.

Where post conglomerate brecciation cuts pre conglomerate breccia, it is practically impossible to distinguish one from the other. This poses the question "why postulate two stages of brecciation?" Perhaps one post conglomerate period of brecciation could have produced the irregular base of the conglomerate. The most convincing evidence that some of the breccia precedes the conglomerate is that the top of the conglomerate is undisturbed over some of the largest irregularities of the base, yet is disturbed and disrupted in areas of second brecciation.

Post conglomerate breccia outlines tend to be elongated rather than circular, extending across the boundary of the preconglomerate basin. This might be due to their having been formed by different processes, but is more likely due to a renewal of intrusive activity. A different shape of breccia column could be expected due to changed conditions. The pre conglomerate breccia is thought to be due to collapse to surface of relatively well indurated rocks, whereas the later brecciation involved buried but still relatively soft rocks.

The upward extent of this brecciation cannot be determined. The footwall breccias are now separated from those in the hanging wall by the ore zone. If a straight through breccia zone existed it is now effectively disguised, which is what one would expect due to dispersal of fragments by ore zone mobility, and their destruction by replacement. However it seems equally possible that the ore zone was not penetrated, but absorbed brecciation movements in the same manner that the smaller ore bands, absorbed fracturing and displacement of their wall rocks.

Relationship of igneous rocks to breccia

Igneous rocks are not found as definite fragments in the breccia except where the various dikes are found broken in the ore. It is known that some of the minor dikes were intruded into brecciated tourmaline chert and are therefore later than tourmalinization. Scott (1954) presented evidence that the hornfels alteration adjacent to the diorite sills preceded tourmalinization. One lamprophyre dike (#4 in Fig.16) is known to have cut the diorite sill. It is younger than the diorite but older than some of the movements in the sulphide zone.

Igneous activity associated with a renewed period of brecciation is indicated. Just as there were periodic repetitions of brecciation, so there were successive intervals of intrusion.

Diorite dikes which are apophyses from the sill are found in outcrop some 300 feet above the ore zone. If Scott's conclusions are correct, we may assume that the ore zone plus an unknown thickness of sedimentary cover (exceeding 300 ft.) was in place before tourmalinization and the succeeding brecciations, and metasomatic events.

A peculiarity of the feldspar dike is that it exhibits very irregular contacts in the footwall breccia, but where found well up in the ore zone it is narrow and straight sided. This is taken to indicate interupted development of vertical brecciation in the ore zone. However there are too few observations of dikes in the ore zone to allow any general conclusions regarding the nature of the wall rocks.

Brecciation in the sulphide zone appears to have had a different character from that in the footwall. Whereas the footwall brecciation involved mostly vertical movement, the ore zone breccias indicate lateral movement. It is postulated here that the ore zone had plastic characteristics compared to the relatively brittle footwall and hangingwall rocks. The reasons for the plasticity are not known, but they seem clearly to be related to the presence of the sulphides. Without entering into the current controversy on syngenetic versus hydrothermal origin; there seem to be possible explanations from either viewpoint

(1) The syngenetic protore was in a plastic colloidal state prior to crystallization, able to attain stability with it's cover due to it's high density, or

(2) The sulphide zone consisted largely of clays that became thixatropic due to the introduction of hydrothermal solutions during the process of mineralization.

The presence of some footwall breccia blocks in the sulphide zone might possibly be attributed to floating of the blocks into a plastic sulphide zone of high specific gravity, but the development of higher grade metamorphic minerals in the sulphide zone and evidence of reaction between fragments and ore, suggest that the zone was hot and chemically active.

Regardless of the composition of the sulphide zone, it is thought to have slumped towards the keel structures, initiating sliding of the hangingwall beds, and resulting in the formation of the hangingwall structures with their attendant brecciation. Sulphides then permeated certain portions of the brecciated hangingwall.

It is not thought that the ore zone and hangingwall breccias happened in one catestrophic event. On the contrary there is the evidence that quartz was introduced after one period of brecciation and prior to another. In the hangingwall, albitite is occasionally found surrounding argillaceous fragments as well albitized fragments being found in a chloritized matrix.

The post conglomerate brecciations with their associated alterations fit rather nicely into Bryner's classification of cohydro-thermal type. This indicates a change in the nature of the magma during the quiescent period following the development of the conglomerate basin. Conceivable during this time, hydrothermal solutions had separated from the magma, and had accumulated in cupolas such as is envisaged at the base of the breccia column.

The literature concerning breccia pipes shows that they commonly occur in groups related to a common structure or set of structures. There is evidence that this holds true for the Sullivan breccia.

A short distance to the south west of the orebody drill holes encountered a thick conglomerate breccia body below the arch in the complex diorite sill. This body is apparently sharply discordant with the enclosing bedded sediments. It does not have associated tourmalinization, chloritization and albitization and is therefore of the pre hydrothermal type.

South of the mine about one mile in the Mark Creek gorge is the Stem Winder sulphide body. This steeply dipping lens is discordant, stratigraphically lower than the Sullivan ore zone in a synclinal structure. The mineralogy of the sulphides is very similar to that of the Sullivan ore. Conglomerate and breccia have been mapped in the wall rocks which have largely been converted to tourmaline "chert". At least one inclusion of conglomerate in the sulphide body is shown in the mapping. This occurrence overlies the diorite sill but the lowest point so far explored approaches close to the sill. (Consolidated Mining and Smelting staff report, private file). Surface mapping about the Stem Winder and to the south, towards the North Star Mine, records a mixed zone consisting of thin bedded rocks, conglomerate, and massive sandy rocks in a disorderly mixture. "Chert" is found in this rock as irregular stringers. The descriptions of the rock strongly suggest that here is another cohydrothermal breccia, extending into close association with the conformable North Star orebody. Fig. shows the relationship between the three orebodies. Their North South alignment strongly suggests a common structural control, and by inference a structure controlling the location of breccia formation.

IN SUMMARY

Brecciation of large volumes of rock has occurred, below, within and above the Sullivan ore body. Two main stages of brecciation are recognized.

(1) Preconglomerate - prehydrothermal

(2) Postconglomerate - cohydrothermal

Collapse to surface above a breccia column formed by magmatic action is considered to be the most satisfactory of several explanations considered for the preconglomerate breccia and conglomerate basin.

Post conglomerate brecciation was not a single catastrophic event, but occurred at intervals punctuated by

(1) diorite intrusion

(2) boron metasomatism

(3) introduction of quartz

(4) potassium and sodium metasomatism

(5) chloritization

(6) introduction of sulphide minerals

(7) intrusion of minor igneous dikes

The order of events is in general as shown above, but overlapping, repetition, and interaction of processes is believed to have occurred.

Conglomerate pebbles, and fragment in the pre conglomerate breccia were derived from fairly well consolidated lower Aldridge sediments which were probably indurated to the extent of being sandstones and mudstones.

Other fragmental rocks are found at approximately the same stratigraphic horizon. A thick discordant conglomerate - breccia body has been drilled below the diorite complex a short distance west and south of the footwall conglomerate body (see Fig.). The discordant Stem Winder ore body which is mineralogically similar to the Sullivan, occupies a brecciated zone about one mile south. It is stratigraphically lower than the Sullivan, but still above the diorite complex.

Rocks described as the mixed zone are mapped between the Stem Winder and the conformable North Star ore body. The mineralogy of the North Star deposit is very similar to that of the Sullivan.

Lead isotope ratios in the three deposits are very similar. So are those of other deposits in the Aldridge. Age of the Sullivan leads deduced from the lead isotope ratios is 1,250 million years. (Leech and Wanless 1963 pp266).

Brecciation below the ore zone was mainly by verical movement, that in the ore zone was at least partly due to lateral movements. The plastic nature of the sulphide zone may have blocked the vertical development of brecciation and is thought to have allowed slumping of the sulphide zone and sliding of hangingwall beds.

Collapse to surface forming the conglomerate basin is conceived of as happening when magmatic support was withdrawn from beneath a breccia column that had approached surface. A period of subsidence and renewed sedimentation in relatively deep water followed during Middle and Upper Aldridge time. The second or postconglomerate stage of brecciation began apparently while the new sediments were still quite soft to judge from twisted and torn fragments.

The preconglomerate breccia preceded metasomatism and therefore fits Bryner's class of pre hydrothermal breccia. The post conglomerate breccia is closely associated with metasomatic events and igneous intrusion fitting Bryner's class of co hydrothermal breccia. It seems reasonable to assume that brecciation, hydrothermal activity, diorite dikes and minor igneous dikes originated from a common parent magma. Concentration of hydrothermal fluids, during the quiescent period, in the cupola that is envisaged at the base of the breccia column is to be expected according to classical theory.

SPECULATION ON RELATION OF BRECCIA TO TECTONIC SETTING

Seeking a plausible correlation of the breccia phenomena with their tectonic setting would seem to be in keeping with current emphases in economic geology. The following thoughts are in many cases nearer to being queries than statements.

During Purcell time the area under consideration was part of the continental shelf receiving sediments from the distant eastern craton. Evidence of orogenic uplift and formation of islands is found following the extrusion of basaltic Moyie lavas at the end of Lower Purcell time.

It has been suggested previously in this paper that in late lower Aldridge time there was a pause in sedimentation during which the surface layers became fairly well consolidated. Igneous intrusion into the wedge of clastic material is believed to have approached surface at this time, producing breccia columns. Uplift was sufficient to allow local erosion of pebbles for the scattered deposits of conglomerate.

Withdrawal of magma from the magma chamber allowed the breccia column associated with the Sullivan to cave to surface. There followed a period of subsidence and renewed sedimentation that formed the Upper Aldridge series.

Igneous activity was resumed with the intrusion of diorite and brecciation of the still relatively soft rocks. Hydrothermal solutions that had been collecting in the cupolas of the magma chamber during the period of igneous quiescence, were introduced into the brecciated rocks during the cohydrothermal breccia phase.

Subsidence of the area slowed so that by Creston time shallow water features were again being formed in the sediments.

Intrusion of diorite from the parent magma chamber is conceived of as an intermittent welling up of magma into the downwarping Purcell sediments along an incipient island arc, finally culminating in a breakthrough to surface with the extrusion of Moyie lavas. (See also Leech and Lowdon 1963 p254).

Hills 1963 (p372) suggests that "sills require magmatic pressure sufficient to lift the overburden, and hence that they are more appropriate to shallow crustal depths". This would suggest that any given period of intrusion there would be one general depth at which the magma would form sills. A repetition of sills at various stratigraphic levels such as is found in the Purcell, may well have been due to successive intrusions. If so, the stratigraphically higher sills should be progressively younger. They might also show progressive shift in remanent magnetism.

Hunt (1962) presents potassium argon dates that indicate Purcell plutonism extended over a period from approximately 1,580 million to 1,000 million years ago, an interval equal to the whole of Phanerozoic time. Acid igneous intrusives in the St. Mary Lake - Kimberley area give ages between 700-800 million years. The minette dike, broken by movement in the ore zone is dated at not less than 765 million years.

The area in which Purcell diorites are found is co-extensive with the exposure of Purcell sediments, indicating extensive proportions of the parent magma. This body could well be co-extensive with the silver lead zinc metalogenetic province in the Aldridge age rocks, that extends from Couer D'Alene to Kimberley. If this magma was indeed an early feature of the formation of an island arc system, it might well be an invasion of the crust by mantle material (see Wilson J.T. in Jacobs, Russell and Wilson 1959 pp298 and 299). This would be in accord with the theory that the leads acquired their isotopic composition in an environment with lower U^{238}/Pb^{204} ratios than are found in the crust.

Let it be said again that the foregoing discussion of tectonic relationships is speculation, perhaps not entirely idle.

Much more information is needed. The following are areas of study that could yield desirable knowledge.

(1) closer dating of individual diorite sills, and information regarding their roots and method of emplacement.

(2) Dating of the potassium metasomatism to determine the age of cohyrothermal brecciation.

(3) Thorough study of the occurrences of conglomerate and fragmental rocks of the Aldridge to assess their origin.

(4) Determining criteria for distinguishing pre Cambrian structures. Of particular interest would be structural control of brecciation.

Respectfully submitted.

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