STRUCTURAL AND STRATIGRAPHIC SETTING OF THE MING AND OTHER SULPHIDE DEPOSITS IN THE RAMBLER AREA, NFLD.

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by

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ABSTRACT

The lithologies present in the Rambler Area are described, a sequence of lithofacies units is defined, and a simplistic model to explain the evolution of the rocks in the area is proposed. As a generalisation the rocks dip towards the northeast and become younger in that direction. The base of the sequence consists of basic (Komatiitic) lavas, and this is overlain by basic pyroclastic volcanic rocks. Towards the end of the basic pyroclastic stage a centre of acid volcanism developed, and the sulphide deposits can be related to exhalite activity during the waning stages of acid volcanism. The termination of basic pyroclastic volcanism was followed by deposition of a sequence of basic volcanogenic sediment and/or waterlain tuff, and extrusion of local pillow lava units. Abundant basic intrusions may be contemporaneous with the build-up of the volcanic pile. The volcanic sequence was intruded by the Burlington Granodiorite on the west, and Cape Brule Porphyry on the east.

All the rocks in the area have been subjected to polyphase deformation and to metamorphism in the upper greenschist facies. The first two deformations involved intense strain with $1 < K < \infty$, and large fold structures were recognised relating to the second and third deformation episodes. The shape and orientation of the sulphide deposits have been modified during deformation; and the ore deposits are elongate parallel to F_2 and F_3 fold axes, and to the Z axis of

the deformation ellipsoid.

The Ming ore body is a Cu, Au, Ag bearing sulphide deposit, and occurs at the top of the acid volcanic rock unit in the area. The settings of the other deposits in the area are also considered and it is concluded that the sulphide deposits are akin to Archean or Kuroko type deposits.

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CHAPTER I

INTRODUCTION

1.1 Location and Access

The thesis area consists of the mining property of Consolidated Rambler Mines Ltd (henceforth described as the Rambler Area), located approximately six miles east of Baie Verte, Newfoundland, (Fig. 1). The centre of the area lies at 49°54' latitude, and 56°05' longitude. Access is from the La Scie Road which runs from Route 414 two miles south of Baie Verte eastwards to La Scie.

Access within the property is provided by service roads to the mines, and by trails to drill sites and prospects. Lines have been cut over much of the area, and all sectors of the property are within one mile of the service roads.

1.2 Physiography and Outcrop

The central part of the Rambler Area is relatively flat lying averaging 150 metres in elevation; the northern part is characterised by low lying hills and valleys, while the southern part of the area is bounded to the south by a large ridge which rises to 250 metres in elevation. Forty percent of the area is covered by ponds and bog, the rest is heavily forested, mainly by spruce.

A cover of glacial drift averaging 2 metres in thickness occurs over the entire area and outcrop under natural conditions is less than 0.5%, reaching 5% locally on the high ground to the south. Development

and exploration on the property has resulted in a considerable amount of overburden stripping and trenching in several areas. Road and power line construction within the property has provided several sections with up to 5% outcrop. Rock exposures are generally small, and the more resistant rock types are favoured.

1.3 Tectonic Setting

The Island of Newfoundland forms the north-eastern margin of the exposed Appalachian structural province. Williams (1964) and Williams et al. (1970) recognize three major Lower Paleozoic tectonic belts in Newfoundland (Fig. 1), these are the Western Platform (Kay, 1967), the Central Mobile Belt, and the Avalon Platform (Kay and Colbert, 1965). The Central Mobile Belt consists predominantly of Eocambrian and Lower Paleozoic variably deformed and metamorphosed volcanic and sedimentary sequences, locally underlain by gneissic basement, and is flanked on both sides by less deformed Lower Paleozoic platformal sequences which lie on Precambrian "basement" rocks. The basement to the Western Platform consists of the Long Range Complex and its equivalents (Grenvillian), while the basement to the Paleozoic platformal sequences in the Avalon Platform consists of mildly deformed Precambrian metavolcanic and metasedimentary rocks, no crystalline basement has been recognized on the Avalon Platform. The Canadian Appalachians were further subdivided on the basis of Late Precambrian to Lower Ordovician depositional and structural histories into nine tectonostratigraphic zones (Williams et al., 1972). Fig. 1 shows the distribution and local names of the

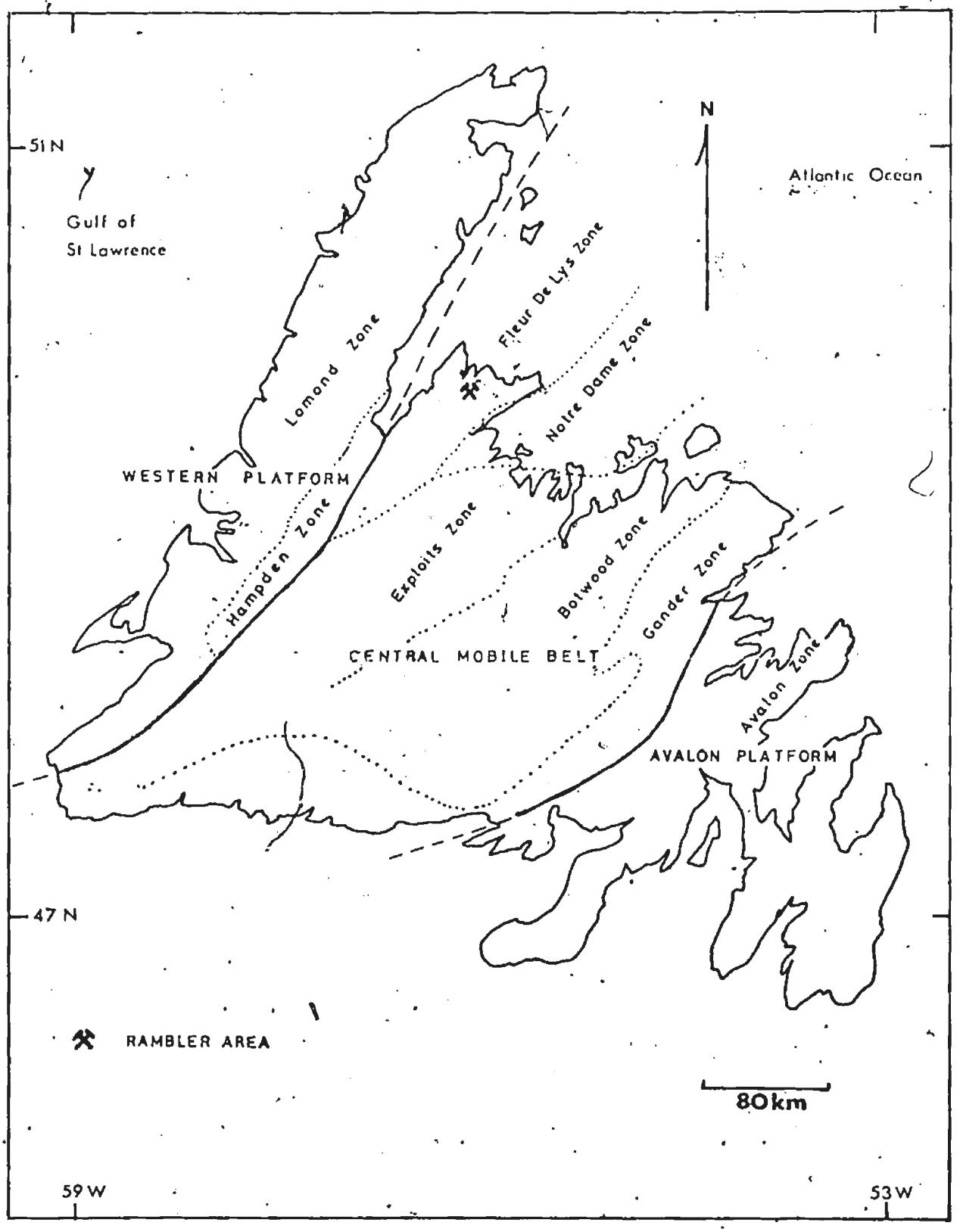


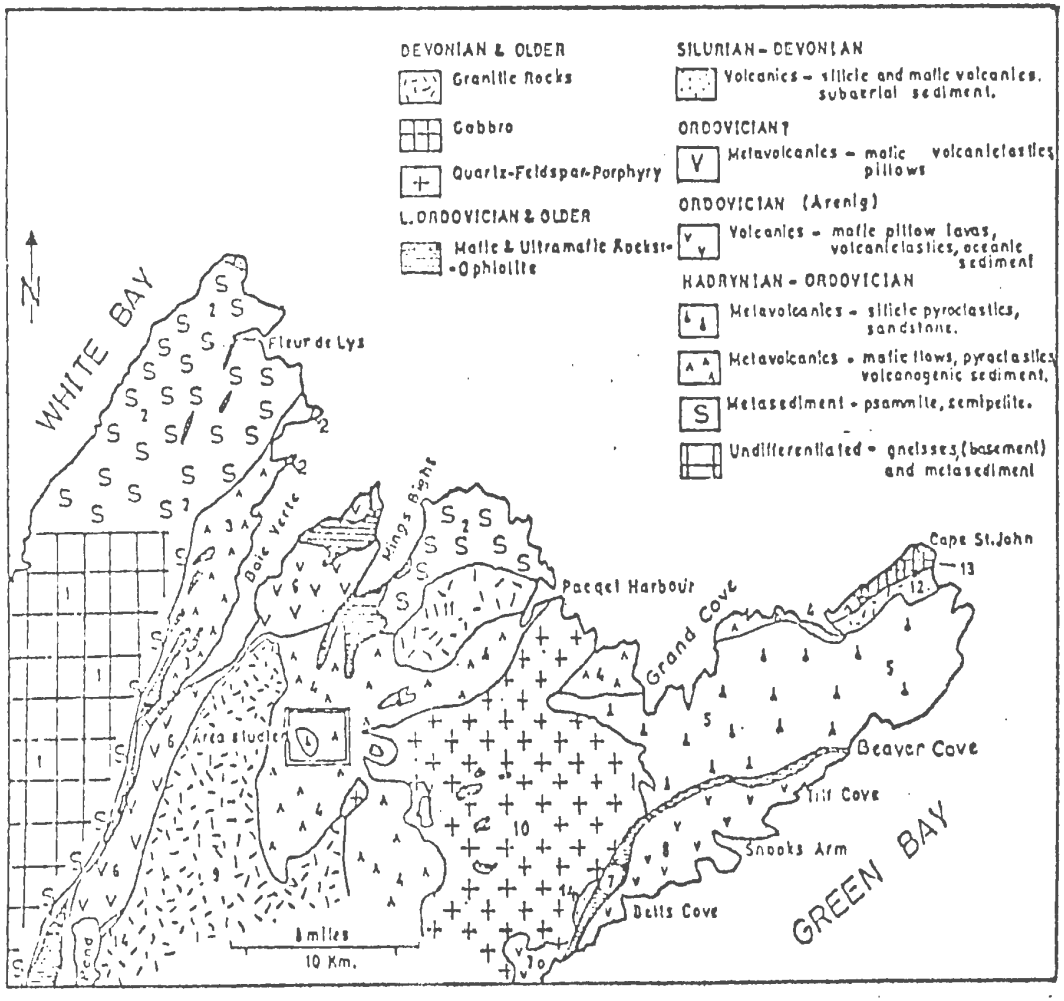
FIG. 1 Map of Newfoundland showing the location of Consolidated Rambler Mines, the major subdivisions of the Appalachian Belt, and tectonostratigraphic zones after Williams et al. (1974)

zones for the Newfoundland Appalachians, (Williams et al., 1974). The present study area lies in the Fleur de Lys Zone (Fig. 1) which is characterised by complexly deformed metasedimentary and metavolcanic rocks of probable late Precambrian to Cambro-Ordovician age on the western margin of the Central Mobile Belt.

1.4 General Geology of the Burlington Peninsula

The distribution of the major rock units in the Burlington Peninsula is shown in Fig. 2. With the exception of the Snooks Arm Group (Arenig), age control from fossils is not available. The contrasting techniques of using lithological and structural correlation as tools in dating the various rock units by different workers has led to considerable controversy with regard to age and geological interpretation. Table 1 summarises the historical development of stratigraphic interpretation in the area and indicates the opinions of current workers. Detailed descriptions of previous work are given by Kennedy (1971) and DeGrace et al., 1975b).

The Fleur de Lys Supergroup was defined by Church (1969) as being characterised by pre-Lower Ordovician polydeformed and polymetamorphosed rocks. These rocks overlie a previously deformed Grenville basement in the west (M.J. DeWit, 1974). The Fleur de Lys Supergroup is divided into eastern and western outcrop by a narrow belt of less deformed metavolcanic and associated mafic and ultramafic rocks called the Baie Verte Group (Baird, 1951). The Burlington Granodiorite and the Cape Brulé Porphyry and the Reddits Cove gabbro are considered by Kennedy et al,



14. Mic Mac Group and the Rouge Harbour Formation.

13. Reddits Cove Gabbro.
12. La Scie Granite and the Seal Island Bight Sequence.
11. Dunmagon Granite.
10. Cape Brule Porphyry.
9. Burlington Granodiorite.

8. Snooks Arm Group.

7. Betts Cove Ophiolite; 7(a) Nippers Harbour Group.
6. Baie Verte Group.

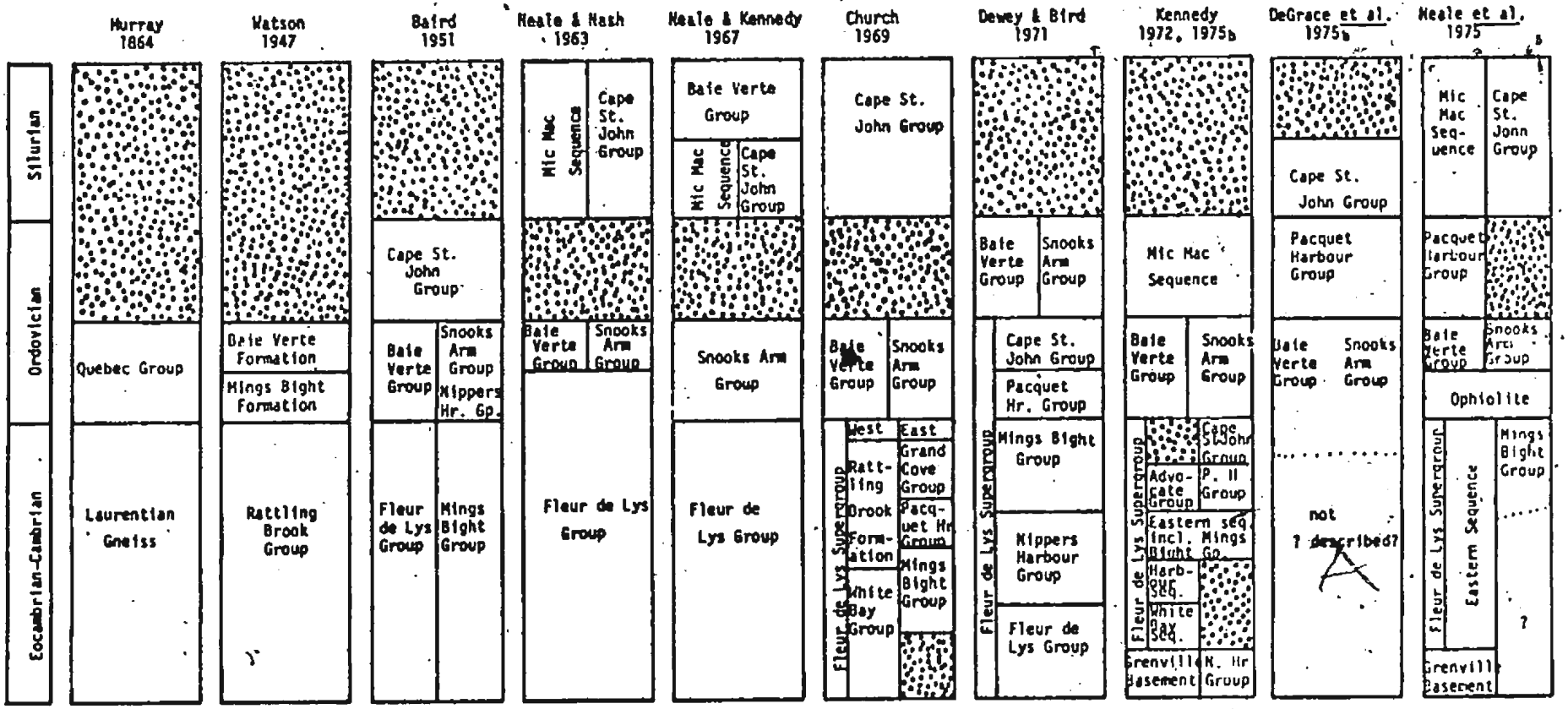
5. Cape St. John Group.
4. Pacquet Harbour Group.
3. Advocate Group, Birchy Schist and other formations of the Eastern Sequence.
2. White Bay Sequence, Harbour Sequence, Mings Bight Group.

1. Undifferentiated - rocks comprised of Grenvillian gneissic basement and Fleur-de-Lys Supergroup metasediments.

NB Units 2 to 5 are termed the Fleur de Lys Supergroup.

Figure 2. Generalised geology of the Burlington Peninsula, Newfoundland, modified after Kennedy, 1975b.

Table 1. Summary of stratigraphic interpretations of the Burlington Peninsula (modified from Norman & Strong, 1975).



(1972), and Kennedy (1975b) to intrude the rocks of the Eastern Sequence and be deformed along with them. Upper greenschist to lower amphibolite facies metamorphism prevailed over much of the area, and large scale folding has been recognized in the Fleur de Lys Supergroup (Kennedy, 1971, 1975b; Kennedy et al., 1972; DeGrace et al., 1975b). Stratigraphic relationships between the component groups of the Fleur de Lys Supergroup are generally obscured by tectonic slides, faults, and intrusions; in the eastern outcrop the contact between the Pacquet Harbour Group and the Ming's Bight Group and the contact between the Pacquet Harbour Group and the Cape St. John Group are stratigraphic and intercalary in nature.

Church (1969), Kennedy (1971, 1975b), and Kennedy et al., (1972) suggest that deformation and metamorphism of the Fleur de Lys Supergroup occurred prior to or during the Lowest Ordovician and that deposition took place in Eocambrian to Cambrian times. This interpretation was based on the presence of polydeformed, metamorphosed fragments found in the Snooks Arm Group (Church, 1969), and in the Baie Verte Group (Kidd, 1974). DeGrace et al., (1975 a,b) and Neale et al., (1975) maintain that the Cape St. John Group unconformably overlies rocks equivalent to the Snooks Arm Group at Beaver Cove and suggest that the Cape St. John Group is Silurian, and that the Pacquet Harbour Group, which underlies or is in part laterally equivalent to the Cape St. John Group is Ordovician in age.

The Cape St. John Group was divided into two Groups (Church, 1969) on the basis of an assumed structural and depositional unconformity;

these subdivisions defined a pre-Lower Ordovician Grand Cove Group, and a Siluro-Devonian Cape St. John Group. This unconformity has not been found and there is a gradual transition from deformed rocks in the north to undeformed rocks in the south (DeGrace et al., 1975b). Kennedy (1975b) acknowledged that the rocks overlying the Snooks Arm Group at Beaver Cove may be Silurian in age and therefore implied that the unconformity assumed by Church remains to be discovered. The controversey concerning the age of the rocks of the Fleur de Lys Supergroup, remains to be settled. DeGrace et al., 1975b have questioned the validity of the concept of Fleur de Lys Supergroup (Church, 1969) and maintain that there is a significant difference in the structural development of the eastern and western portions of the Fleur de Lys Supergroup.

The Baie Verte Group (Norman, 1973; Kidd, 1974; Norman & Strong, 1975), the Snooks Arm Group (Upadhyay et al., 1971), and the Nippers Harbour Group (Schroeter, 1971) are all interpreted to represent Lower Ordovician, disrupted ophiolite sequences.

The Mic Mac sequence in the west (Neale and Kennedy, 1969) unconformably overlies the Burlington Granodiorite and the Baie Verte Group (Kidd, 1974). The Rouge Harbour Formation in the east (Schroeter, 1971) unconformably overlies the Nippers Harbour Group. Both the Rouge Harbour and the Mic Mac rocks are considered to be Siluro-Devonian in age.

Neale et al., (1975) and DeGrace et al., (1975b) define the Cape Brulé Porphyry as being Silurian in age. DeGrace et al., (1975b) interpret the Burlington Granodiorite to be Silurian in age. The Dunamagon Granite is considered by Neale (1958b) to be Devonian in age. The Burtons

Pond Granite porphyry intrudes the Rouge Harbour Formation (Schroeter, 1971), and is thought to be Devonian in age, and the Reddits Cove Gabbro, the La Scie Granite and the Seal Island Bight Syenite are considered by DeGrace et al, to be Carboniferous(?).

Low grade regional metamorphism affected Ordovician and Siluro-Devonian rocks, and is attributed to the Acadian Orogeny. Late stage upright folding in the Fleur de Lys Supergroup may also be related to the Acadian Orogeny.

It is noted that the unconformable contact between the Mic Mac Group and the Burlington Granodiorite represents not only an erosional episode but also indicates that structures of the Fleur de Lys which deform the granodiorite, predate deposition of the Mic Mac Group; the Burlington Granodiorite intrudes the Pacquet Harbour Group. If the Mic Mac Group is Silurian in age, it implies that some of the deformation affecting parts of the eastern outcrop of the Fleur de Lys Supergroup is pre-Acadian in age. The presence of fragments of Fleur de Lys schist in the Baie Verte Group also indicates the presence of Ordovician or earlier deformation.

1.5 Recent megatectonic interpretations

In recent years the rocks in the Burlington Peninsula have featured in the development and application of some major tectonic concepts.

Church (1965a, b; 1966; 1969), Phillips et al. (1967); Kennedy (1968, 1975a) and Kennedy et al. (1972) suggested that the similarities in

the structure and stratigraphy between the Burlington Peninsula and north west Ireland provide geological evidence in support of continental drift, viz. the geologically recent opening of the present Atlantic Ocean.

Plate-tectonic models for the development of the Newfoundland Appalachians have been proposed by Wilson (1966), Dewey (1969), Stevens (1970), Bird and Dewey (1970), Church and Stevens (1971), Dewey and Bird (1971), Church (1972), Kennedy (1973, 1975b), Strong et al. (1974) and Kean and Strong (1975). It is generally agreed that the metasediments of the Fleur de Lys Supergroup represent an easterly derived clastic wedge of Eocambrian to Cambrian age deposited on continental crust at the western margin of a Proto-Atlantic ocean, and that the Mic Mac sequence represents continental deposition during or after closure of the Proto-Atlantic Ocean; the tectonic settings of the other major rock groups in the Burlington Peninsula have been variously interpreted by different authors. Early attempts to apply and develop the theory of plate tectonics in the Burlington Peninsula by Dewey (1969), and by Dewey and Bird (1970) suffer from major stratigraphic inconsistencies; at present, four main tectonic interpretations can be considered.

Church and Stevens (1971) suggested that the Baie Verte Group and the Betts Cove ultramafic belt are ophiolite, and that these rock groups along with the ophiolite klippe on the Western Platform form remnants of a single sheet of oceanic crust obducted over the Fleur de Lys Supergroup across a S-E dipping subduction zone in the early Ordovician. They suggest that the clastic sediments, and the basalt-rhyolite volcanic

rocks (the Pacquet Harbour Group and the Cape St. John Group) were deposited in a fault bounded basin underlain by sialic crust, and that plutonism, deformation, and metamorphism occurred in the Late Cambrian prior to ophiolite obduction.

Dewey and Bird (1971) have suggested an alternative model; in Late Cambrian-Early Ordovician times the Pacquet Harbour Group and the Cape St. John Group were formed as "island arc" deposits on top of oceanic crust adjacent to the continental margin clastic wedge above a N-W dipping subduction zone; plutonic emplacement, metamorphism, and deformation relate to temperature increase above the subduction zone. They suggest that extension of the previously deformed Fleur de Lys Supergroup occurred in the Lowest Ordovician, that the ophiolite klippe on the Western Platform were formed in a marginal ocean basin, and that the Baie Verte Group and Snooks Arm Group were formed in intra-arc basins. Contraction of the marginal basin occurred in the Middle Ordovician with emplacement of the klippe onto the Western Platform, and structural emplacement of the Baie Verte Group and the Snooks Arm Group took place during continental collision in Mid-Devonian times.

Kennedy and Phillips (1971) assigned mafic and ultramafic rocks on the west side of Baie Verte Peninsula (previously mapped as Baie Verte Group) to the Fleur de Lys Supergroup on the basis of structure and metamorphism. Kennedy (1973, 1975b) named these rocks the Advocate Sequence and suggested that these and other polydeformed ultramafic rocks in the Peninsula are ophiolitic in character, and represent remnants of a marginal ocean basin which opened within the continental

rise sedimentary prism above a westerly dipping subduction zone. Deposition of the Pacquet Harbour Group and Cape St. John Group with subsequent intrusion took place above the subduction zone, partly overlapping the eastern section of the continental rise prism (the Mings Bight Group). He suggests that divergent obduction of ophiolite from the marginal ocean basin in the Late-Cambrian to Early-Ordovician (the Burlingtonian Orogeny) resulted in deformation to produce divergent structural facing directions, and metamorphism of the whole of the Fleur de Lys Supergroup. He suggests that the Baie Verte Group and the Snooks Arm Group may have formed in the main ocean basin to the east and have been thrust into their present position during later (post Lower-Ordovician) obduction and preserved in the cores of Acadian synforms, or alternatively they may represent smaller ocean basins opened by a process of oblique spreading.

Recently Kennedy (1973, 1975b) has suggested that the repeated movement during ophiolite obduction has caused the series of coaxial tight recumbent folds observed in the Burlington Peninsula, furthermore he maintains that the facing directions of the isoclinal folds can be analysed to indicate the direction of ophiolite movement during obduction.

DeGrace et al. (1975b) have provided a fourth model; on the basis of their structural, geochemical, and age determinations, they suggest that the Cape St. John Group formed during the late stages of calc-alkaline volcanism and early rifting related to the late stages of development of an Ordovician Island Arc which is represented by rocks in central Newfoundland, and which developed over an eastward dipping subduction zone (Kean and Strong, 1975).

In addition to these four models, Hutchison (1973) suggested that the Rambler Area developed in the early stages of formation of an island arc at the onset of subduction, and Gale (1973), analysed the rocks in the Rambler Area, found them to be komatiitic and tholeiitic in composition, and suggested that they formed at a site of oceanic spreading.

1.6 Previous Work

Geological investigation of the Burlington Peninsula was started in 1864 by Alexander Murray. In 1873 he published the first geological map of Newfoundland on which he showed the Burlington Peninsula to be underlain by Laurentian gneisses. A report by Murray and Howley (1881) made general reference to the Mings Bight - Baie Verte area.

Since these early days, published contributions to the geology of the Burlington Peninsula have been made by Murray and Howley (1918), Snelgrove (1931, 1935), Watson (1947), Baird (1951), Neale (1957 1958a, b; 1959), Neale and Nash (1963), Church (1966, 1969), Neale and Kennedy (1967), Kennedy (1971), Dewey and Bird (1971), Upadhyay et al. (1971), Kennedy and Phillips (1971), Kennedy et al (1972), Gale (1973), DeWitt (1974), DeGrace et al. (1975a, b), Norman and Strong (1975) and Neale et al. (1975). In addition papers by Dewey (1969), Bird and Dewey (1970), Stevens (1970), Dewey and Bird (1971), Church and Stevens (1971), and Kennedy (1973, 1975b) have dealt with plate tectonic models for the Burlington Peninsula and for Newfoundland in general.

M.Sc. theses on aspects of the geology of the Burlington Peninsula have recently been completed by Coates (1970), Schroeter (1971),

Riccio (1972, and Norman (1973); Ph.D. theses have been completed by Gale (1971), Dewit (1972), Upadhyay (1973) and Kidd (1974).

Direct contributions have been made to the geology of the Rambler Area by Livingston (1942), Quinn (1945), Watson (1947), Baragar (1954), De Jeoffrey (1961), Cockburn (1970), and in particular by Gale (1971, 1973) and Heenan (1973).

Table 1 shows a summary of stratigraphic interpretations made by various authors over the years; the evolution of the presently accepted nomenclature will not be discussed in this thesis.

1.7 History of Mining

In 1903 sulphide mineralisation was found along the banks of Rambler Brook by Enos England. In 1905 a 20 metre shaft was sunk by Naylor & Co. of New York, low metal values were encountered and work was stopped; the deposit is known as the South Pyrite Zone.

In 1936, Enos England and his son William discovered gold, copper, zinc mineralisation approximately 200 metres north of the South Pyrite Zone. This deposit was known as the Rambler vein. Between 1938 and 1941 the Geological Survey of Newfoundland examined the property and carried out 1650 metres of diamond drilling in 18 holes.

In 1944, Rambler Mines Ltd. was formed and the company increased the known size of the deposit by trenching and drilling. In 1945 Siscoe Gold Mines optioned the property and carried out 3,500 metres of

drilling in 31 holes. In 1951 Rambridge Mines Ltd. was formed when the property was optioned by Falconbridge Nickel Mines Ltd. and 4,700 metres of drilling in 14 holes increased the known size of the deposit, however the property was allowed to become dormant.

The Underdeveloped Minerals Act was invoked by the Newfoundland government in 1960, and the property was leased to M.J. Boylen Engineering Ltd.; Consolidated Rambler Mines Ltd. was formed and brought the "Rambler Vein" into production as the Rambler Mine (also known as the Main Mine or the Main Zone). In 1967 the Rambler Mine was closed after production of 440,000 tons of ore with average grades of 1.3% Cu, 2.16% Zn, 0.15 oz./ton Au and 0.85 oz./ton Ag.

Between 1961 and 1964 Consolidated Rambler Mines Ltd. carried out exploratory drilling on the Norris Showing located approximately 1.6 kilometers N-W of the Rambler Mine, an ore body was outlined and brought into production as the East Mine in 1967. Ore reserves were exhausted in December 1974, and the mine was abandoned after recovery of approximately 2,000,000 tons of ore grading 2% Cu.

A geochemical soil survey in 1968 led to the discovery of the Big Rambler Pond Mine located about 1.6 kilometers S-W of the Rambler Mine on the shores of Big Rambler Pond. About 50,000 tons of ore grading 2% Cu were mined in 1969. This small deposit was called the Big Rambler Pond Mine.

In 1970, airborne and ground geophysical surveys and a follow-up geochemical soil sampling survey led to initiation of a diamond drilling programme on the Ming Zone located about 2 kilometers N of the

Rambler Mine. Massive sulphides were found in bedrock 200 metres N-E of the La Scie Road - Mings Bight Road intersection. By June, 1971, 16,000 metres of diamond drilling had been completed and ore reserves of 1,000,000 tons grading 2.7% Cu, .08 oz./ton Au and .57 oz./ton Ag had been proven. Present ore reserves at the Ming Deposit are 1,000,000 tons grading 3% Cu, and the deposit is open below a depth of 500 metres.

1.8 Present Study and Methods of Investigation

The present study was undertaken with several objectives in mind:

(1) To determine the geological setting of the known mineralisation in the area, in particular the setting of the Ming Ore Deposit.

(2) To determine the deformational and metamorphic history of the Rambler Area.

(3) To attempt to map the distribution of large scale fold structures in the Rambler Area.

(4) To describe the geology of the Ming Deposit for the purpose of comparison with other base metal massive sulphide deposits.

These four objectives are in practice inseparable.

In view of the economic potential of the area, and in spite of the poor exposure it was felt that the results of the investigations might provide useful guidelines to future exploration programmes.

Minor structures and fabrics resulting from deformation and metamorphism were mapped by examination of new outcrop, and re-examin-

ation of outcrop located by previous workers. Diamond drill cores were studied, and the upper levels of the Ming ore body were examined underground.

A study of the petrography and textural relations of the minerals in the country rocks and in the ore horizon in the Ming Zone was performed.

1.9 Acknowledgements

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CHAPTER II

LITHOLOGY AND PETROLOGY

2.1 Introduction

All the rocks in the Rambler Area have been subject to polyphase deformation. Upper greenschist facies metamorphic conditions were attained over much of the area and metamorphic recrystallisation was extensive, no relict primary igneous mineralogy has been preserved. Outcrop in the area is commonly small and difficult to identify.

Two maps are presented with this thesis, Figure 3 is a geological outcrop map of the Rambler Area and has been constructed from basic field data with a minimum of interpretation; much of the work of Gale (1971) is included in the southern part of this map. Figure 4 is a structural and lithofacies map which is based on data presented in Figure 3, and also on information obtained from drill core (Figure 6), from geophysical maps of the Rambler Area, and from structural mapping in the field. The lithofacies are established on the relative abundance of rock types in the area. The volcanic sequence in the area is divided into 5 lithofacies units, and the lithofacies boundaries are transitional. The intrusive rocks in the area constitute another three units. Sections A,B,C,D,E,H, I and E,F,G (Figure 3) were constructed from diamond drill hole data.

The maps were constructed using vertical aerial photographs on a scale of 1 inch to 1/4 mile, and the grid shown on the maps is the approximate mine survey in feet. All references to localities are

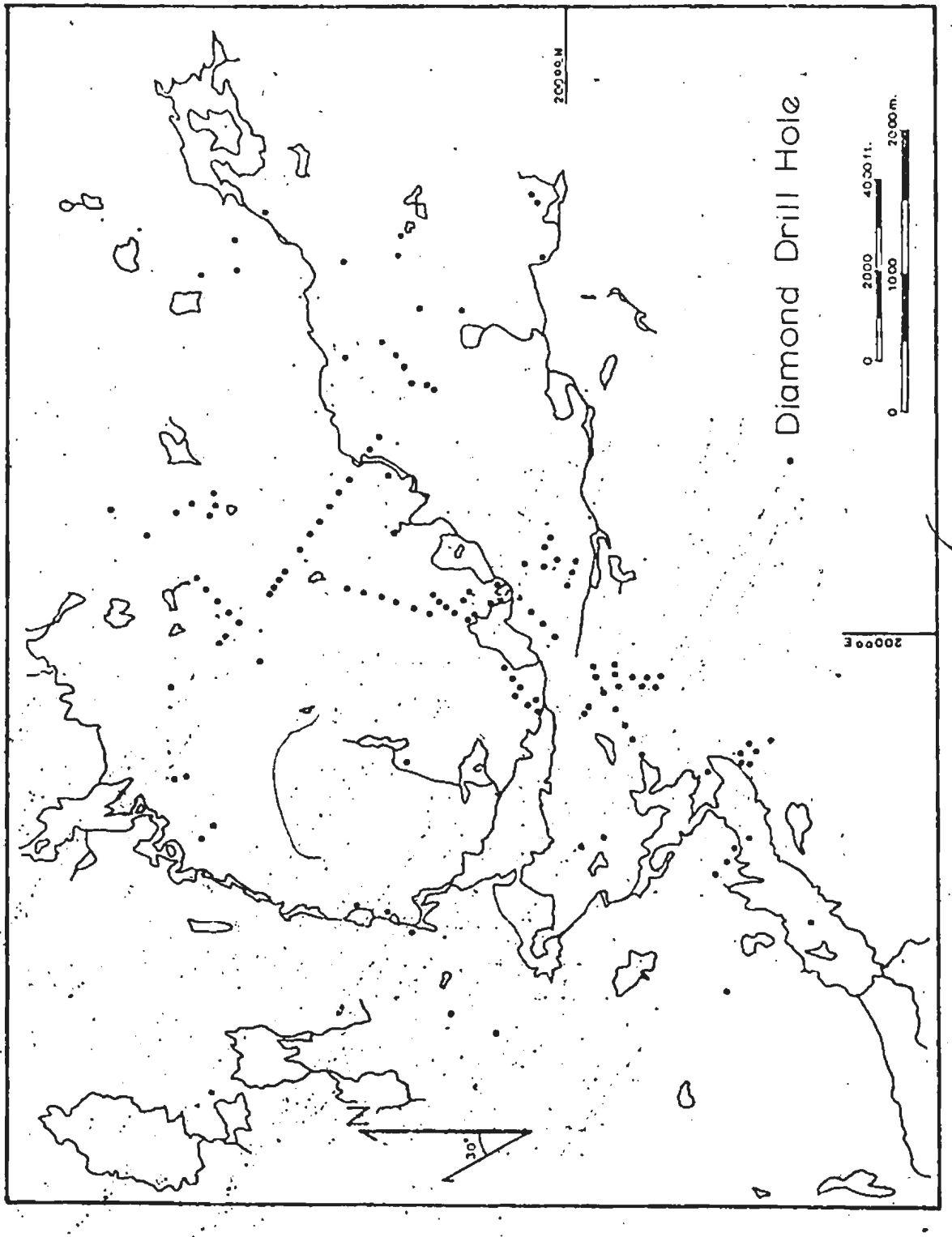

Figure 6. Location of exploration diamond drill holes, the Rambler Area, Baie Verte.

given to the nearest 100 ft., the easting is written first and the northing follows in the grid reference.

2.2 Predominant Lithologies (Figure 3)

2.2.1 Basic Flows

The term undifferentiated refers to outcrops which are too small to be identified as pillowed or massive in aspect, and also to fine grained vesicular volcanic rocks in which various diamond drill holes were collared.

The pillowed (Plate 1) and massive flows are light to dark green, very fine to fine grained, and commonly possess elongated amygdales. The pillows are elongate (as a result of deformation) and average 0.5 by 0.5 by 1.0 metres, the degree of elongation increases to the N. and N.W. of the area. Typical pillow textures are usually preserved, original outlines, recrystallised selvages, amygdale size variation within pillows and epidotised pillow cores are recognisable. Up to 20% basic interpillow matrix and minor interpillow chert may be present locally.

Massive vesicular flows are readily identified, non-vesicular massive flows are difficult to identify and may be confused with fine grained basic intrusive rocks; the massive flows are slightly finer grained and lighter in colour than fine grained intrusions. Narrow epidote and calcite veins are commonly present within the flows.

L to L-S fabrics are well developed in the pillow margins and in the interpillow matrix, they commonly form augen round the pillows.

Fabrics are also developed within the pillows (Plate 14), and locally three schistosities can be seen.

Actinolite, epidote, and albite are the dominant minerals, minor chlorite, quartz, calcite, and biotite are present, sphene, pyrite, and magnetite are common accessory minerals.

Fabrics are defined by mineral lineation in the matrix and by elongation of the amygdales. S_2 is defined by a strain slip schistosity with chlorite growing preferentially in the strain slip planes or by overprinting of the main schistosity by a secondary mineral growth fabric parallel to the strain slip planes.

The actinolite is pale green and slightly pleochroic, it occurs as the dominant mineral in the fine grained matrix (0.1 mm) and as porphyroblasts (0.5 mm). The actinolite crystals are rarely euhedral and usually exhibit fibrous and terminations, porphyroblasts are commonly twinned. Actinolite also occurs as a minor constituent in veins and amygdales. Blue-green hornblende was recorded in several pillows by Gale (1971).

Plagioclase (An_2-An_{10}, Gale, 1971) occurs as relict phenocrysts, (0.5 mm), as polycrystalline aggregates in amygdales (Plate 14), and in veins; the crystals are partially or completely altered to epidote, and commonly show polysynthetic twinning, partial replacement is controlled by composition planes which result in straight trails of granular epidote within the plagioclase crystal.

Epidote occurs as an alteration product in feldspar crystals and

as individual crystals or aggregates of crystals (0.1 mm) in the matrix; it also occurs in veins and amygdales. The minerals epidote and clinozoisite are most common, minor zoisite is present. Epidote minerals average less than 10% in the rock, although locally 75% epidote is present.

2.2.2 Basic Volcaniclastic Rocks

It is commonly impossible to make a definitive decision as to the exact origin of many of these rocks, and they are described in three broad categories, these categories are (a) agglomerate and tuff which includes possible pillow breccias, and coarse reworked pyroclastics, (b) volcanogenic sediment and/or waterlain tuff, and (c) basic schists.

(a) Agglomerate and Tuff:- These rocks contain from 5-95% angular to elongate blocks of basic lava (often vesicular) embedded in a finer grained basic matrix, fragment size averages 10 cm (Plate 2), and locally blocks up to 60 cm are present. The intensity of elongation increases towards the W. and N.W. At locality 182E, 194N angular fragments of thinly bedded basic sediment 15 cm in size were noted (Plate 3). Blocks of acid volcanic material are present in a basic matrix in several localities (Plate 4, locality 104E, 231N and at 206E, 205N).

Penetrative L to L-S fabrics are well developed, and a strong mineral lineation is developed parallel to the direction of fragment elongation.

The mineralogy (in the matrix) is similar to that in the fragments

Plate 1. Pillow lavas; locality 185E 178N.

Plate 2. Elongate vesicular basic agglomerate fragments in basic matrix; locality 170E 227N.

Plate 3. Volcanogenic conglomerate comprised of unsorted angular to sub-angular blocks of basic volcanic sediment (quartz chlorite schist in fresh surface) in a finer grained matrix. The rusty veins (stockwork ?) crosscut the fragments and are composed of quartz, pyrite and chalcopyrite; locality 182E 194N.

Plate 4. Rhyolitic fragments in basic chloritic matrix, picture looking N.E.; locality 104E 231N.

actinolite, chlorite, plagioclase, epidote, and quartz, are the dominant minerals, finely disseminated pyrite is present in most specimens, and biotite, hornblende and sphene occur locally.

The main fabric in chlorite rich rocks is defined by thin laminar anastomosing ferromagnesian-rich domains which are separated by domains rich in quartz and feldspar (Plate 16). The mafic minerals are generally orientated parallel or sub-parallel to the trend of the domain ; locally the mafic minerals provide evidence of an earlier fabric which is preserved at a low angle to the domains or transposition planes within the quartzo-feldspathic domains. Crenulation of the main foliation which was accompanied by minor recrystallisation is occasionally present. In rocks which contain minor quartz and feldspar, and in which actinolite is the dominant mafic mineral, the main structural feature is a strong mineral and vesicle lineation.

In the northern part of the area, pale green pleochroic acicular actinolite is the dominant mafic mineral, and blue-green hornblende is developed locally. The amphiboles occur as prophyroblasts (0.1 mm), as a fine grained matrix (0.01 mm), and locally, in the mafic rich domains in chlorite-rich rocks. Occasionally, blue green hornblende is seen to overgrow the matrix actinolite.

Chlorite is the dominant mineral in the rocks in the southern part of the area, it occurs in mafic rich domains and is orientated parallel or sub-parallel to the orientation of the domains. Chlorite is a minor component of the rocks in the north.

Quartz (0.05 mm) is present in all the rocks, and tends to occur in

distinct quartz-rich domains. The common habit of quartz is of elongated grains with sutured grain boundaries and showing undulose extinction; it can also occur as small polygonal unstrained grains.

Plagioclase (to 0.5 mm) is present in the quartzofeldspathic domains and commonly shows partial or complete alteration to epidote.

Epidote also occurs as individual crystals (to 0.5 mm) disseminated throughout the rock.

Biotite occurs as an alteration product from actinolite, and as intergrowths with chlorite. Disseminated pyrite is present in most samples, and minor sphene occurs locally.

(b) Volcanogenic Sediment and/or Waterlain Tuff:- These are fine to medium grained, medium to dark green, clastic rocks. Bedding is generally 2 to 7 cm thick, but locally reaches 1 metre; the thinner beds are commonly internally laminated. Sorting is highly variable within and between beds. Graded beds were noted at localities 241E, 270N and 188E, 171N. Locally a granoblastic texture is developed in some beds, presumably in response to metamorphism, and the texture is comparable to that of the equigranular basic intrusive rocks. A conglomerate bed is present at locality 275E, 277N. Locally massive medium grained sedimentary rocks contain isolated basic volcanic fragments (Plate 5).

An S to L-S fabric is well developed, and several exposures exhibit folding and refolding of the bedding and the main foliation (Plate 6). Crenulation cleavages are locally developed on earlier schistosity surfaces.

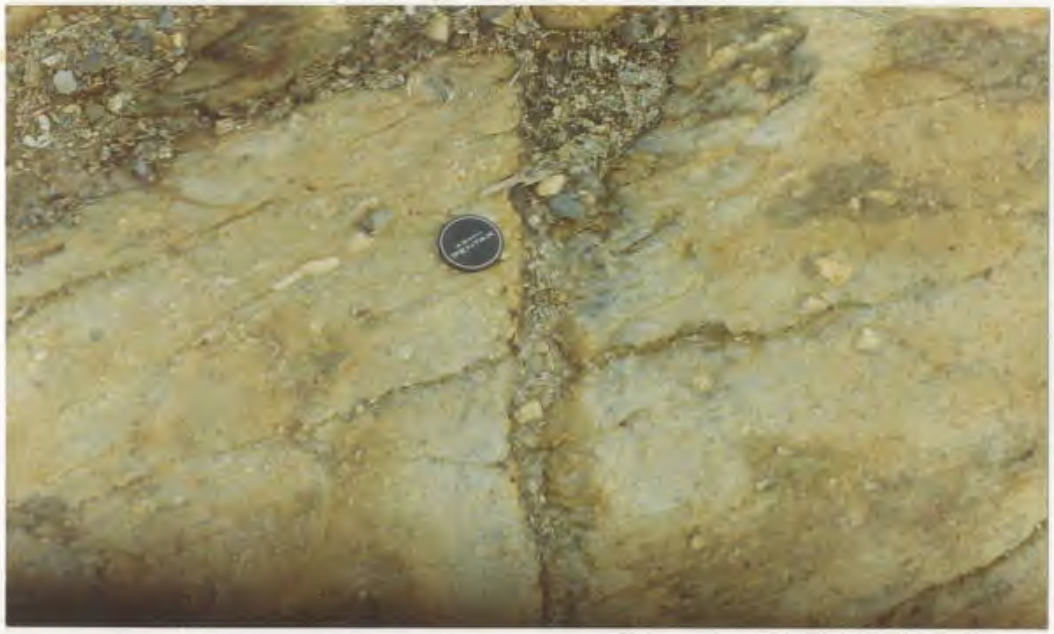

Plate 5. Basic volcanogenic sediment with isolated basic volcanic fragments; locality 246E 186N.

Plate 6. Folded and refolded basic sediments. The prominent fold of bedding, S_2, and parallel quartz veins, plunges to the N.W. at approximately 50 degrees; small attenuated F_2 fold closures of quartz veins are present and are folded by the later (F_3 ?) fold; locality 305E 290N.

The composition is highly variable within beds, between beds, and between outcrops. Chlorite, quartz, actinolite, and plagioclase are ubiquitous, calcite and biotite are common, magnetite, pyrite, and sphene are present as accessory minerals, and basic and silicic fragments and clasts are commonly present.

The main foliation is defined by anastomosing ferromagnesian rich laminar domains which are separated by matrix quartz and/or calcite rich domains and clasts. The domains are generally less than 1.0 mm thick, and the minerals within the domains are generally orientated parallel or sub-parallel to the trend of the domains. The clasts are elongated in the plane of the main schistosity, and are augened by this schistosity. The clasts may show pull-apart texture and quartz, chlorite, calcite and biotite are present in strain shadows. An earlier schistosity is locally preserved at a low angle to the main foliation in the quartz rich domains, and is defined by elongated matrix quartz grains, by parallel orientation of fine grained disseminated mafic minerals, and by elongated pyrite. Post main fabric crenulation is locally accompanied by recrystallisation of the mafic minerals.

The clasts are dominantly single feldspar and/or quartz grains or monomineralic aggregates or feldspar or quartz; basaltic clasts with ophitic texture, and coarse grained granitic clasts of interlocking quartz and feldspar are present locally. A granitic clast in the conglomerate bed exhibits myrmekitic texture. Clasts of fine grained quartz rich material similar to the matrix material in the rhyolitic pyroclastic rocks are present. The feldspar clasts and grains in the clasts

show minor alteration to epidote, quartz exhibits undulose extinction, and both quartz and fedlspar grains have sutured boundaries.

The matrix to the clasts is highly variable. The dominant mineral is fine grained quartz, which is commonly elongated and exhibits undulose extinction; polygonal quartz is present in strain shadows. Calcite can constitute up to 30% of the matrix as large (0.5 mm) grains elongated in, and augened by the main schistosity. Epidote occurs as an alteration product from plagioclase, or as small disseminated grains in the matrix.

The mafic minerals can constitute up to 50% of the rock, and they average about 20%. Biotite, chlorite, actinolite or sericite can comprise from 0 to 100% of the mafic minerals present, but generally one mineral predominates and the others are present as minor constitutents. The mafic minerals are orientated parallel or sub-parallel to the orientation of the mafic rich domains.

Disseminated pyrite occurs in all specimens, it is elongated in the plane of the main foliation, or in the plane of the earlier fabric in the quartz rich domains. Fine to coarse grained magnetite is present locally and occurs in octahedral form.

(c) Basic Schists:- Highly chloritic, schistose green rocks, in which the original texture is unrecognisable are mapped as basic schist. Chlorite, quartz and actinolite are the dominant minerals, with minor disseminated pyrite, epidote, calcite and sphene present locally.

The main fabric is an L to L-S fabric. Ferromagnesian and quartzofeldspathic minerals occupy destinct laminar, parallel bands which define the main fabric. An earlier fabric is locally present in the quartz rich lamellae and is defined by elongate quartz grains and by parallel orientated mafic minerals. The main fabric is commonly crenulated.

2.2.3 Acid Volcaniclastic Rocks

Rhyolitic and dacitic rocks in the Rambler Area are predominantly fragmental. Metamorphic recrystallisation and deformation has destroyed all the possible original primary textures (welding, flow banding, fiamme textures) with the exception of fragment outlines. The rocks are fine grained, and cream coloured on weathered surfaces, on fresh surfaces the rocks vary from grey to green to red to purple in colour. Up to 25% of the rock may be comprised of evenly distributed quartz and feldspar eyes. Up to 10% of the rock may consist of lenses and stringers of actinolite which may reach 7 mm in length; these lenses give the rock a mottled appearance.

The origin of the quartz and feldspar eyes is problematic; it is likely that they may in some occurrences represent primary phenocrysts, however, the even distribution of the eyes throughout both the fragments and the matrix in many of the acid volcaniclastic rocks, the presence of quartz and feldspar eyes in basic fragments in the acid rocks and locally in chlorite schists, and the presence of small quartz eyes in bedded chert bands suggests that the eyes may be metamorphic in origin.

The author prefers to call the eyes porphyroblasts in view of the probable recrystallisation, and renucleation of original phenocrysts, and the probable nucleation of fresh eyes during metamorphism.

The acid pyroclastic rocks generally possess elongate fragments which are highly variable in size and in proportion of the rock, commonly the matrix and the fragments are identical in composition. Fragments generally average 15 cm or less in diameter, however at locality 178E 212N fragments up to 60 cm in size occur (Plates 7 and 8), these outcrops can be termed "Mill Rock"[1] (Sangster, 1972). Locally, minor basic fragments are present in acid fragmental rocks. Gale (1971) described many of the acid rocks in the centre of the area as massive flows, however examination reveals the suggestion of fragment outlines, suggesting that the massive appearance of many of these outcrops is due to recrystallisation during metamorphism. Fine grained acid layered tuffs are present, notably in the hangingwall of the East Mine, and in the footwall of the Ming Mine where they are interbedded with layers of pyrite. Several outcrops (Unit 3a) are fine grained massive or bedded in appearance, no fragments are apparent. Locally these massive units are interbedded with basic rocks. In thin section they are similar to the fragmental rocks. It is possible that they have originated as massive flows, however in most cases they are probably silicic sediment or fine grained tuffs.

Disrupted and folded banding is evident in an exposure of predominantly acid agglomerate at locality 181E 216N (Plate 19). Several outcrops exhibit parallel, light coloured bands up to 5 cm wide which

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[1] Mill Rock - A very coarse pyroclastic breccia situated within hearing distance of a mine mill (within 1/2 mile from a massive volcanogenic sulphide deposit).

Plate 7. Acid agglomerate, "Mill Rock"; thin light coloured bands parallel to the bottom of the picture are alteration zones round hair line fractures; picture looking N.W.; locality 178E 212N.

Plate 8. Acid agglomerate; same outcrop as above; picture looking N.E. S_3 fracture cleavage well developed on this surface; locality 178E 212N.

cross the outcrop (Plates 7 and 8) and which can resemble bedding, locally these bands are seen to cut across fragments, and to possess hairline fractures in the centre of the band. The bands are thought to result from alteration by fluids in the fractures.

The most pronounced structural feature is a strong particle and mineral lineation; a flat strain slip surface is commonly developed, and locally up to three schistosity surfaces are present in a single outcrop. Schistosities are penetrative through the fragments and form augen round the quartz and feldspar prophyroblasts.

Quartz and feldspar prophyroblasts to 3 mm comprise up to 25% of the rock but may be absent locally; they are set in a fine grained matrix (0.02 mm) of quartz and feldspar, with minor biotite, actinolite, chlorite, epidote and pyrite.

Fabrics are defined by mineral lineation in the fine grained matrix, by orientated porphyroblasts, and by the development of narrow planar (0.2 mm) ferromagnesian rich domains which are separated by wider (to 2 mm) domains rich in quartz and feldspar (Plate 9). The domains define the prominent schistosity in the rock, and show better development with an increasing proportion of mafic minerals. An earlier fabric is locally preserved in the quartzofeldspathic domains and is defined by elongate quartz and by parallel orientation of disseminated mafic minerals in the quartz rich domain. The plagioclase and the quartz porphyroblasts are elongated in the plane of the main foliation and are augened by the main foliation, pull-apart texture is developed locally, and polygonal quartz is formed in strain shadows.

The plagioclase porphyroblasts occur as single subhedral to anhedral grains, or as aggregates of smaller grains. Alteration to epidote and sericite is common.

Quartz porphyoblasts occur as single subhedral to anhedral grains or as aggregates of smaller polygonal or sutured quartz grains. Very fine grained(0.02 mm) matrix quartz grains are generally elongate, and have sutured grain boundaries. Both porphyroblasts and matrix quartz have undulose extinction.

Biotite(0.2 mm) comprises less than 5% of the rock, it occurs in the mafic rich domains and is orientated parallel or sub-parallel to the trend of the domain, it also occurs as parallel disseminated grains in the quartz rich domains.

Acicular actinolite is present in most rocks as a minor constituent, and occurs dominantly in the mafic rich domains. Locally actinolite can comprise up to 10% of the rock and occurs as aggregates of grains (to 2 mm) up to 7 mm by 2 mm in size which may be pseudomorphs after pyroxene. Actinolite is the principal mineral in the basic fragments in the acid fragmental rocks, and commonly shows a strong mineral lineation. Locally, quartz and feldspar porphyroblasts are present in the basic fragments.

Minor epidote and sericite are present, generally as an alteration product from plagioclase, chlorite is present locally, and minor disseminated pyrite is present in all samples. Garnet was identified in a single outcrop in the field, however, this was a flat glaciated exposure and collection of a sample for thin section was not possible.

2.2.4 Basic Intrusive Rocks

Fine to medium to coarse grained to porphyritic metabasite bodies intrude all the other minor rock types in the Rambler Area; these intrusive rocks comprise over 70% of known outcrop in the area. The intrusions were called metadolerites by Gale (1971). The larger bodies show a wide variety of textures, most of which are probably primary and related to the cooling history of the bodies; these textures include coarse grained pegmatitic phases (crystals up to 2.5 cm in size), quartz and feldspar rich segregation in the form of small blobs and veins, dendritic amphiboles (Plate 10) up to 7 cm long, and local brecciation textures. Numerous internal chilled margins are present in metabasite[1] bodies intersected in drill core. The attitude of these internal contacts, and the attitudes of intrusive contacts with country rock are generally parallel or subparallel to schistosity and to tuff and sedimentary banding in the drill core. Few of the intrusions can be traced for any distance in the field, and their trend can seldom be determined.

Tectonic fabrics vary from intensely schistose metabasite with an apparent composite fabric, to massive metabasite devoid of any tectonic features. The intensity of the fabric tends to increase towards the margin of the intrusion.

The rocks contain amphibole, plagioclase, and epidote, with minor amounts of chlorite, quartz, biotite, sphene and pyrite.

In several thin sections a penetrative mineral lineation of phenocrysts and matrix minerals is apparent; in other sections fracturing

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[1] Metabasite -"a metamorphosed basic rock" (Miyashiro, 1973). The term is here used to describe metamorphosed basic intrusive rocks and possibly massive basic flows as destinct from recognisable basiv volcanic rocks.

Plate 9. Anastomosing planar ferromagnesian rich domains separated by wider quartz and feldspar rich domains in acid agglomerate. The quartzofeldspathic minerals are elongate and parallel or subparallel to the domains, locality 176E 218N; crossed polars, (x 30).

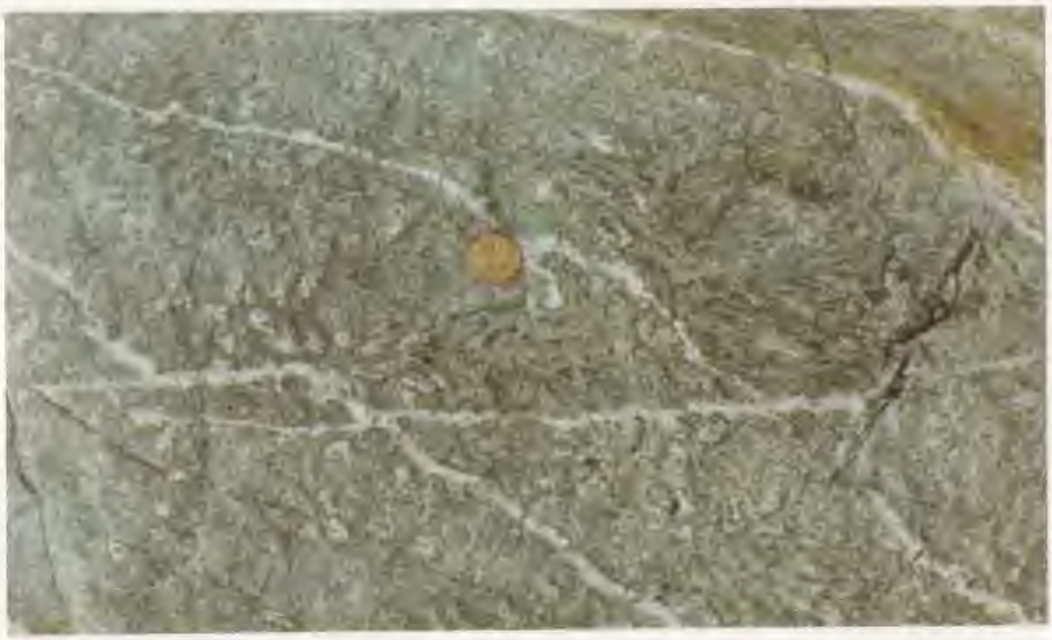


Plate 10. Dendritic actinolite crystals in medium grained basic intrusive rock; locality 195E 190N.

and bending of plagioclase and actinolite porphyroblasts are the only evidence for deformation. A foliation is often developed as the result of chlorite being preferentially grown in fractures spaced from 0.1 to several mm apart.

Hornblende is commonly developed and is pale green to green, grain size ranges from 0.1 to 2 mm, and anhedral crystals are rare. The hornblende is intergrown with plagioclase and in some instances poikiloblasts overgrow pseudomorphs of plagioclase. Actinolite is more common in the south of the area and occurs in a similar form to hornblende.

Plagioclase is present in most of the rocks examined, and reaches 4 mm in size in the porphyritic intrusive rocks. Variable amounts of alteration to epidote along composition planes within the plagioclase is common, and total replacement has resulted in pseudomorphs of granular epidote after plagioclase.

Chlorite is a minor constituent in most rocks; it occurs in thin parallel zones in an otherwise massive rock; these zones probably represent a fracture cleavage into which the chlorite has preferentially grown.

Biotite represents less than 1% of the rock, and commonly replaces hornblende cores. Minor sphene is present in most of the sections studied. Disseminated pyrite occurs in small amounts in all specimens and fine grained granular quartz is present in some sections.

Fine grained granular epidote is commonly seen to replace plagioclase, and minor calcite occurs locally.

2.2.5 Granodiorite

The Burlington Granodiorite, on the western margin of the area studied, is a medium grained, mottled grey-white, weakly foliated rock. Plagioclase (65%), quartz (15%), biotite and hornblende (15%), potassium-feldspar (5%), are evident in hand specimen.

In thin section, the mineral composition is albite, quartz, hornblende and/or biotite, and microcline, accessory apatite, sphene, zircon, and pyrite are present. Epidote and sericite occur as alteration products from feldspar, and chlorite is present, probably as an alteration product from biotite.

The schistosity is defined by parallel orientated individual crystals or aggregates of biotite. Locally elongated quartz grains with serrated boundaries help to define the main foliation.

Quartz and feldspar crystals range to 2 mm in size, the plagioclase shows alteration to epidote (1 mm granular crystals), and to sericite (1 mm acicular crystals).

Biotite is pleochroic, green to greenish brown, and grain size averages about 5 mm.

Up to 1% sphene, with minor amounts of apatite, zircon, and pyrite are present; the grain size of the accessory minerals is generally less than 1 mm.

2.2.6 Quartz-Feldspar Porphyry

The western margin of the Cape Brulé Porphyry is situated to the east of the area studied. The porphyry is schistose and has a knobbled

appearance in hand specimen. Fifty to seventy per cent quartz and feldspar phenocrysts are present in approximately equal proportions, and average 2 by 2 by 3 mm in size. The rock is mottled pink to grey. The phenocrysts occur in a fine grained (0.05 to 0.10 mm) matrix of quartz, epidote, chlorite, feldspar, biotite and calcite.

The quartz phenocrysts show euhedral to anhedral outlines and are commonly composed of aggregates of smaller grains (0.5 mm) which show polygonal to irregular outlines, and which generally exhibit undulose extinction; locally single quartz crystals are present. The aggregates of smaller quartz grains probably originated as a result of renucleation of quartz during deformation and metamorphism of primary quartz phenocrysts. Locally elongate and polygonal quartz grains occur in strain shadows.

Orthoclase microcline and albite occur in decreasing order of abundance, the crystals are euhedral to anhedral in outline, and commonly aggregates of several crystals are present. Alteration of the feldspars to sericite, epidote, and calcite is common.

Biotite and chlorite can comprise up to 10% of the rock and commonly occurs as elongate aggregates of very fine grained crystals up to 4 mm in length.

Accessory octahedral magnetite and cubic pyrite grains are common; magnetite and pyrite occur as elongate irregular aggregates of smaller grains. Minor zircon, muscovite, and locally apatite are present.

The main schistosity is defined by parallel orientation of the

phenocrysts and by parallel orientation of the biotite and chlorite rich lenses. The phenocrysts are locally fractured and show weak, pull-apart texture; quartz is recrystallised in the fractures and in the strain shadows.

2.3 Minor Lithologies

2.3.1 Ultrabasic Intrusive Rocks

Several conformable ultrabasic intrusive lenses to 3 metres thick, are present in drill core in the hangingwall above the Ming Ore Horizon (Figure 5). Some of the contacts show fine grained chilled margins and grade to coarse centres with 5 mm crystal outlines; in other intersections the margins of the lenses are chloritic and highly schistose. The rocks are light to dark grey and are soft and soapy to touch.

No relict primary minerals are present; the dominant mineralogy is talc, serpentine, carbonate, and chlorite. Pseudomorphs after olivine (?) can comprise up to 70% of the rock and are composed of talc and/or serpentine, they are commonly rimmed by trails of fine grained magnetite with irregular grain outlines. Small euhedral magnetite crystals are disseminated through the matrix to the pseudomorphs. The matrix to the pseudomorphs is talcose, and carbonate and minor chlorite is commonly present.

2.3.2 Acid Intrusive Rocks

Several fine grained, pink to grey felsic intrusive units averag-

ing 1 metre in thickness were noted in drill core from holes collared in the S.E. of the property. These units have definite chilled margins, and may exhibit up to 10% small (0.1 mm) feldspar phenocrysts in the centre of the intrusion. The matrix consists of extremely fine grained quartz and feldspar; 5-10% actinolite crystals (0.1 mm) are disseminated through the matrix and define an L fabric in the rock.

Coarse grained (5 mm) granitic intrusive material is recorded in drill logs at localities 140E 150N and 137E 250N. The material is comprised of coarse plagioclase and K-feldspar crystals, and finer inter-crystal quartz, biotite and actinolite.

2.3.3 Cherts and Silicic Rocks

These are fine grained, brown weathering rocks which are white to green-white on fresh surface; the rock commonly contains up to 10% pyrite, and a sugary texture is developed as a result of weathering of pyrite. The green colour is due to the presence of mariposite (Gale, 1971). Quartz eyes to 3 mm are present locally.

The rocks commonly occur in close spacial proximity to economic and subeconomic mineralisation in three settings:

(i) In distinct bands up to 1 metre thick and locally with considerable strike length (300 metres at locality 179E 164N) in the basic rock. They have sharp contacts with the surrounding rocks, and have been subject to folding and boudinage. The bands are interpreted as chert horizons.

(ii) In footwall rocks exposed at surface at the East Mine (locality 246E 221 N), and at locality 182E 186N an irregular stockwork of pyrite

bearing silicic veins which average 2.5 cm in thickness and which cut basic pyroclastic and basic sedimentary rocks (Plates 3 and 11), locally the veins cut fragments in the pyroclastic rocks and are probably epigenetic in origin.

(iii) Numerous exposures of highly silicic rocks are found throughout the area which cannot be directly classified as i or ii above. Intermediate rocks between basic schists, (quartz-chlorite schists) and the fine grained silicic rocks are commonly found in close spatial proximity to the silicic rocks, and in the East Zone area a transition from basic through intermediate into silicic rocks was noted. The inference is that the silicic rocks in some instances developed by silicification of basic volcaniclastic rocks, perhaps as alteration products in relation to migrating mineral bearing fluids.

A weak to strong L to L-S fabric is developed and forms augen round the quartz eyes. Fracture planes are common.

The matrix in the rocks composed of 95 per cent quartz with minor plagioclase, and locally up to 2 per cent mariposite, minor actinolite, chlorite and sericite can occur. The quartz grains (0.03 mm) show sutured grain boundaries. Quartz porphyroblasts (up to 10 per cent of the rock) locally reach 3 mm and consist of single grains which commonly exhibit undulose extinction or of aggregates of polygonal grains which do not show undulose extinction.

The fabric in the rock is defined by parallel orientation of the elongate matrix quartz grains and the quartz porphyroblasts, and by

parallel orientation of the minor mariposite, chlorite, actinolite, and sericite.

2.3.4 Quartz-Sericite Schist

These are highly foliated, poorly consolidated, fine grained acid rocks commonly containing up to 25% quartz eyes (porphyroblasts?) embedded in a fine grained matrix (0.05 to 0.10 mm) of quartz and sericite. The colour varies from pale green to mottled grey and pale green to light grey, the green colour is due to the presence of mariposite.

The sericite schist commonly contains up to 10% fine grained disseminated pyrite and several units are adjacent to economic and sub-economic sulphide deposits.

The main fabric is defined by alternating quartz rich and sericite rich lamellae (Plate 12) which commonly form augen round the porphyroblasts; a strain slip fabric is commonly developed across the main foliation.

The porphyroblasts are euhedral to anhedral and are comprised of single grains or aggregates of several polygonal grains of quartz which exhibit undulose extinction. The grains are commonly elongate in outline, and pull-apart texture is locally developed (Plate 13), polygonal unstrained quartz grains are common in strain shadows.

The matrix quartz can be polygonal or elongate and sutured in habit. Sericite grains in the matrix are orientated parallel or sub-parallel to the orientation of the sericite rich lamellae.

Plate 11. Stockwork of pyrite-quartz veins cutting basic volcanic sediment; footwall of the East Mine (locality 246E 221N).

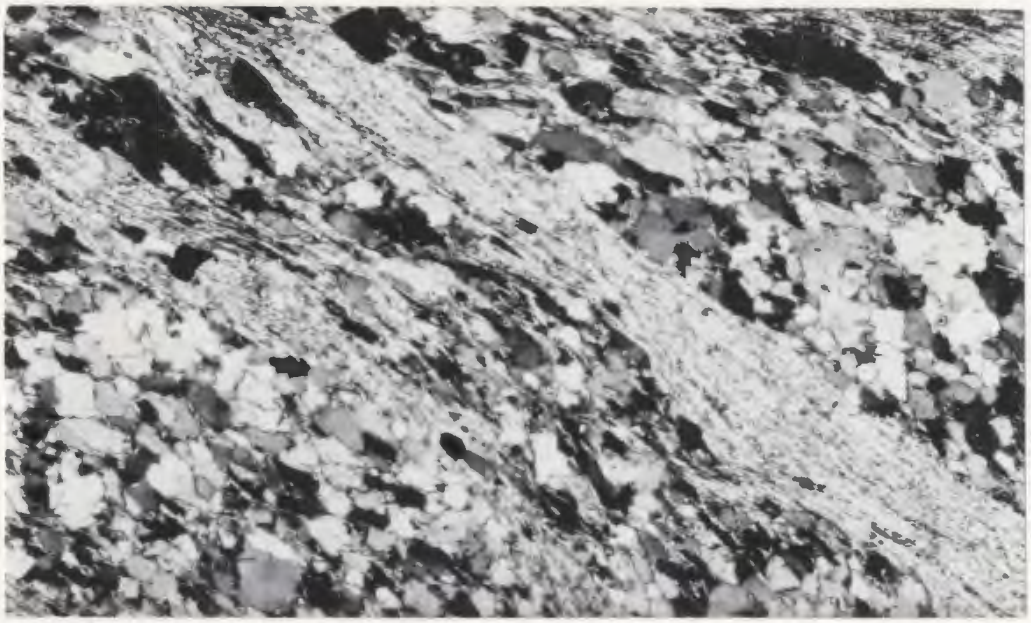


Plate 12. Quartz-sericite-schist. Main foliation (S_2) defined by composite fabric of alternating quartz rich and sericite rich lamellae. Small quartz porphyroblast present in top right. Weak strain slip fabric parallel to base of picture (S_3). Crossed nicols (x 20).

Two outcrops of quartz-muscovite schist are present at locality 142E 227N, and similar schists are present in thin bands at locality 999E 226N. These rocks have a strong S to L-S fabric defined by planar muscovite-rich and quartz-rich lamellae, the main schistosity is isoclinally folded and later strain slip surfaces are developed. An earlier fabric is locally preserved in the quartz-rich lamellae, and is defined by parallel orientation of the micaceous minerals. The rock consists of approximately 65% polygonal quartz, and about 20% orientated muscovite grains. Biotite, chlorite, epidote, and pyrite are minor constituents. Grain size averages 0.1 mm. Muscovite and biotite are locally recrystallised in the later strain slip planes.

2.4 Lithofacies (Figure 4)

The lithofacies units are defined on the relative abundance of rock types present in an area. The boundaries between the units of volcanic rock are transitional and their position is subject to revision as drawn on Figure 4, when further data becomes available. The lithofacies distribution is compiled from field evidence and from data available from drill core.

2.4.1 Basic Flow

The southern part of the Rambler Area is predominantly underlain by pillow lavas and massive flows, minor basic volcaniclastic rocks, and locally minor thin felsic intrusions occur.

2.4.2 Basic Volcaniclastic Rocks

Large portions of the central part of the Rambler Area are underlain by rocks representing a complex basic volcanic environment. Probably 50% of the area is underlain by small isolated pillow lava units; the remainder of the area is underlain by basic agglomerate, tuffs, and possibly pillow breccias, with lesser amounts of reworked fragmental rocks and volcanogenic sediment. Minor chert, silicic rocks, and quartz sericite schists are present, and locally small felsic intrusions are present in the south-east portion of the unit.

2.4.3 Mixed Acid and Basic Rocks

This unit is comprised of varying proportions of rhyolitic pyroclastic beds, and basic pillowed and volcaniclastic rocks. These rocks are intimately intermixed on a scale varying from alternating acid and basic laminae to acid and basic units 100 metres thick. In general, acid fragments are less obvious, and where present are smaller than in the acid volcaniclastic unit. The outcrops in which acid fragments are present in a basic matrix are within this unit; several outcrops are recorded in which the acid fragments in the basic matrix reach 30 cm in size, but generally the fragments are smaller. Chert, silicic rocks and quartz-sericite schists are a minor constituent in this unit.

2.4.4 Acid Volcaniclastic Rocks

The central part of the Rambler Area is underlain primarily by

coarse acid fragmental rocks, together with a subordinate amount of finer grained acid material. The coarsest material is found in the south central part of the area (locality 178E 212N). Minor basic tuffaceous material may be present locally, and minor quartz sericite schist units are present.

2.4.5 Basic Sediment

This unit is comprised of bedded and laminated volcanogenic sediment and/or waterlain tuff, minor reworked tuff is locally identified in drill core, and minor basic pillow lavas may be present. A single conglomerate bed is present at locality 275E 277N. Thinly bedded and laminated impure grey chert is locally associated with the sediments.

2.4.6 Younger Intrusions

Basic intrusive rocks which are too small to be recognised as individual lithofacies units comprise approximately 25% of the volcanic sequence, and locally they may form 60% of the rocks exposed. The basic intrusive rocks intrude all of the rock types in the Rambler Area, the contacts are generally parallel or sub-parallel to the schistosity planes and bedding. Approximately 75% of all outcrop in the area is comprised of basic intrusive material, and lithofacies F may possibly reflect the lack of outcrop of intervening rock types rather than represent a single large basic intrusive unit.

The Granodiorite (Unit G) forms the eastern margin of the Burlington Granodiorite and intrudes the volcanic sequence.

The quartz-feldspar porphyry (Unit H) is part of the western margin of the Cape Brulé Porphyry and is thought to intrude the volcanic sequence. Although no intrusive contact is exposed in the Rambler Area an intrusive contact is reported at Woodstock (Coates, 1970; DeGrace et al., 1975b).

2.5 Stratigraphic Relationships

The lithofacies are defined on the relative abundance of constituent rock types, and the boundaries within the volcanic sequence are depositional and transitional. The available facing criteria in the Rambler Area suggests that the sequence becomes younger to the northeast, no evidence to suggest the presence of a major unconformity, major faulting or thrusting, or large scale folding has been noted. The analyses reported by Gale (1971) suggests that the basic rocks in the central and south of the area are komatiitic in composition, and the basic rocks to the northeast are tholeiitic in composition, this may suggest that the more differentiated rocks in the northeast are younger in age.

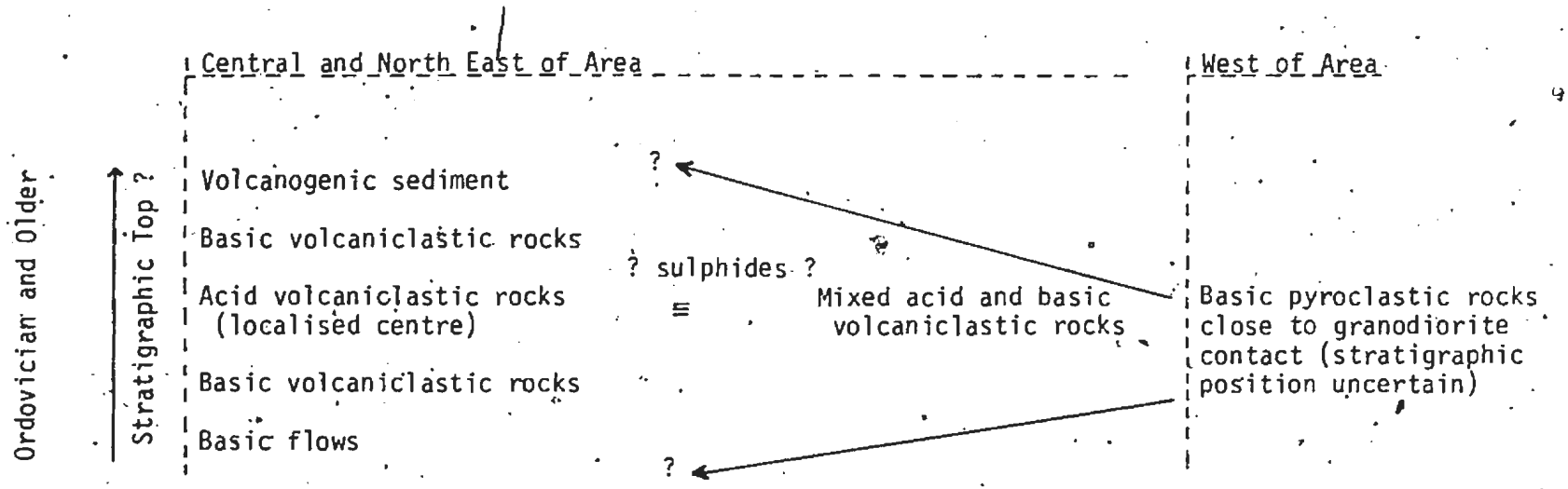
A belt of basic volcaniclastic rocks is interpreted to be present along the margin of the Burlington Granodiorite on the basis of total field magnetic surveys, and isolated outcrop. The relationship of this unit with the pillow lavas to the east and northeast is unknown

and the unit may owe its present position to folding, faulting, thrusts or tectonic slides, or possibly to a pretectonic unconformity either overlying or underlying the pillow lavas.

Table 2 illustrates the generalised stratigraphic succession in the Rambler Area.

A tentative age of 460 million years has been obtained from study of lead isotope compositions in massive sulphide ore from the Ming Mine and the Rambler Mine (Sangster, pers. comm. 1974, Sangster and Thorpe, 1975). No figure for experimental error is given with this data, however, this may suggest that deposition of the sulphides, and thus the volcanic sequence in the Rambler Area took place during the Ordovician. Deformation and metamorphism of the rocks of the Pacquet Harbour Group may have occurred after the Ordovician and prior to deposition of the Silurian Mic Mac Group.

Table 2. Generalised Stratigraphic Succession in the Rambler Area.



Contacts between units are transitional.

CHAPTER III

STRUCTURE

3.1 Introduction

The structural history outlined in this chapter was constructed using the principles of small scale structure analyses as expounded by Wilson (1961) and as subsequently developed by many workers in structural geology, and by interpretation of metamorphic recrystallisation and growth textures as outlined by Zwart (1960), Rast (1965), and Spry (1969). The major deformation episodes are regionally developed and are associated with penetrative L-S and S tectonic fabrics (Flinn, 1962, 1965) or with strain slip fabrics. The folds are described after Fleuty (1964). Folding and deformation which does not appear to be regionally developed is noted but is not designated as individual separate deformation episodes.

Identification and correlation of individual fabrics is an important aspect of the present study. The problems in correlation are particularly acute in the Rambler area due to the combined effects of:

(a) The absence of primary bedding features, the generally massive nature of the rocks, and the probable complexity of the initial stratigraphy.

(b) The scarcity of outcrop.

(c) The primary lithological variation and its effects on fabric development during metamorphism.

(d) The grade of metamorphism, the fine grained nature of the rocks

and the general absence of static growth phases.

The abbreviations D_1, D_2, D_3, etc. are used to signify successive regional deformational events; F_1, F_2, F_3, etc. refer to folds produced during the successive deformational events; S_1, S_2, S_3, etc. refer to schistosities, and L_1, L_2, L_3, etc. refer to stretching and crenulation lineations produced during the individual regional deformation episodes.

Table 3 summarises the structural history in the Rambler Area, Figure 4 and Figure 7 illustrate the structure in the area.

3.2 The Earliest Recognised Deformation (D_1)

In most of the lithologies S_1, when present is defined by parallel elongate quartz and feldspar (pyrite and sphene) grains and by small relict orientated ferromagnesian minerals which are preserved between S_2 transposition planes, generally at a low angle to the planes. S_1 is also preserved in and folded round the noses of F_2 folds. S_1 is commonly parallel or sub-parallel to bedding in the area. In other samples the presence of narrow quartz rich laminar domains between planar anastomosing ferromagnesian rich domains suggest that the fabric is composite, and that the S_1 mineral phases have been recrystallised during D_2. Within the pillow lavas S_1 is defined by orientation of matrix actinolite grains although the prominant fabric in the field is defined by S_2 strain slip planes (Plate 14).

S_1 is a definite L-S tectonic fabric shown by elongated quartz, feldspar, pyrite, and sphene grains which commonly exhibit serrated grain boundaries. S_1 cannot be considered to be a bedding schistosity

Table 3. Summary of the Structural History in the Rambler Area.

	Fabric	Folds	Strain
Later	Faults and Shear Zones		Minor
D_4	Local vertical NE trending crenulation cleavage	Open NE plunging warps and folds.	Minor
D_3	Crenulation cleavage and strain slip. Fabric, flat to NE dipping.	Open to mod. tight inclined, NE plunging recumbent minor and major folds.	Minor
D_2	Penetrative strain slips and transposed S_1.	Minor tight inclined and upright folds with NE plunge. Probable large F_2 upright folds.	Regional $\infty < K > 1$
D_1	Relict penetrative fabric.	None observed	Possible $\infty < K > 1$

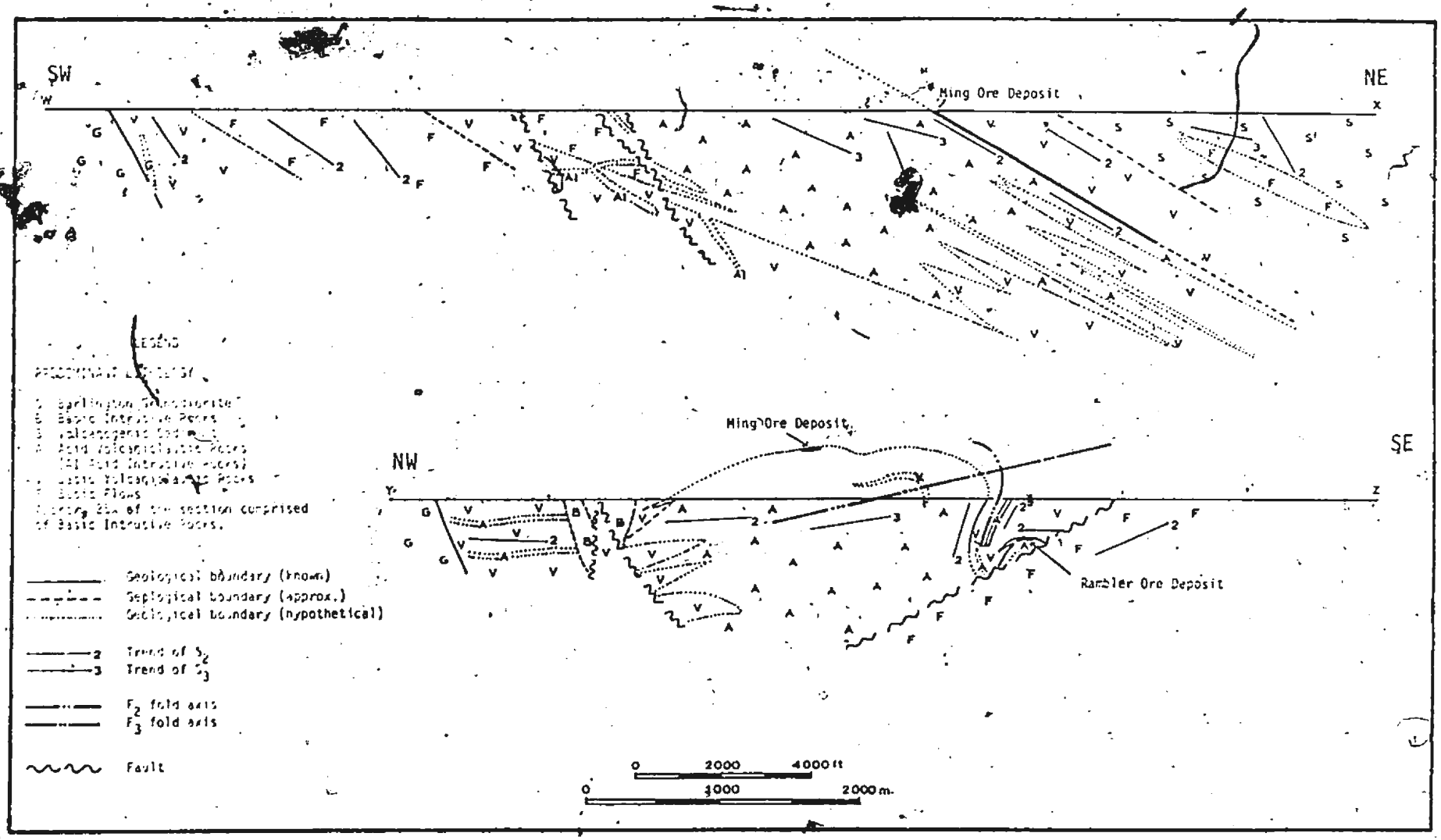


Figure 7. Geological cross sections through the Rambler Area, Baie Verte, Newfoundland. (refer to Figures 3 or 4 for location of sections).

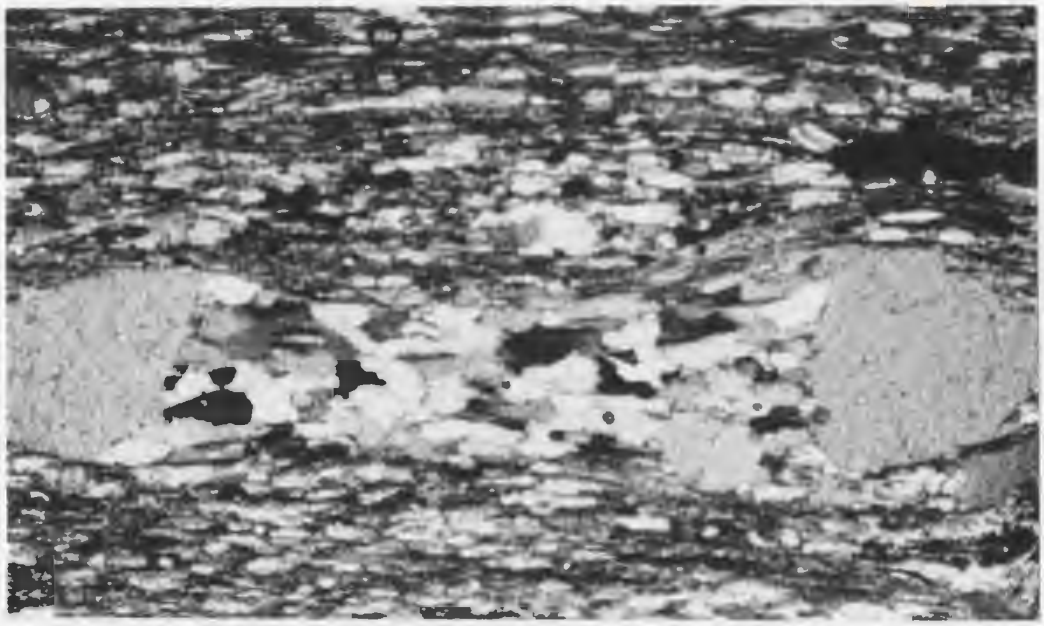


Plate 13. Quartz-sericite-schist. S_2 foliation forming augen round pulled-apart quartz porphyroblast; crossed polars, x 40

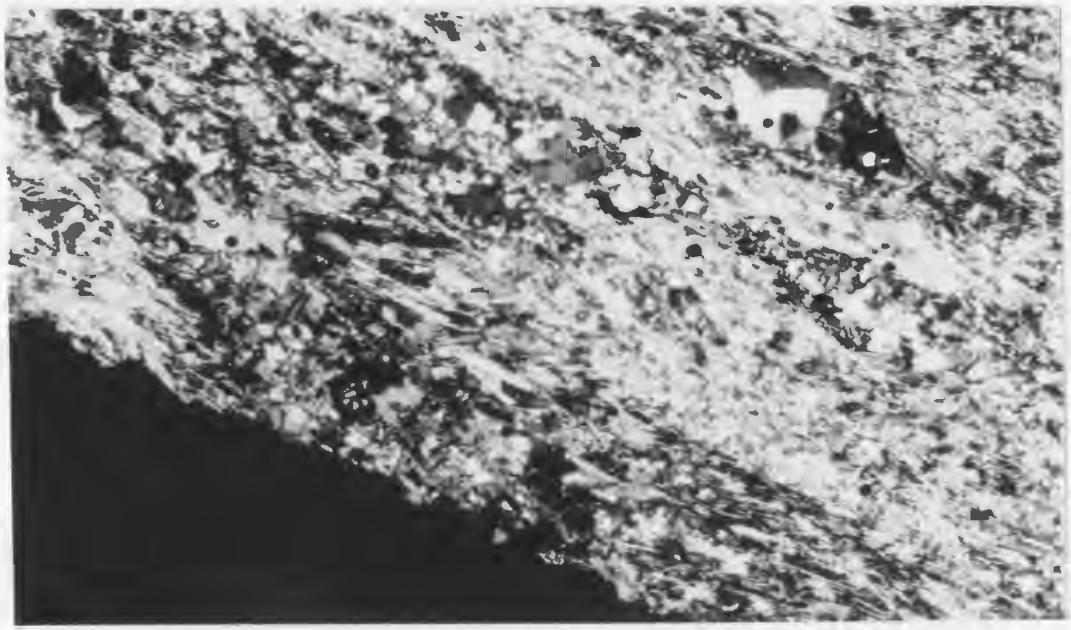


Plate 14. Vesicular pillowed lava. Transposition planes of actinolite (S_2) forming augen round plagioclase filled elongate vesicles. Lineate actinolite grains define S_1; crossed polars, x 20.

since it occurs in massive volcanic rocks. When small particles are augened by S_1 they are lineated and suggest a K value $1 < K < 00$ (Flinn, 1962) during D_1 however, this lineation is subparallel to L_2 and in these cases may be modified by D_2. In the pillows to the south S_2 is sometimes weakly developed and it is probable that elongation of vesicles etc. occurred during D_1.

No minor F_1 folds were observed and the absence of major repetitions of the stratigraphy suggest that possible F_1 major folds are either absent or are extremely large scale.

3.3 The Second Deformation (D_2)

Over much of the area S_2 is defined by an intensive penetrative transposition fabric (plates 15 and 16) which was accompanied by variable amounts of recrystallisation and differentiation of the metamorphic minerals. Complete differentiation notably in the chlorite schists, in the quartz saricite schists and the quartz muscovite schist, resulted in the development of a composite fabric. S_2 planes are defined by laminar or anastomosing mafic rich domains which are separated by quartz and feldspar-rich domains (Plates 12 and 17). In the basic rocks, the mafic domains (Plate 16) are predominant and S_2 fabric varies from a completely transposed S_1 to thin S_2 strain slip-planes along which chlorite has preferentially grown. The pillow lavas in the south of the area are more difficult to interpret. Elongate vesicles, mineral lineations, and locally weak schistosities are evident in the field. The pillows are very fine grained and fabrics

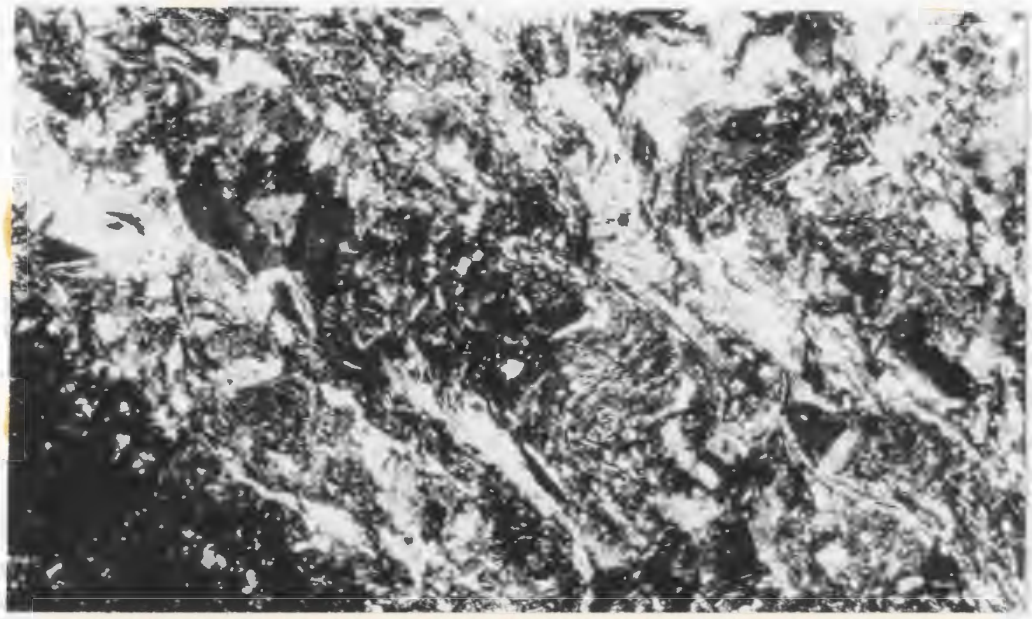


Plate 15. Basic Sediment. Transposition of S_1 defined by elongate quartzo-feldspathic and ferromagnesian minerals into S_2 planes in which biotite and chlorite are preferentially grown; crossed polars, X 30 .

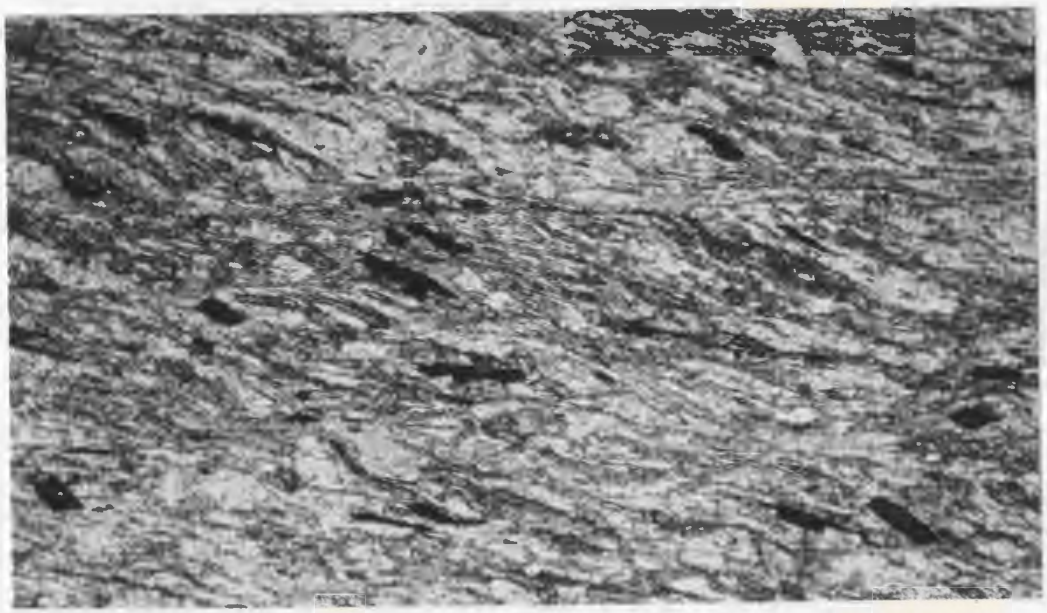


Plate 16. Basic fragment in agglomerate. S_2 transposition planes of S_1 with actinolite and chlorite growing preferentially in S_2.Actinolite, epidote and pyrite grains elongate in S_1. Light grey cloudy patches consist of epidote (after plagioclase);plane light, X 30.

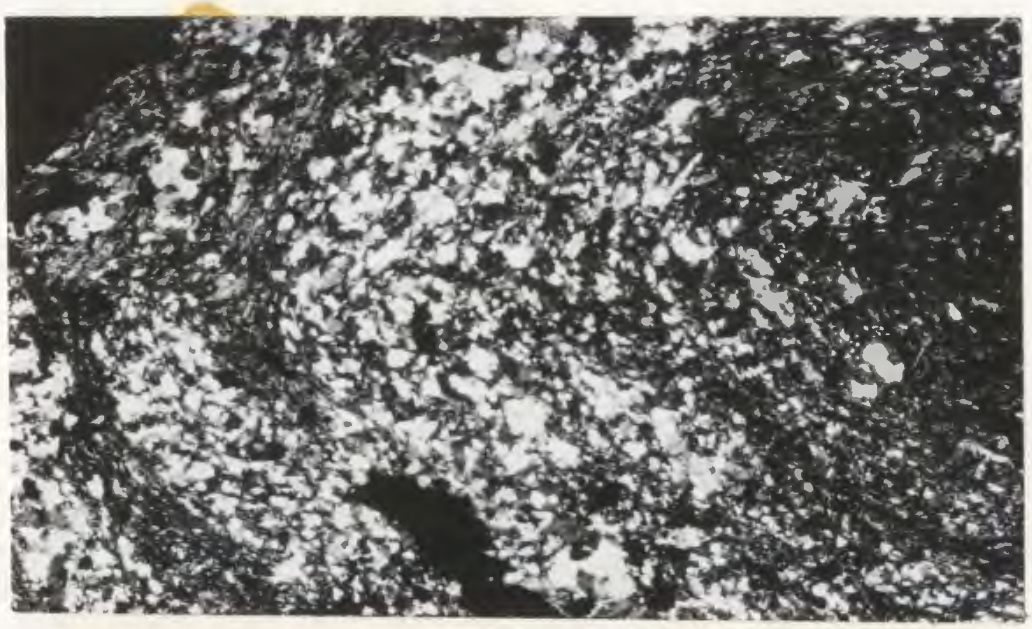


Plate 17. Quartz-chlorite schist. Alternating lamellae of chlorite (dark) and quartz and feldspar (light) defining S_2. Elongate pyrite grain parallel to S_2. The S_2 lamellae are folded by an F_3 crenulation; crossed polars, X 40

Plate 18. F_2 closure in hangingwall basic tuffs above the Ming Mine, locality 202E 268N.

cannot be recognised with any degree of certainty in thin section. In the field the dominant fissility was mapped as S_2 on the basis of its apparent composite nature. This practice is continued in this thesis. Within the basic volcanic and the sedimentary lithofacies in the Rambler Area, S_2 forms the dominant planar feature and the main schistosity as measured in the field represents S_2.

The prominent structural feature in the area is defined by elongate fragments (Plates 2 and 7), grains, and vesicles which are parallel or sub-parallel to L_2 mineral lineations and to F_2 fold axes. The elongation suggests a k value > 1 during D_2, and the N.E. plunging direction of elongation and of mineral lineation is constant throughout the area. F_2 folds are locally extremely tight (Plate 6) and suggest that considerable strain occurred during D_2; it is possible that strain related to D_1 may have contributed significantly to the overall D_2 strain pattern for the Rambler Area. The Z axis of the deformation ellipsoid is parallel to the minor F_2 fold axis. Narrow schistose zones averaging 20 cm wide are common in the area, they are usually planar, and parallel the main foliation or the bedding. The zones are composed of soft chloritic schist in the basic rocks, and quartz sericite schist in the acid rocks. These may represent zones of intense D_2 strain.

Minor F_2 fold axes have been recorded from several localities; they are identified by the presence of S_2 axial planar schistosity, and by folded S_1 planes. In the 310 exploration drift in the Ming Mine the noses of several moderately N.E. plunging folded quartz veins are

present; in the noses of the folds the veins are less than 5 cm thick, and thin rapidly in the limbs. At the entrance to the 310 drift in the Ming Mine an F_2 fold of a massive sulphide lens is preserved in quartz sericite schist. In the Ming open pit, the nose of a tight N.E. plunging F_2 fold with half wave length of 60 cm is present (Plate 18) in the hangingwall tuffs. In the 1034 exploration drift at the East Mine folded quartz veins similar to those in the Mine Zone are present. At locality 182E 216N in the south of the acid pyroclastic terrain small F_2 folds in 5 cm acid tuff bands are present, they are upright, close to tight and plunge to the N.E. at a moderate to steep angle (Plate 19). F_2 folds of quartz veins are also present in this locality. At locality 999E 228N several upright N.N.E. plunging isoclinal folds of basic tuff bands are present and at locality 305E 288N several isoclinal folds of quartz veins, and locally 5 cm wavelength folds of S_1 are present as intrafolial folds between S_2 planes.

A definitive structural analysis of the Rambler Area cannot be made due to lack of adequate structural criteria. Nevertheless, a probable upright F_2 fold of approximate half wavelength of 350 metres is developed in the south central part of the Rambler Area (section E-F-G on Figure 3, and Figure 7). This fold is interpreted to be an F_2 fold because the S_2 foliation is steep to vertical in the area, and strikes to the northeast, and minor F_2 folds at locality 182E 216N are tight and upright. Bedding cleavage intersections on this fold are present only on the northwest limb and a single top indication from graded bedding suggests that the fold is a syncline overturned to the S.E.

Plate 19. F_2 fold closures of "disrupted acid tuff (?)" bands and of syntectonic quartz veins. The folds plunge to the N.E. at a moderate angle and axial planar S_2 foliation dips to the S.E. at approximately 70 degrees. A flat lying strain slip cleavage cuts across these fold closures but is not evident from the photograph; locality 182E 216N.

Plate 20. S_3 crenulation cleavage in basic sediment. The rock is comprised predominantly of chlorite and biotite, and locally clasts are present; crossed nicols, x 20.

3.4 The Third Deformation (D_3)

Moderate to shallow northeast dipping crenulation cleavages S_3 (Plates 12 and 20) and moderately plunging crenulation lineations (L_3) are common throughout the area particularly in rocks which possess a good S to L-S D_2 fabric. These fabrics are locally accompanied by recrystallisation of chlorite, biotite, and muscovite in the plane of the S_3 fabric. Locally S_3 is axial planar to open recumbent to shallow inclined N.E. plunging folds of S_2 and bedding (Plate 21). A crenulation lineation is developed parallel to the axes of the folds, the folding is best developed in the basic sediments in the N.E. of the area. In the Ming Mine comparable F_3 and S_3 structures are developed in the ore zone and the country rock, and are discontinuous down plunge and disharmonic in nature; the folds in the Ming Mine reach 20 metres in amplitude. In the East Mine, in the 1034 drift, the nose of a large shallow north plunging recumbent post S_2 fold of an acid tuff horizon is present and has an associated shallow N.E. dipping crenulation cleavage.

In most of the [illegible]ral acid pyroclastic terrain, the dominant fabric is a shallow N.E. dipping strain slip cleavage (S_3) (Plate 22) which has minor associated recrystallisation; this fabric commonly appears as a fracture cleavage in the field. The fabric cuts across minor F_2 fold closures and associated steep axial planar S_2 fabric at locality 182E 216N. No associated minor F_3 folds are noted in this area.

Strain related to D_3 does not appear to be a significant factor in the strain history of the Rambler Area; the F_3 folds appear to be

Plate 21. F_3 fold hinge showing axial planar crenulation cleavage in chloritic sediment. S_2 planes are defined by chlorite rich and quartz rich lamellae; chlorite is recrystallized in the plane of the S_3 cleavage. Locality 275E 277N.

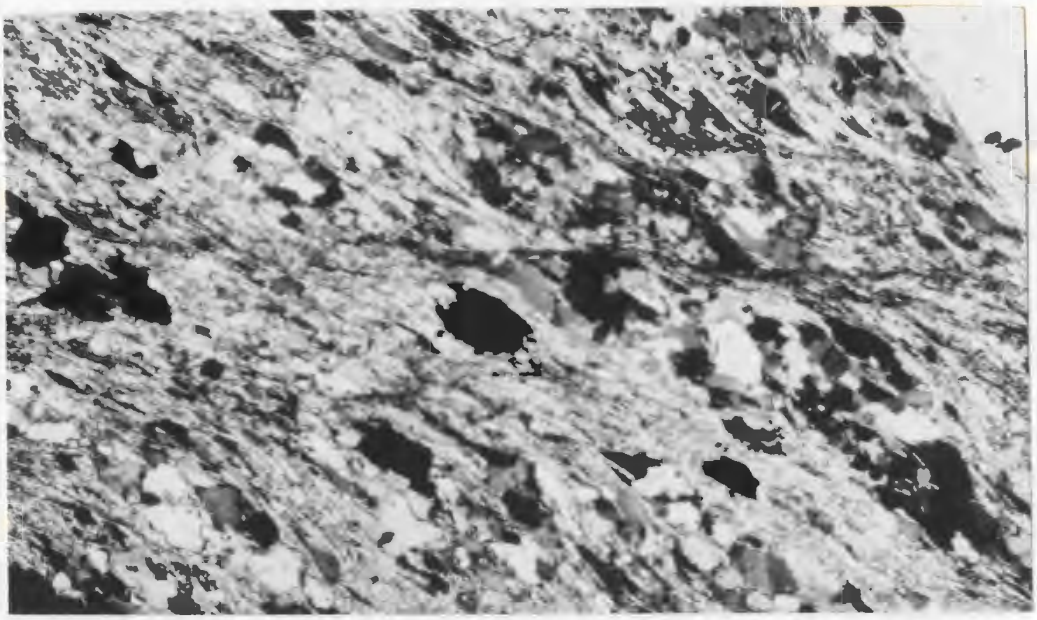


Plate 22. S_3 strain slip fabric in acid agglomerate; crossed nicols, X30.

open and disharmonic in nature, locally however D_3 strain may be significant in the rock.

The large scale variation in the attitude of S_2 can be explained if the presence of large scale open disharmonic F_3 fold structures are postulated. The position of F_3 fold axial plane traces are drawn on Figure 4 and Figure 7.

3.5. The Fourth Deformation (D_4)

A weak, vertical to subvertical N.E. striking crenulation cleavage is commonly developed on N.E. dipping S_2 surfaces, and an associated N.E. plunging crenulation is common in the area. This fabric is axial planar to open (locally tight) warps and folds of S_2 and bedding. Comparable warping of S_3 is common, but no associated fabrics were noted. The open folds have an amplitude of up to 5 metres and a wavelength of up to 30 metres (Plate 23) although the dimensions are commonly much smaller.

3.6 Local Deformation Features

In addition to the apparent regional deformation features described above, minor post-D_2 deformation features are present which cannot be directly related to the major features.

Open to close recumbent "cross folds" are present locally, these have an amplitude of up to 5 metres and the axis trends to the N.W. An associated N.W. striking, flat to gently N.E. dipping crenulation

cleavage is present. Notable examples occur in the 60 level drift and in the 300 level #4 stope in the Ming Mine, other examples are present in the deeper levels of the Ming Mine (R. Norman, pers. comm.). At locality 190E 313N the same type of open folds are noted. These folds are disharmonic and do not appear to significantly affect the regional attitude of S_2 in the area. At locality 305E 290N close, moderately to steeply inclined, moderate N.W. plunging folds of S_2 and bedding are present (Plate 6), and F_2 fold closures appear to be folded round the fold axis; a N.W. plunging crenulation lineation is developed on S_2 surfaces parallel to the fold axis. Most of the folds have round fold hinges but several are box folds. Locally significant mineral recrystallisation is associated with these folds.

The folds have a gentle to steep N.E. dipping axial plane and are probably D_3 strucutres.

3.7 Late Deformation Features

3.7.1 Faults

A small dextral N.W. striking fault is present in the Ming Ore Zone (Figure 5). The fault dips at about 80 degrees to the S.W., has a lateral displacement of approximately 10 metres, and a down-throw to the S.W. of approximately 4 metres. A prominent post-S_2 breccia zone is developed, and the fault is a late stage feature in the deformation history of the Area.

In the rest of the Rambler Area, a lack of detailed stratigraphy prevents definite identification and evaluation of fault zones.

A marked linear feature is observed striking W.N.W. along Rambler Brook, and through Rambler Pond; the apparent break in the lithofacies distribution pattern in the area coupled with evidence from drill core in the Rambler Mine Area suggests that the linear represents the outcrop of a low angle (30 degrees) N.N.E. dipping fault plane. Small outcrops of chlorite schist are present along the fault zone, and 1-2 metres of chloritic gouge material are present in drill core. No large scale brecciation, or variation in attitude of the main foliation was noted in the vicinity of the fault, however, the apparent trend of the fault cuts the main foliation and apparent fold pattern in the area, and probably postdates the main deformation episodes. The lithofacies distribution pattern suggests that the rocks to the N.E. of the fault have been downthrown (perhaps in the order of 500 metres), with respect to the rocks of the S.W. side.

The remainder of the faults indicated on Figure 4 have been assumed on the basis of topographic linears, possible lithofacies breaks, and from detailed geophysical maps.

There may be other significant faults or tectonic slides in the area.

3.7.2 Joints and Joint Drags

Vertical to sub-vertical and horizontal to sub-horizontal joints are common in all rock types in the area; chlorite is commonly grown in

the plane of the joints. In the quartz sericite schists in the Ming Mine, rotation between closely spaced joint planes have produced subvertical "kink bands" or joint drags (Dewey, 1965) up to 5 cm wide. A single 7 cm wide kink band was observed at locality 242E 270N.

3.8 Strain and Strain Variation

Strain measurements were performed by Gale (1971) and shows that $b \approx 1$ and that $1 < K < \infty$ (Flinn, 1962); he suggests that the fabrics throughout the area approach those of pure L-tectonites. Visual examination of the deformed objects in the area suggest that there is a minor flattening component to the deformation; furthermore, weak to moderately strong schistosity planes in actinolite rich rocks suggest that there is an S component to the strain. The present author describes the rocks as L-S tectonites. The Z axis of the deformation ellipsoid plunges constantly to the N.E. throughout the area.

The major episode of strain appears to have occurred during D_2, however it is possible that considerable amounts of strain occurred during D_1. The relatively open nature of post D_2 folds, and the local development of D_3 and D_4 structures suggest that the rocks were subject to only minor strain after the second deformation.

The intensity of strain varies throughout the area, the pillows in the south show little or no evidence of strain, there is a general increase in elongation of pillows and particles towards the north of the area, and in particular towards the margin of the Burlington Granodiorite where extremely elongate fragments with relative dimensions

of 1 to 1.5 to 10 are present. A second notable feature is that strain intensity has no relationship to the intensity of the fabric as observed in the field, highly strained pillows may possess weak fabrics while apparently unstrained pillows and fragments may possess an intense chloritic schistosity; the acid rocks often appear massive to weakly foliated while elongated fragments and tight F_2 closures suggest that they have been subject to a considerable amount of strain.

The acid volcanic, the basic volcanic, and the basic sedimentary lithofacies appear to have suffered roughly comparable amounts of strain. The presence of relatively unstrained pillows in the south may suggest that the deformation decreases in intensity in this direction, possibly as a result of either the pillows acting as a competent unit during deformation or the intensity of the tectonic processes responsible for deformation decreasing towards the south of the Rambler Area. However, south of the area, deformation is again intense.

With the Burlington Granodiorite, the Cape Brulé Porphyry, and the metabasite intrusions, strain markers are absent and the amount of strain suffered cannot be estimated. Fabrics are present within these rocks. In general the metabasites are only mildly recrystallised, and original textures are commonly present; strong recrystallisation is confined to the margins of the intrusions.

CHAPTER IV

METAMORPHIC HISTORY

4.1 Introduction

The metamorphic history is described in terms of metamorphic growth stages which are identified with reference to periods of deformation. The development of preferred orientation during periods of dynamic or syntectonic mineral growth (Flinn, 1965) provides markers in the metamorphic history of the area. The metamorphic growth stages are referred to as MS_1, MP_1, MS_2, etc., after Sturt and Harris (1961), and they probably represent a continuous sequence of events. The major metamorphic stages recognisable in the Rambler Area result from syntectonic growth and recrystallisation events, static metamorphic growth phases are developed only locally. No pretectonic metamorphic mineral assemblages have been identified although their original presence may be suspected in relation to either alteration of the basic rocks prior to deformation (Cann, 1969; Spooner and Fyfe, 1973), or to contact metamorphism in relation to the Burlington Granodiorite and the Cape Brulé Porphyry.

4.2 Syntectonic Mineral Growth with respect to D_1 (MS_1)

Syntectonic mineral growth during D_1 led to the development of a L-S to L tectonite fabric which is locally preserved throughout the area between S_2 transposition planes; within the pillow lavas, S_1 fabric is defined by actinolite and feldspar and is preserved between S_2 strain

slip planes, it locally forms the dominant fabric in the pillows. Elongated quartz and feldspar grains predominantly define S_1 in the acid rocks and in the basic sediments and volcaniclastic rocks; elongate epidote grains, locally elongate pyrite grains, and disseminated orientated grains of actinolite, chlorite, sericite and biotite also define S_1. It is possible that recrystallisation of early low grade MS_1 minerals occurred during progressive metamorphism to form biotite and actinolite.

4.3 Post Tectonic Mineral Growth with respect to D_1 (MP_1)

No unambiguous MP_1 phases were recorded from the area. Straight inclusion trails of epidote and sericite are common in feldspars throughout the area, in several cases two sets of trails form at right angles and are clearly related to alteration along cleavage planes within the crystals; it seems probable that most if not all of these trails formed in this manner.

4.4 Syntectonic Mineral Growth with respect to D_2 (MS_2)

Varying degrees of metamorphic recrystallisation and differentiation accompanied crenulation of the S_1 fabric. In most of the lithologies S_1 has been largely obliterated with the tendency for quartzofeldspathic and ferromagnesian minerals to occupy separate laminar domains (Plates 9 and 12); S_1 is preserved locally between these domains, and in many of the rocks S_1 has been completely transposed.

Quartz, feldspar, chlorite, biotite, sericite, muscovite, actinolite and epidote apparently recrystallised or renucleated during D_2, and locally hornblende.

4.5 Post Tectonic Mineral Growth with respect to D_2 (MP_2)

Garnets with straight inclusion trails of S_2 are locally present in the acid volcanic rocks, these crystals have been rotated during the development of S_3 strain slip planes. Elsewhere in the area MP_2 biotites (Plate 24 and 25) and locally MP_2 actinolite and hornblende crystals (Plate 26) cut across S_2. The age of these crystals with respect to D_3 and D_4 was not determined since S_3 and S_4 were not observed in relation to MP_2 crystals, but it seems likely that they grew at the same time as the garnet, perhaps immediately after the growth of MS_2 minerals.

4.6 Syntectonic Mineral Growth with respect to D_3 (MS_3)

Variable amounts of recrystallisation occurred in relation to S_3 strain slip fabrics (Plate 21). In the acid rocks, biotite, chlorite and actinolite recrystallised within S_3 planes; spectacular recrystallisation of chlorite and quartz during S_3 is demonstrated at locality 190E 313N. At locality 305E 288N orientated MS_3 biotite and muscovite crystals overprint S_2.

Plate 23. F_4 fold of hangingwall tuffs in the Ming Mine; Locality 202E 268N.

Plate 24. MP_2 biotite crystals overgrowing lineated actinolite quartz and epidote crystals. Large MP_2 pyrite grain in lower left of picture; crossed polars, X 15.

Plate 25. MP_2 biotite crystals overgrowing lineated actinolite crystals, the actinolites are cut parallel to the 001 section. White areas are holes in the thin section, and small grains of epidote are present; plane light, X 20.

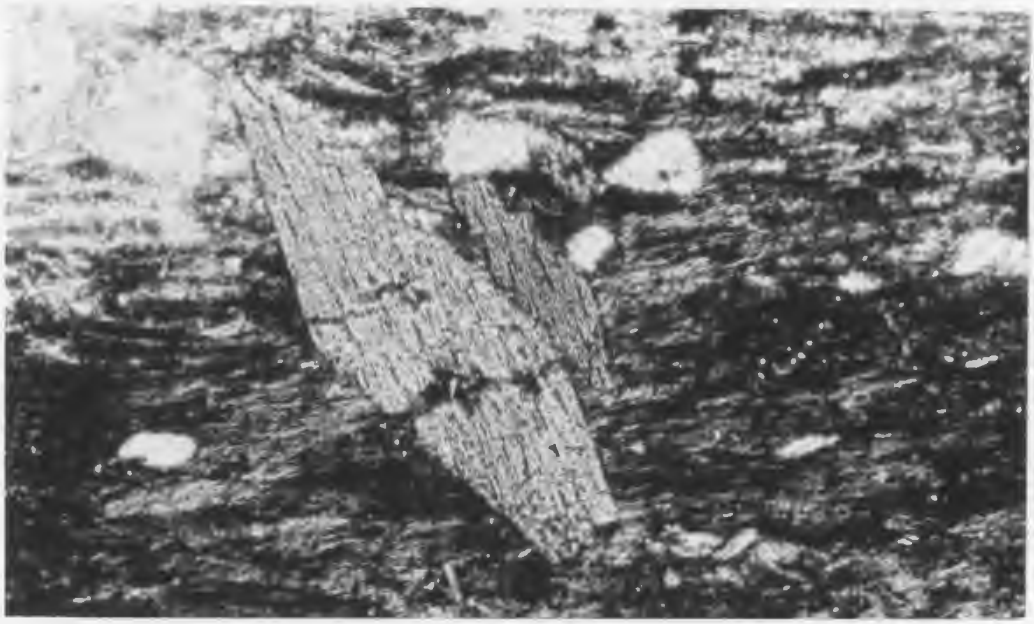


Plate 26. MP_2 actinolite overgrowing S_2; crossed nicols, X 20

4.7 Syntectonic Mineral Growth with respect to D_4 (MS_4)

Locally minor amounts of recrystallisation of quartz and chlorite occurred during D_4.

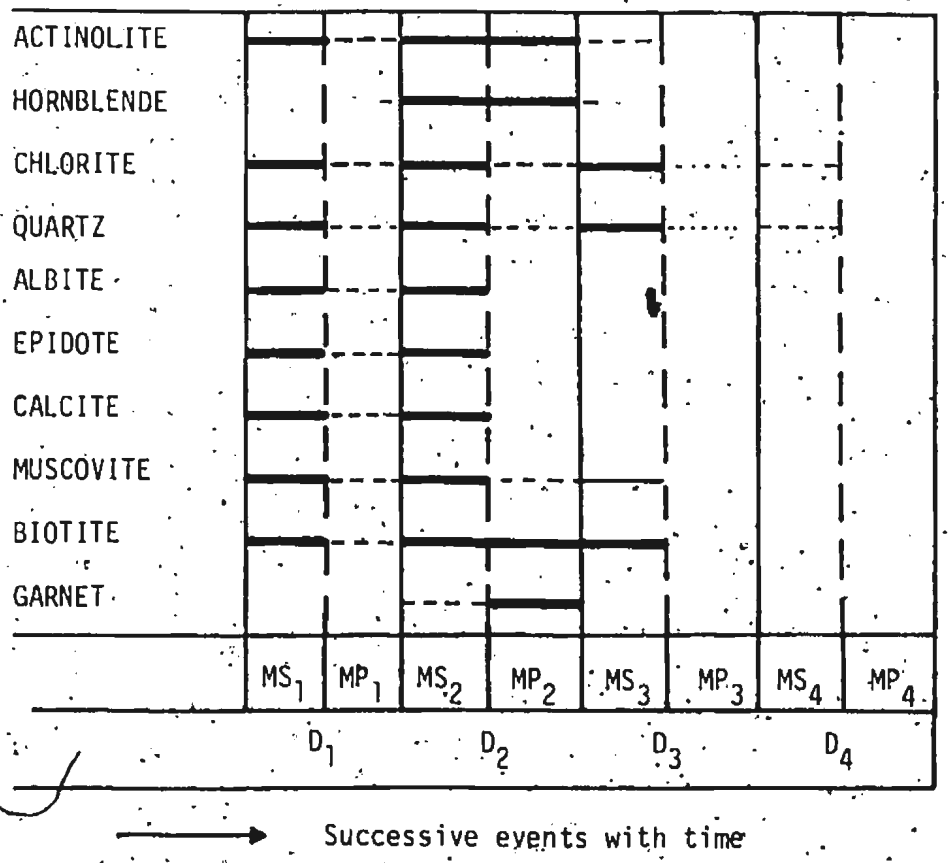
4.8 Metamorphic Grade

The mineral assemblages present in the Rambler Area were described and discussed by Gale (1971). He concluded that conditions of the quartz-albite-epidote-almandine subfacies (Winkler, 1967) existed in the northern part, and conditions of the quartz-albite-epidote-biotite subfacies existed in the southern part of the Rambler Area during and after the main D_2 episode. The presence of albite indicates conditions of the upper part of the greenschist facies were prevalent in the area.

The widespread presence of disequilibrium textures in the rocks in the Rambler Area, and the possible controls of primary lithological variation on the metamorphic mineral assemblages, cast doubt on the usefulness of establishing subfacies, and indeed Winkler (1970) suggests that subfacies classification is cumbersome and should be abolished.

Table 4 summarises the metamorphic history in the Rambler Area with respect to the individual deformation episodes. It is evident that a sequence of prograde metamorphism occurred, the metamorphic climax was attained towards the end of, and after D_2 with the growth of hornblende, garnet, and biotite. The metamorphic climax was followed by local retrogression associated with D_3 and D_4, indicated by replacement of hornblende by biotite and chlorite, the feldspars by epidote and sericite, and biotite by chlorite.

Table 4. Metamorphic History in the Rambler Area



CHAPTER V

THE MING ZONE

5.1 Introduction

The following descriptions and conclusions result from study of several drill cores in the Ming Zone, from personal observations underground and on the ore stockpile, and from discussions with the geologists at Consolidated Rambler Mines; 24 polished ore specimens were examined. The sections in Figure 5 were constructed by R. Norman, Mine Geologist.

The study is of a reconnaissance nature and is intended to provide a basis for comparison with other massive sulphide deposits (i.e. Hutchinson and Searle, 1971; Sangster, 1972; Lambert and Sato, 1974; Ishihara, 1974; and, Vokes and Gale, 1976). A brief description of the Ming Zone has been published by Heenan (1973).

5.2 General Description

The Ming Ore Deposit is a tabular-elongate shaped, stratiform massive sulphide body producing copper, gold, and silver; chalcopyrite is the dominant ore mineral. It is situated in the north-central part of the area studied (Figure 3). The ore body outcrops about 200 metres northeast of the Mings Bight-La Scie road intersection, it has a northwest strike length from 100 to 160 metres, and plunges to the northeast at a dip of 30 to 40 degrees for a known plunge length of 1000 metres.

Longitudinal and strike sections of the Ming Ore Deposit are presented in Figure 5. It should be noted that the diagram is scaled in feet because the Mine Survey does not use the metric system. The massive sulphide lenses are seen to have a complex facies relationship with the adjacent acid and basic rocks, but in the overall lithofacies picture in the Rambler Area the massive sulphide lens is situated at or near the northeast contact between the main acid pyroclastic unit, and the basic volcaniclastic unit. As a generalisation the ore lenses are within the acid unit on the southeast side of the deposit and they tend to lie in the basic tuff or volcanogenic sediment unit on the northwest side; bedding where present is parallel to the sulphide lenses, and the ore lenses cross the facies boundary between the acid and basic rocks. In the mine terminology the rocks above the upper ore lens are termed hangingwall rocks and the rocks beneath the lower ore lens are termed footwall rocks. Locally acid and basic tuff units are interbedded and interlaminated.

5.2.1 Hangingwall Rocks

The hangingwall rocks consist of basic flows and pyroclastic rocks, basic intrusions and minor lenses of intrusive ultrabasic rocks; these have been described in Chapter II.

A unit of banded basic tuffs or volcanogenic sediment (Plate 29) generally less than 15 metres thick is present throughout the hangingwall rocks. On the northwest side of the deposit similar basic tuffs are present below the massive sulphide horizon and between the massive

sulphide lenses. On the southeast side of the deposit up to 3 metres of acidic rocks occur between the highest massive sulphide lens and the basic tuffs.

The basic tuffs are schistose and consist of alternating sharply defined layers (averaging 2.5 cm thick) of actinolite-biotite-rich and calcite-epidote-quartz-rich material. Minor lenses of magnetite-actinolite and magnetite-chlorite schist are present in the tuffs. Several thin lenses of quartz-garnet-magnetite assemblage occur in the silicic rocks in the hangingwall, these rocks may have originated as iron and manganese rich cherts. Biotite prophyroblasts reaching 5 mm in size are common and can constitute up to 30 per cent of the basic layers in the tuffs, actinolite porphyroblasts are found locally. Boundinage and folding of the layers occur locally.

Minor thin stringers of pyrite and chalcopyrite are present within several centimetres of the upper sulphide lens, generally mineralisation in the hangingwall rocks consist of disseminated pyrite grains and pyrite in vein fillings and seldom comprises more than one per cent of the rock.

5.2.2 Footwall Rocks

The footwall rocks, and the rocks beneath the hangingwall tuffs vary in character from quartz-eye sericite schists (see below) to acid tuffaceous and agglomerate rocks, to massive rhyolite, to quartz feldspar porphyry. The lateral distribution of these rock types appears to be irregular, in general, the quartz eye sericite schists occur in

close to the ore horizon while acid pyroclastic and more massive rhyolitic rocks become more evident at a distance of 10-30 metres beneath the ore horizon. The quartz-eye sericite schists appear to be developed from the acid pyroclastic and more massive rhyolitic rocks.

The quartz-eye sericite schist (Plate 27) is comprised of up to 20% by volume of augened (single or coarse polygonised crystals) deep blue to white quartz grains up to 4 mm in size; these are set in a matrix of fine grained (0.05 mm) elongated or polygonised quartz grains and/or orientated sericite, locally minor chrome mica (mariposite?) is disseminated throughout the sericite schist. The blue colour of the quartz eyes probably relates to single or several large strained quartz crystals forming the quartz eye, the white colour probably relates to polygonised unstrained quartz grains forming the quartz eye or to fluid inclusions in the grains.

The acid pyroclastic and rhyolitic porphyry rocks are similar to the rocks described in Section 2.2.3.

Mineralisation in the footwall rocks takes three forms:-

(i) Disseminated pyrite can comprise up to 10% of the footwall rocks but generally comprises less than 2%.

(ii) Alternating layers of pyrite rich and silica rich material (Plate 28) (generally less than 5 cm thick) are present, the layering parallels the recognisable bedding, and is here interpreted to represent a primary depositional feature. Locally minor chalcopyrite is present as matrix to the pyrite in the pyrite rich layers, and several

Plate 27. Quartz -eye sericite schist; footwall, Ming Mine.

Plate 28. Banded, probably bedded, layers comprised of alternating pyrite rich and chert or silicic tuff; a pyrite-quartz rich, cross cutting vein is present at the bottom of the picture; footwall, Ming Mine

bands were noted with sphalerite as the dominant mineral. The acid layers are predominantly cherty, but occasional acid fragments are recognisable.

(III) The third type of footwall mineralisation consists of irregular thin stringer veins filled with pyrite or with pyrite and quartz. These veins are usually less than 3 cm thick and are not abundant. Locally chalcopyrite veins are present but these are not common. The stringer mineralisation does not appear to represent a large scale stockwork under the ore lens and probably originated during deformation as a result of mobilisation.

5.2.3 Basic Intrusions

Several large metabasite intrusions cut across the footwall, the ore horizon and the hangingwall rocks; within the ore horizon these intrusions have steep contacts and are in dyke form, several thin sill like offshoots intrude the ore horizon. In the hangingwall rocks observed in drill core, most of the intrusive contacts are subparallel to the schistosity and to the tuffaceous layering present in the country rocks. All the intrusive rocks are recrystallised and they commonly possess tectonic fabrics; these fabrics are most intense in sills and in the margins of dykes.

Minor amounts (0.05%) of disseminated pyrite are present in the metabasites. Small fractures are often filled with pyrite and/or quartz and/or chalcopyrite. Larger fractures or gash veins in the intrusions are

filled with variable amounts of quartz, carbonate, pyrite, chalcopyrite, chlorite, sphalerite, and occasionally minor amounts of magnetite. Mineral zonation is common in the veins but was not studied in detail, in general chlorite and carbonate occur as an outer rim, quartz, chalcopyrite and sphalerite occur in the centre; these gash veins are usually lenticular in form and can reach 3 metres in width. Pyrite porphyroblasts up to 5 cm were noted in the margins of a gash on the 400 level in the Ming Mine, several of the porphyroblasts possessed striated and gouged crystal faces and rounded corners. Several of the thin sills may in fact represent metamorphosed basic tuff units in which the original textures have been destroyed by recrystallisation, since locally the sills do not possess recognisable chilled margins, and they appear to grade up dip and along strike into tuffs.

5.2.4 The Ore Horizon

The sections on Figure 5 demonstrate the continuity of the ore lenses both down plunge and across strike. The lenses have been cut by several dykes and sills, and have been subject to disharmonic folding (section 12+00 and 15+50 N.E.). The contacts between the massive sulphide lenses and the host rocks are sharp and parallel to tuffaceous bedding (Plate 29). Four distinct varieties of ore are present; the boundaries between the varieties are transitional.

(1) Massive Pyritic Ore:- The most common ore variety constitutes over 80% of the ore deposit (visual estimate) and consists dominantly (70%) of fine grained pyrite (0.05 to 5 mm). Continuous or discontinuous

Plate 29. Massive pyritic ore- hangingwall basic tuff contact. Minor disseminated chalcopyrite is present in the basic tuff, and a fragment of basic tuff is present within the massive pyrite; Ming Ore Deposit.

Plate 30. Massive pyritic ore showing banding due to variation in grain size, (top of block), and to variation in composition and abundance of the matrix minerals (bottom half of block); Ming Ore Deposit.

layering (to 5 cm thick) is a common feature of the massive ore (Plate 30) and is due to a variation in pyrite grain size between layers, variation in pyrite/matrix ratio, and to variation in the composition and abundance of the matrix minerals between layers (chalcopyrite is the dominant matrix mineral, sphalerite, quartz, actinolite, and chlorite are also present). Graded pyrite banding was recorded from several specimens collected from the ore reserve pile, and results from variation in pyrite grain size across the layers; this feature may possibly have arisen during metamorphic recrystallisation of the pyrite, and is probably not a primary feature. When observed in situ the layering is parallel to the bedding in the country rocks.

Isolated fragments of quartz sericite schist and of basic tuff (Plate 29) were noted within the massive ore; these fragments are tabular and have irregular contact with the sulphides. Foliation within the fragments (where noted) has the same attitude as the foliation in the host rocks. The fragments were not studied in sufficient detail to determine whether they represent boudins of original continuous layers or whether they represent primary fragments in the sulphide horizon.

(11) Banded Ore:- The layering in the banded ore (Plate 31) is defined by variation in the dominant mineral between layers. Layering averages 3 cm in thickness, and is commonly laterally continuous over distances greater than 3 metres and parallel to layering in the country rocks. Pyrite is the most common constituent in the individual bands and alternates with chalcopyrite, quartz, actinolite-biotite, or carbonate rich bands, and locally with sphalerite rich bands. A sharp distinction

Plate 31. Banded ore consisting of alternate layers of sphalerite (dark grey), chalcopyrite (deep yellow) and pyrite (light grey-green) rich material; Ming Ore Deposit.

Plate 32. Chalcopyrite and quartz in fracture along the margin of a basic intrusive rock cutting massive pyrite ore; blocks at base of picture are of massive pyrite ore; Ming Ore Deposit.

between banded ore and massive pyritic ore is often difficult to make, as massive pyritic and banded ore are commonly interlayered.

(III) Chalcopyrite-Pyrrhotite Ore:- This variety occurs as individual lenses up to 2 metres thick either within massive pyritic ore, or as individual lenses within the hangingwall or footwall rocks, the lenses are sometimes observed to cut across the main schistosity, and tend to occur in the hinge zones of post-main schistosity isoclinal reclined folds.

Chalcopyrite and pyrrhotite are commonly concentrated in a zone along the margins of the metabasite intrusions (Plate 32) and are often present in fractures within the intrusions.

Chalcopyrite is the dominant mineral in the ore variety, comprising up to eighty per cent; pyrrhotite is always present and occurs in thin continuous or discontinuous stringers or lenses (1 cm) which show curved boundaries with the chalcopyrite. Sphalerite is common but seldom constitutes more than three per cent of the rock; it can occur in small thin continuous or discontinuous lenses, or in small (3 mm) aggregates disseminated through the chalcopyrite and pyrrhotite

Pyrite porphyroblasts to 1 cm in size occur locally (Plate 38) in the chalcopyrite-pyrrhotite matrix; these porphyroblasts can constitute up to seventy per cent of the rock, but generally comprise less then fifteen per cent. Chalcopyrite-pyrrhotite lenses containing pyrite porphyroblasts are usually small (30 cm thick) and can occur throughout the ore horizon, the lenses are not spatially related to the cross-cutting dykes and sills

and the porphyroblasts probably grew during regional metamorphism. The porphyroblasts often show rounded corners and striated and gouged crystal faces (duchbewegung texture, Vokes, 1969) and are commonly fractured, these textures suggest rolling and grinding of the pyrite porphyroblasts during plastic flow of the matrix.

Chalcopyrite and pyrrhotite can occur in thin, small (0.5 cm long) monomineralic lenses with fibrous end terminations; these define a schistosity in the massive ore which locally forms augen round the pyrite porphyroblasts.

(IV) Breccia Ore:- The breccia ore variety consists of massive pyrite ore (locally banded ore) fragments sitting in a matrix of chalcopyrite and pyrrhotite with minor sphalerite (Plate 33). The brecciation varies from fractured massive pyrite ore in which the fragments show evidence of only minor dilation, to single isolated fragments within a chalcopyrite-pyrrhotite matrix. It is possible that some of this ore variety may be primary depositional breccia in origin, however, metamorphic crystallisation has destroyed any possible primary textures.

A distinctive variety in which the massive pyrite fragments are well rounded and oval shaped occurs (Plate 34); the long axis of the fragments are parallel to each other. This feature can be termed duchbewegung texture, and is thought to result from rolling and grinding of the massive pyrite fragments during deformation. Fractures within the fragments occur perpendicular to the long axis.

Chalcopyrite-pyrrhotite in the matrix to the pyrite fragments commonly occurs as thin monomineralic elongate lenses (to 1 cm long)

Plate 33. Breccia ore. Fragments of massive pyrite ore (grey-green) in matrix of chalcopyrite (deep yellow); Ming Ore Deposit.

Plate 34. Polished surface of breccia ore. Rounded and oval shaped fragments of massive pyrite ore in a chalcopyrite rich matrix, fragments exhibit chalcopyrite filled fractures which tend to form perpendicular to the long axis of the fragments. Ming Ore Deposit.

with fibrous end terminations and serrated boundaries, these define a schistosity in the matrix which commonly forms augen round the fragments.

The author did not make a detailed study of the relative spatial distribution between the ore varieties. A study of the relationship between the massive pyrite ore, the brecciated ore, and the massive chalcopyrite-pyrrhotite ore may be of interest in problems related to the mobilisation and relative mobilisation of sulphides during deformation and metamorphism.

Several other less common minerals are present. Arsenopyrite occurs in the massive pyrite ore, in fractures in the massive pyrite ore, and as porphyroblasts in the massive chalcopyrite-pyrrhotite ore. Very minor amounts of galena and tetrahedrite are common in the massive pyrite ore, magnetite was recorded in a specimen of breccia ore within the massive sulphide lenses. A large monomineralic pod of tennantite, 3 metres in diameter was noted. Free gold was observed in a single sample of pyrite ore, and cubanite occurs locally as exsolution lamellae from chalcopyrite within the massive chalcopyrite-pyrrhotite ore.

Bornite was recorded from specimens obtained in the open pit (i.e. the surface exposure of the ore body), and malachite and azurite are found in the surface area of the ore body and are presently forming on exposed surfaces underground.

5.3 Microscopic Textures of the Ore

(1) Pyrite (FeS_2):- Pyrite is the dominant mineral in the

massive pyrite ore, in the fragments in the breccia ore, and in the pyrite rich layers in the banded ore. The grain size is variable within and between layers, and ranges from 0.05 mm to 0.5 mm, this variation in grain size often defines the layering in the massive pyrite ore. The crystal form is variable and appears to depend on the amount of pyrite present in the sample, crystals in contact with other sulphides minerals (Plate 35) or with silicates tend to be idiomorphic in outline; when pyrite grains are in contact with each other they commonly tend towards a polygonal outline, the polygonal texture becomes more common with the greater the amount of pyrite present and triple junction grain interactions and slightly curved grain boundaries are developed between adjacent pyrite grains (Plate 36). Occasionally thin irregular bands of relatively coarse anhedral pyrite grains trend across the banding in the massive pyrite ore, in other samples thin irregular bands of fine grained polygonal pyrite are present; both of these features are here interpreted to result from fracturing in the massive ore horizon, in the first case renucleation occurred within the fractures, and in the second case annealing textures outline a 'healed' fracture.

Along the margin of the breccia ore fragments (Plate 37), and in fractures in the massive ore (Plate 41), aggregates of polygonal grains, and individual grains with polygonal outline are present. These polygonal grains or aggregates sit in a matrix of chalcopyrite and/or sphalerite and/or pyrrhotite, and/or gangue. The fractures develop either across individual pyrite crystals or along grain boundaries.

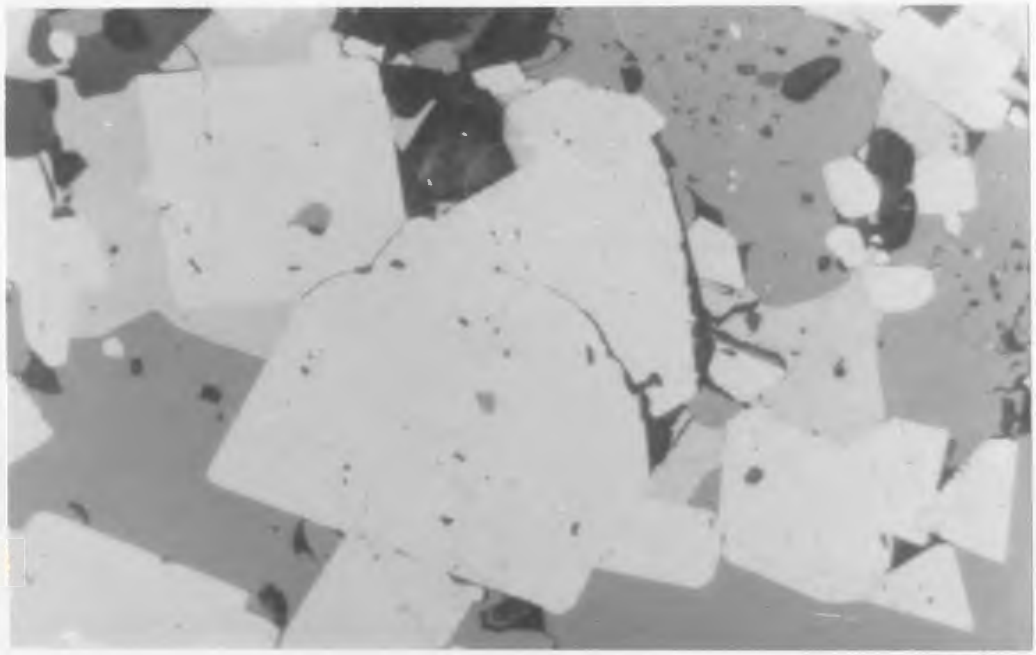


Plate 35. Massive pyrite ore. Idiomorphic pyrite grains in contact with chalcopyrite (light grey), sphalerite (medium grey) and gangue (dark grey to black), note inclusions of sphalerite and gangue within the pyrite grains; plane light, x 24. Ming Ore Deposit.

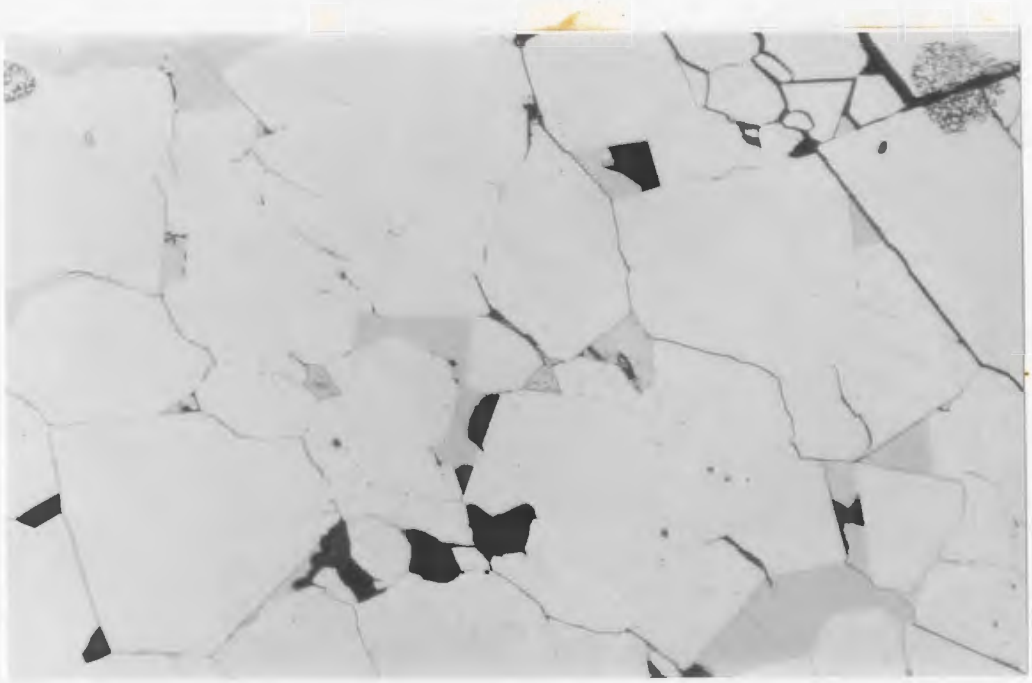


Plate 36. Massive pyritic ore. Pyrite grains show triple junction grain intersections and curved grain boundaries. Matrix is comprised of galena (light grey) and silicates (dark grey); x 20. Ming Ore Deposit.

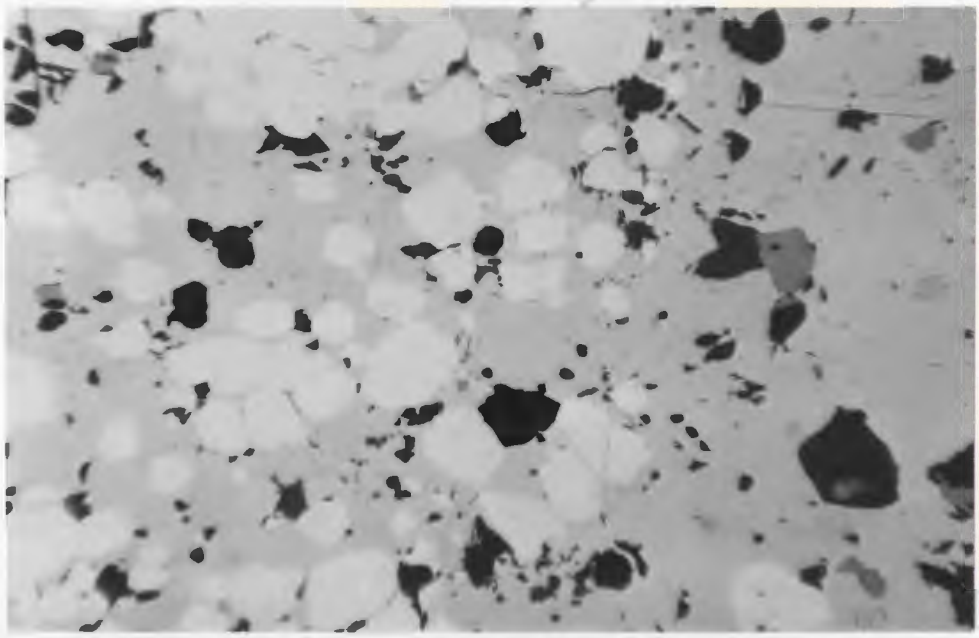


Plate 37. Breccia ore. Individual pyrite grains (white) and aggregates of pyrite grains with a tendency to polygonal grain outlines in a matrix of chalcopyrite (light grey) and gangue (dark grey to black); Ming Ore Deposit, plane light, x 16. Sample from margin of breccia fragment.

A

B

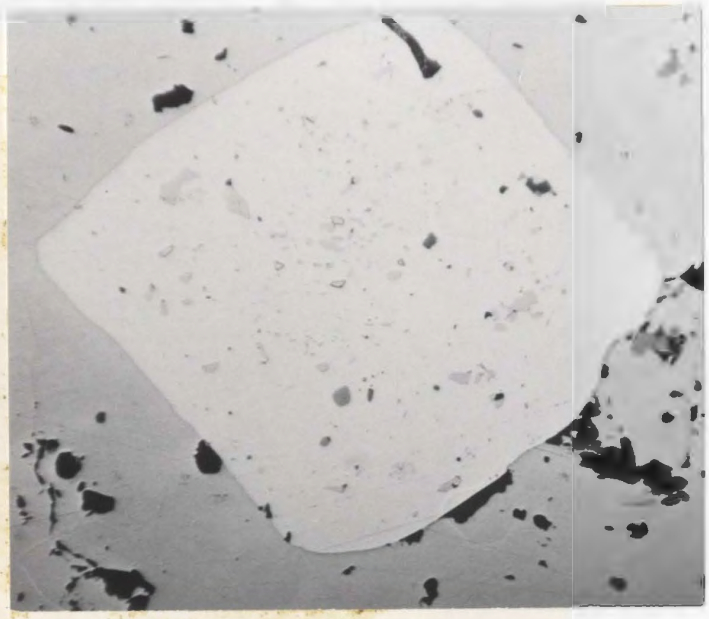


Plate 38. Pyrite porphyroblasts. A- hand specimen. B -polished section showing individual pyrite crystal (white) in a chalcopyrite rich matrix (light grey). Sphalerite (med. grey), and gangue (black) is present; note inclusions of chalcopyrite, sphalerite and gangue in the pyrite porphyroblasts, and also the slightly rounded corners of the porphyroblast; Ming Ore Deposit, x 10.

The texture is interpreted to indicate post-polygonisation development of fractures with mechanical or plastic flow of the softer sulphides into the fractures. This phase of deformation is post-dated by later cross cutting gangue filled fractures.

Pyrite also occurs as large porphyroblasts to 2 cm in size (Plate 38) sitting in a matrix of chalcopyrite and/or pyrrhotite with minor sphalerite. Locally porphyroblastic euhedral pyrite occurs within the massive pyrite ore but in these cases the grain size does not greatly exceed that of the groundmass pyrite. The porphyroblasts occurring in the chalcopyrite- pyrrhotite matrix can be anhedral or euhedral, they are commonly fractured. Matrix sulphides are present in the fractures. In hand specimen the well rounded crystals often exhibit striated and polished crystal faces (Duchbewegung texture).

Inclusions of chalcopyrite, sphalerite, and gangue are common in the pyrite porphyroblasts, locally galena and tetrahedrite inclusions are present.

Large pyrite crystals (up to 5 cm in size) with rounded corners and striated crystal faces occur locally in the predominantly quartz-filled gash veins in the metadolerites and country rocks.

Pyrite also occurs as disseminated euhedral grains in non-pyrite rich bands in the banded ore, and individual crystals are disseminated in the hangingwall and footwall rocks. In the country rocks the pyrite crystals are sometimes elongated parallel to the mineral lineation in the silicates, and strain shadows are developed round the pyrite grains.

(II) Chalcopyrite ($CuFeS_2$):- Chalcopyrite is the dominant mineral in the chalcopyrite-pyrrhotite ore, and in the matrix to fragments in the breccia ore. It also occurs in chalcopyrite rich bands in the banded ore and is the most common sulphide mineral in the matrix to pyrite grains in the massive pyrite ore.

In the massive ore and in the matrix to the breccia ore the chalcopyrite exhibits allotriomorphic texture with triple junction grain intersections and lobate grain boundaries, twin lamellae are common (Plate 42). Grain size ranges from 005 mm to 0.5 mm. Elongated chalcopyrite lenses (Plate 39) in the schistose chalcopyrite-pyrrhotite ore consists of small grains similar to those described above for the massive ore. Exsolution lamellae of cubanite from chalcopyrite are present to 1 cm long.

Chalcopyrite in the matrix to the massive pyrite ore occurs in irregular patches and lenses interstitial to the pyrite grains, the shape of the lenses is determined by surrounding idiomorphic and polygonised pyrite grains; several of these lenses consist of mosaics of small chalcopyrite grains showing allotriomorphic textures and triple junction intersections.

Within the fractures chalcopyrite is usually similar to that described above, several specimens however, show elongate chalcopyrite grains with serrated grain boundaries within the fractures; in one specimen the fractures and the direction of elongation of the chalcopyrite lenses are axial planar to an F_3 fold of the ore horizon.

Chalcopyrite shows mutual grain boundaries with sphalerite, pyrrhotite, and locally with gangue (although generally the silicates are more idiomorphic in outline).

(III) Pyrrhotite ($Fe_{1-x}S$):- Pyrrhotite comprises up to 20% of the massive chalcopyrite-pyrrhotite ore; it tends to occur in monomineralic lenses and layers up to 1 cm thick which show curved boundaries with the surrounding chalcopyrite. Pyrrhotite also occurs in fractures in the massive pyritic ore and in the matrix to the breccia fragments in the breccia ore. Very minor amounts of pyrrhotite are present in the matrix to pyrite grains in the massive pyrite ore.

The individual grains within the layers and lenses of pyrrhotite commonly show polygonal outlines with well developed triple junction intersections. In other samples pyrrhotite grains (to 1 mm) show deformation lamellae, twinning and undulose extinction. Elongate parallel pyrrhotite grains which are elongate perpendicular to a monomineralic pyrrhotite layer (5 mm thick) in massive chalcopyrite-pyrrhotite ore are present; the elongation is locally developed throughout the layer, and may result by development of individual crystals from deformation lamellae in earlier strained pyrrhotite grains. Locally the elongate grains consist of a mosaic of polygonal grains and show the final stage in annealing or recovery of the original strained crystal.

The pyrrhotite which occurs in the matrix to the massive pyritic

ore and in the lenses which define a schistosity along with chalcopyrite lenses (Plate 39) is fine grained and polygonised.

Pyrrhotite shows mutual boundaries with chalcopyrite and with sphalerite; the grain boundaries with pyrite are determined by the more idiomorphic pyrite grain outline.

Exsolution lamellae of pyrrhotite from cubanite are present in cubanite exsolution lamellae from chalcopyrite.

(IV) Sphalerite (ZnS):- Sphalerite occurs as a minor constituent and comprises 1-2% in most specimens studied. It is present in the matrix to the massive pyrite ore; it occurs as thin lenses and as disseminated irregular blebs in the massive chalcopyrite-pyrrhotite ore, and in the chalcopyrite-pyrrhotite matrix to the breccia ore. Monomineralic bands of sphalerite occur in the banded ore.

Grain boundaries are irregular, mutual boundaries with chalcopyrite and pyrrhotite are common and the more idiomorphic pyrite grains control the shape of the sphalerite-pyrite grain boundaries.

Locally exsolution lamellae of chalcopyrite are present in the sphalerite grains.

(VI) Arsenopyrite (FeAsS):- Minor amounts of arsenopyrite (Plate 40) are present in massive pyritic ore, in fractures in the massive pyritic ore and as isolated (commonly rounded and fractured) porphyroblasts in the massive chalcopyrite-pyrrhotite ore.

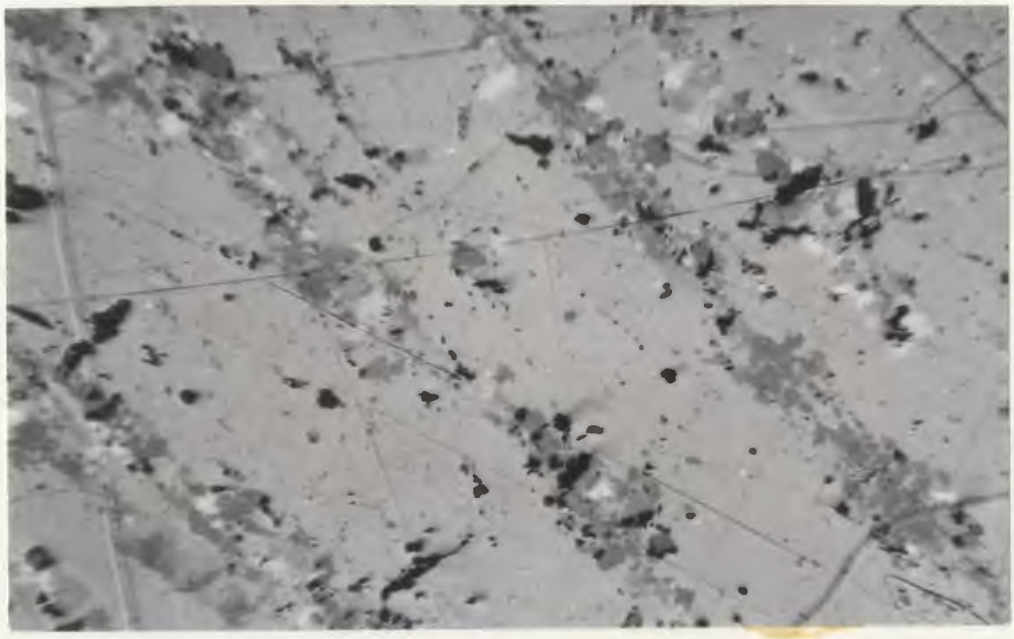


Plate 39. Elongate lenses of chalcopyrite consisting of a mosaic of grains showing a tendency to polygonal outline; intervening lenses of pyrrhotite (medium grey) are present; the straight lines are scratches on the polished surface. Ming Ore Deposit, crossed polars x 16.

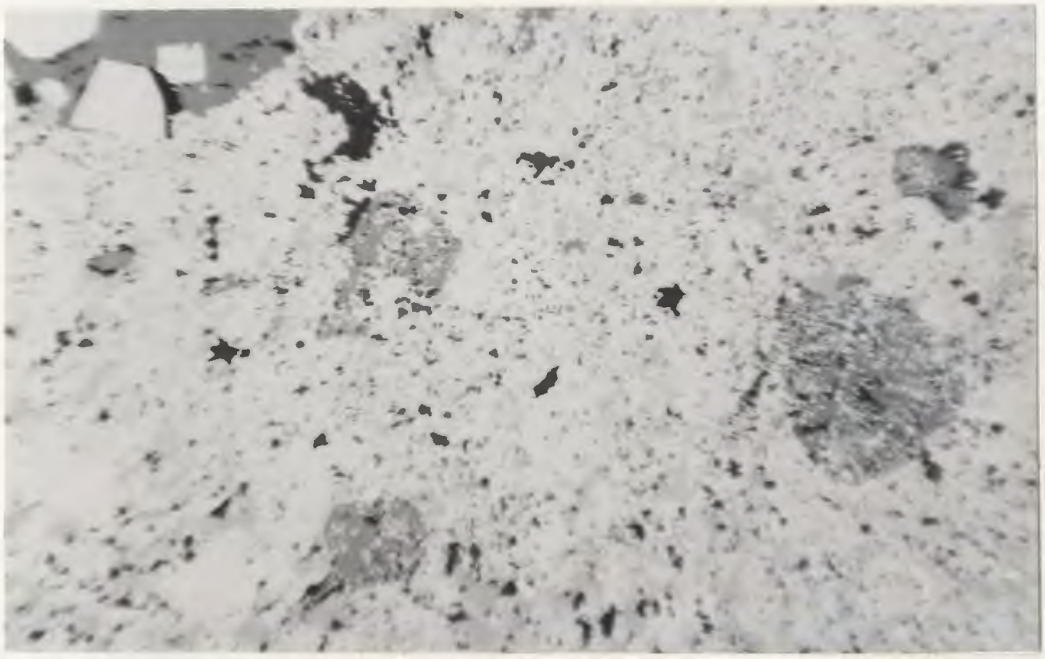


Plate 40. Porphyroblasts of magnetite in a massive pyrite ore fragment in breccia ore, note numerous inclusions of fine grained pyrite (white), of chalcopyrite (light grey), and of gangue (black) in the porphyroblasts. Large white crystal in the top left of the picture is arsenopyrite; Ming Ore Deposit, plane light, x 16.

Within the massive pyritic ore, arsenopyrite grains are euhedral and of similar size to the surrounding pyrite grains. Euhedral arsenopyrite grains are commonly found in narrow chalcopyrite rich fracture zones in the massive pyritic ore, the grain size is similar to or smaller than in the host massive pyrite.

Rounded and slightly fractured crystals occurring in massive chalcopyrite-pyrrhotite ore, reach 4 mm in size, inclusions of chalcopyrite and sphalerite are commonly present.

(VII) Galena (PbS):- Galena occurs as a very minor constituent in the ore body. It typically occurs in the massive pyritic ore along pyrite grain boundaries or pyrite triple junction intersections (Plate 36). Locally pyrite is present as inclusions in the galena grains.

(VIII) Cubanite ($CuFe_2S_3$):- Cubanite occurs as exsolution lamellae from chalcopyrite within the massive chalcopyrite-pyrrhotite ore; the lamellae are straight and reach 1 mm in length.

(IX) Magnetite (Fe_3O_4):- Euhedral porphyroblasts of magnetite (up to 1 mm) were noted in a sample of breccia ore (Plate 40), the magnetite occurs in the pyritic fragments and commonly contains a large number of pyrite inclusions.

(X) Gold (Au):- Two grains of free gold (grain size approximately 0.005 mm) were observed in a single sample of pyritic ore. The gold occurs in the margin of an arsenopyrite grain in a chalcopyrite rich fracture zone. Several small fractures in proximity to the gold grains are also filled with gold. It should be noted that free gold in the Ming Ore Body can only account for approximately 10% of the gold present in the deposit (Smitheringale, 1974) and Smitheringale suggests that most of the gold occurs in solid solution with the chalcopyrite.

5.4 Structure, Metamorphism and Mobilisation in the Ming Zone

The dominant fabric in the host rocks to the Ming Zone is a moderate N.E. dipping S_2 surface. S_2 is axial planar to several minor F_2 folds, and locally to minor tight reclined folds in the sulphide horizons; S_2 and bedding are generally parallel or subparallel. S_3 is axial planar to open to tight reclined N.E. and possibly N.W. plunging disharmonic folds of the ore horizon, bedding and S_2 (section 12 00 N.E., Fig. 5). Open N.E. trending warps and folds (F_4) of the ore horizon S_2 and bedding (Plate 23) with an associated N.E. plunging steep crenulation cleavage are developed.

A penetrative schistosity of the sulphide minerals is not observed in the ore horizon, phylloblastic minerals in silicate rich layers within the ore horizon commonly define S_2. Locally a schistosity is defined in the massive pyritic and banded ore by orientation of thin lenses of sphalerite and chalcopyrite in the matrix. These fabrics commonly cross the sulphide banding at a shallow angle. A

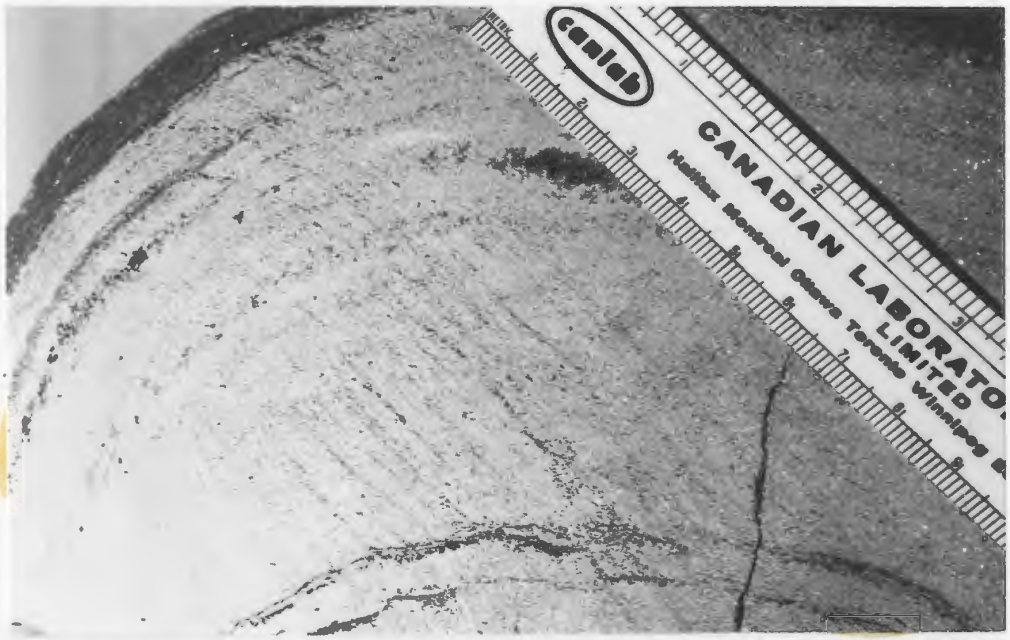


Plate 41. F_3 fold of massive pyrite ore and of hangingwall tuff (sharp contact). Axial planar fractures are developed in the massive ore and are filled with chalcopyrite, these are illustrated in detail on Plate 42. Small elongate pyrite grains help to define S_2 in the tuff.

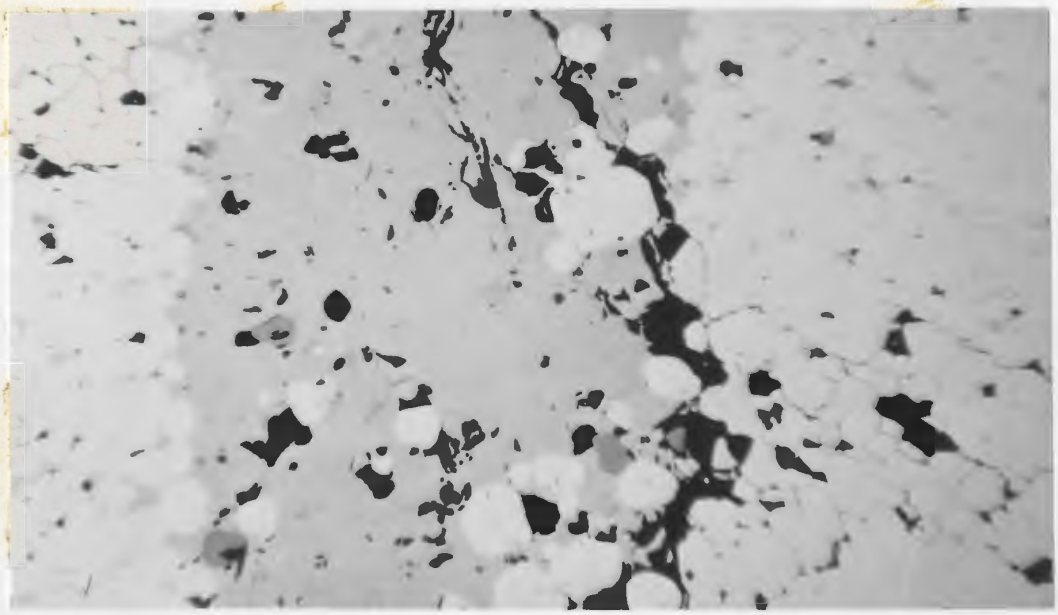


Plate 42. Detail of chalcopyrite filled fracture (white) (axial planar to F_3 fold illustrated in Plate 41). Pyrite in massive pyrite ore exhibits polygonal grain outlines (MP_2); individual grains of polygonal-pyrite are present in a chalcopyrite (light grey) matrix. The chalcopyrite exhibits twin lamellae and polygonal grain outlines. Sphalerite (med grey) and gangue are present as grains in the chalcopyrite matrix, and a late gangue filled fracture is present. Ming Ore Deposit, plane light, x 16.

crude schistosity is locally defined in the massive chalcopyrite pyrrhotite ore and in the matrix to the breccia ore by alternating lenses and wisps of chalcopyrite and pyrrhotite.

Plate 41 shows an F_3 fold of the massive pyritic ore, hangingwall tuffs and S_2 (the elongate pyrite grains in the tuff indicate that the pyrite was deformed during D_2) an S_3 fracture schistosity is developed in the massive sulphides and is illustrated in detail in Plate 42. These fractures developed after polyonisation (MP_2) of the massive pyritic ore and suggest mechanical (plastic flow) differentiation of the chalcopyrite from the massive ore during D_3. The chalcopyrite exhibits polygonal grain outlines and twin lamellae which indicates annealing of the chalcopyrite after migration. The silicate filled fractures occurred after migration, but may have developed prior to annealing of the chalcopyrite.

The relationship between most of the fabrics in the sulphides and the fabrics in the country rock has not been determined. Individual pyrite grains in the country rock are commonly elongate parallel to S_2 and thin lenses of chalcopyrite and locally sphalerite help to define S_2 in the host rocks to the sulphides. No D_1 features were observed in the sulphide lenses.

Tight fold closures of minor amplitude were noted in the banded ore. Transposition of the limbs of these folds commonly result in the development of a pseudo-cross stratification texture in the ore.

All the country rocks in the Ming Zone are comprised of metamorphic mineral assemblages, with dynamic metamorphic growth features dominant. Upper greenschist facies conditions were attained during and after the main D_2 event.

Gale (1971) concluded that fluid inclusion filling temperatures on quartz gangue and on remobilised sulphide veins in the East Mine and in the Rambler Mine indicated temperatures of crystallisation of 145-330 degrees C (uncorrected for pressure), however the veins may have formed late in the deformational history of the deposits. Accurate temperature and pressure estimates based on the sulphide mineral assemblages and on the sulphide mineral compositions require further analytical work and an understanding of the relationship of the sulphide phases to the deformational history of the deposits.

The sulphide textures described in the Ming Zone can be attributed to metamorphic crystallisation and to post-deformational annealing (Vokes, 1969; Stanton, 1972), and are typical of metamorphosed massive sulphide deposits in general. The euhedral to subhedral outline of many of the pyrite grains reflect the greater tendency of the pyrite grains to idiomorphism relative to the other softer sulphide minerals. The presence of both polygonal and fractured pyrite grains around the fragments in the breccia ore, and in fractures which may be related to D_3 suggests that the main phase of polygonisation took place prior to D_3 and may be MS_2 or MP_2 in origin; these and the presence of duchbewegung textures suggest that at least some of the brecciation

is related to D_3 deformation. The polygonal texture of the chalcopyrite and pyrrhotite grains in schistose lenses of chalcopyrite and pyrrhotite suggest that annealing took place after the development of the schistosity. In general the relationship between deformation and metamorphism in the sulphides can only be determined locally.

The foliation within the silicate rocks has developed by growth and orientation of the phylloblastic minerals during deformation, during D_3 the main foliation was kinked and crenulated and minor renucleation and growth of phylloblastic minerals occurred. Within the sulphide rocks, the elongate lenses of chalcopyrite and pyrrhotite suggests that large (probably annealed) grains may have been flattened to produce the schistosity with subsequent annealing to form a fine grained mosaic of polygonal grains. These features demonstrate the fundamental difference in behavior of the silicate and sulphide minerals during deformation. Pyrite grains deformed by D_2 within the silicate rocks commonly maintain their deformed shape and their crystal outlines are determined by the more idiomorphic silicate minerals. In the massive sulphide ore and locally in the silicates, the pyrite grains have generally annealed after the main deformation.

In general the highest grade ore occurs in the vicinity of the D_3 recumbent structures, this may be a cause rather than an effect with regard to the mobilisation of sulphides since the highest strain will be in the less competent chalcopyrite rich portion of the ore body (Fig. 8), and it provides no evidence to suggest that chalcopyrite was

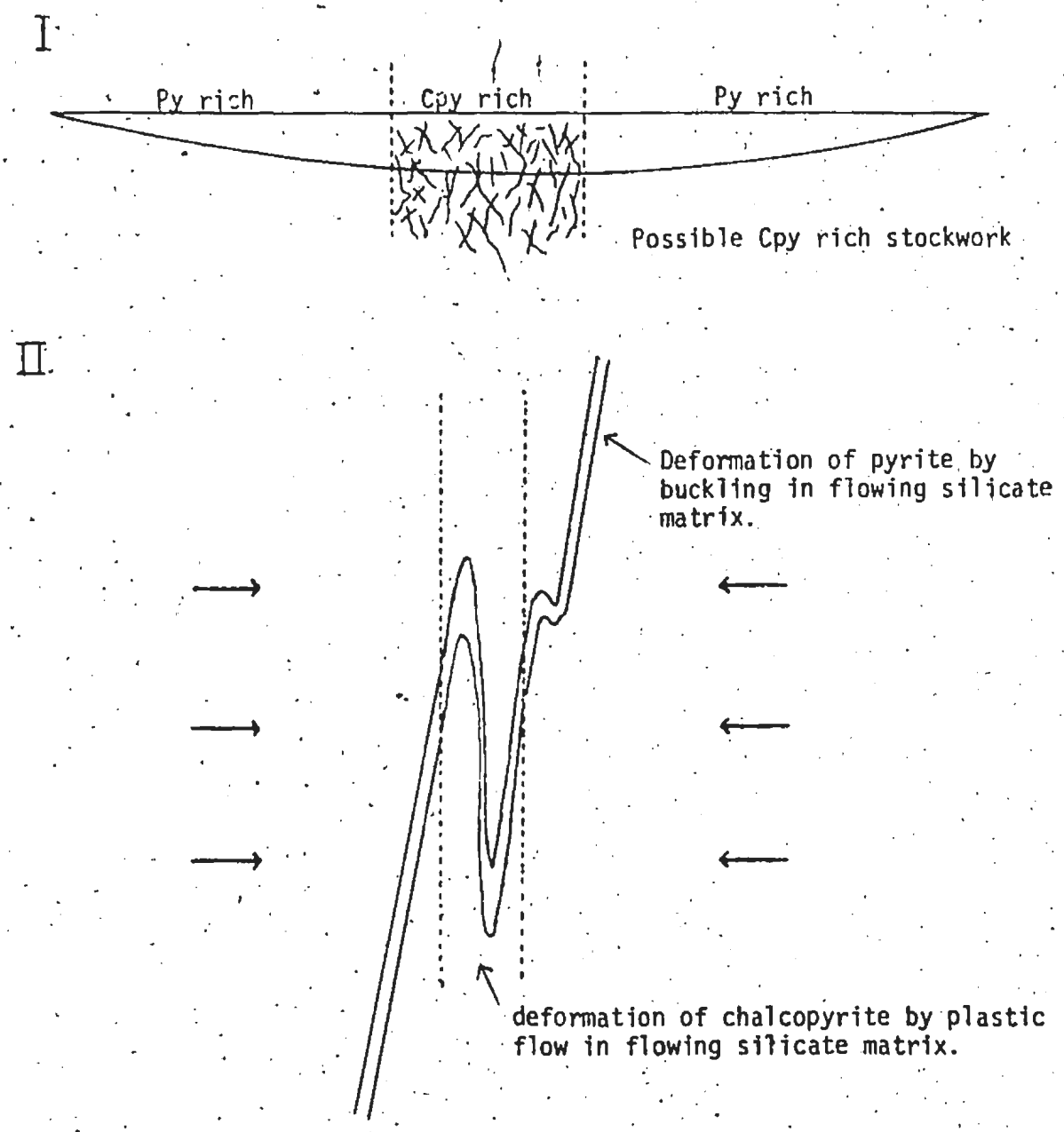


Figure 8. Schematic illustration of possible difference in deformational behavior of a zoned Py-Cpy massive sulphide deposit. I, possible predeformational zonation; II, post-deformational pattern with apparent enrichment of sulphides in zones of folding.

mobilised into the folded area. The chalcopyrite was mobilised at least on a small scale; this is shown by the matrix to the breccia ore fragments, by chalcopyrite rich veins cutting S_2, and by the presence of chalcopyrite in gash veins.

A detailed study of the spatial relationship of the main ore types in the Ming Mine was not undertaken. As a generalisation, the breccia ore and the massive chalcopyrite ore occur in the folded and disturbed areas, and massive pyrite and banded ore occur towards the margins and outside of the economic ore deposit.

5.5 Mineral Zonation

Heenan (1973) observed that the sphalerite in the Ming Mine is concentrated towards the bottom of the ore deposit, and suggested the deposit may be stratigraphically overturned. The observation is correct, however the situation is more complex than that described by Heenan, since there are generally three lenses of sulphide present. The currently available information suggests that in most cases the assay values for copper and zinc increases towards the bottom of each individual ore lens, and the highest values for zinc are found in the lowest ore lens. Table 5 shows assay values over 1 ft. intervals from drill hole No. 540 # 10, the hole intersected the ore body at approximately section 9 00 N.W. and 13 00 N.W.. Three lenses of sulphide were intersected, from underground mapping (R. Norman pers. comm.) the three layers are part of a single lens which is recumbently folded, the central lens is overturned with respect to the upper and lower lens.

The results (Table 5) indicate that in all three lenses the highest copper and zinc values occur towards the bottom of the lens, and the highest zinc and copper value occur in the lowest lens. In the central and lower lens, the highest Pb to Cu ratios occur at a slightly higher elevation than the highest Zn/Cu ratios, in the upper lens the highest Pb/Cu ratios occur beneath the highest Zn/Cu ratios. The results are confusing, which is not surprising with respect to the possible mobilisation effects relating to deformation. Further detailed work is required before a definitive statement can be made. These features may be worth further investigation since it is generally accepted that metal zonation is a primary feature in massive sulphide deposits (Sangster, 1972; Ishihara, 1974), however Govett and Whitehead (1974) suggest that in some cases metal zoning may be a secondary phenomenon in response to electrical potentials developed within the sulphide bodies.

Copper assay values are extremely erratic and can vary from 1% to 20% in ore broken from adjacent rounds of blasting. On average, the highest grade ore is found in the centre of the deposit in the vicinity of the F_3 fold.

Table 5. Assay values for copper, lead, and zinc in D.D.H. 540-10, Ming Mine. Assays at 1 ft. intervals in each ore lens.

	(DDH footage)	% age			Ratios		
		Cu	Pb	Zn	Zn/Cu	Pb/Cu	Pb/Zn
	122 ft.	1.00	0.08	0.06	0.06	0.08	1.33
		0.76	0.08	0.11	0.15	0.11	0.73
		0.67	0.12	0.08	0.12	0.17	1.50
		0.59	0.04	0.04	0.07	0.07	1.00
Lens 1		0.77	0.08	0.05	0.07	0.06	1.60
		0.79	0.08	0.06	0.08	0.10	1.33
		2.34	0.50	0.20	0.09	0.21	2.50
		5.00	0.40	0.25	0.05	0.08	1.60
	131 ft.	16.00	0.25	2.14	0.13	0.01	0.12
	139 ft.	2.53	0.04	0.06	0.03	0.02	0.67
		0.64	0.01	0.05	0.08	0.01	0.20
		0.98	0.03	0.06	0.06	0.03	0.50
		1.02	0.11	0.05	0.05	0.11	2.20
Lens 2		1.07	0.13	0.08	0.07	0.12	1.62
(overturned with		0.95	1.23	0.08	0.08	1.29	15.38
respect to lens		1.51	0.83	0.10	0.07	0.54	8.30
1 and 3)		1.78	0.71	0.30	0.17	0.39	1.01
	148 ft.	4.14	0.24	0.63	0.15	0.05	0.38
	159 ft.	3.29	0.38	0.19	0.06	0.11	2.00
		1.92	0.33	0.08	0.04	0.17	4.12
Lens 3		3.68	0.74	0.38	0.10	0.20	1.95
		11.88	0.62	2.21	0.18	0.05	0.28
	163 ft.	4.38	0.14	0.35	0.07	0.03	0.40

CHAPTER VI

DISCUSSION AND CONCLUSIONS

6.1 Structure

Early structural interpretation in the area by Livingston (1942), and by Neale (1958) suggest the presence of a N.E. plunging synform in the area. Gale (1971) recognised three major phases of deformation in addition to the later phases of brittle deformation; he recognises the main foliation and lineation (S_2 and L_2 in current study) and identified two subsequent fold styles, he was unable to identify the relationship between his second and third deformations nor did he recognise any major folds in the area. The author does not disagree with Gale's work but suggests that a sequential deformation history can be recognised in the Rambler Area, that evidence to indicate an earlier deformation episode than recognised by Gale is present, that major and minor folds relating to the main deformation are present, and that large open post main deformation folds are also present. The structural history indicated from the current study is described in Chapter 3, and is summarised in Table 3, and the geometry and distribution of recognisable folds is depicted in Figure 4 and Figure 7. The major phases of folding in the area are co-axial.

It cannot be definitely proved that the sulphides in the Ming Ore deposit were subject to D_1; they have been subject to D_2 and later episodes of deformation. The deformational and metamorphic features in

the Rambler Deposit and in the East Deposit have been described by Gale (1971) and can be related to the main deformation episode (D_2). It is probable that the sulphide deposits are syngenetic and have been subject to all the deformation phases in the Rambler Area.

The plunge of the long axes of the sulphide deposits in the area are subparallel to each other and to the direction of particle and mineral elongation and are also parallel to the axis of the major fold episodes. In view of the probable complexity of the initial volcanic environment it is probable that considerable modification of the shape of the ore lenses took place during the main D_1/D_2 strain episodes, and that the ore deposits were rotated and elongated to parallel the Z axis of the Deformation ellipsoid. The main foliation is parallel or subparallel to the strike of the known ore deposits; if the flattening component was significant during D_1/D_2 then the strike of the deposits may have been rotated towards parallelism with the Z-Y plane of the deformation ellipsoid. Possible sulphide zones in the area in which S_2 has a steep to vertical attitude may be expected to strike subparallel to S_2, to plunge parallel to L_2 at a moderate angle towards the N.E., and to have a sub-vertical to vertical dip. In conclusion it appears that sulphide deposition was not controlled by deformation, however the present configuration of the deposits result from modification of the original shape of the deposit during the main D_1/D_2 event. From a practical point of view, the single most important structural feature is the particle lineation since it is probable that the shape and

attitude of the deformed fragments in the area reflect the shape and attitude of the sulphide deposits.

The fact that massive sulphide deposits in strongly deformed volcanic terrains are commonly tightly folded and are elongate parallel to the fold axes is widely recognised (Vokes, 1969; Stockwell and Tupper, 1965; Zachrisson; 1971; Sangster, 1972; Wilson, 1973). Several of these authors refer to the fact that the ore deposits are elongate parallel to mineral, intersection, and crenulation lineations in the enclosing rocks, and they suggest that the ore deposits were elongated and/or flattened during deformation. Roscoe (1971) states that 'elongation of the rocks' occurred in the vicinity of the Caribou Deposit in New Brunswick, and Wilson (1973) refers to stretching lineations being parallel to the ore deposits in the Sulitjelma District in Norway. In most cases, stretching lineations are not referred to, in the case of the Rambler Area the stretching lineations provide evidence that the strain regime can be defined by $1 < k < \infty$ and provide further evidence to support the suggestion that the shape of the ore deposits were extensively modified during deformation.

Structural analyses and interpretation in other parts of the Eastern Sequence of the Fleur de Lys Supergroup have been made by Kennedy (Kennedy et al., 1972; Kennedy, 1973, 1975b) along the north coast of the Burlington Peninsula, and by DeGrace (DeGrace et al., 1975b) within the Cape St. John Group to the east of the Rambler Area (Table 6). The three structural histories are comparable, however the interpretations advanced by Kennedy and DeGrace differ significantly; Kennedy suggested

Table 6. Comparison of structural sequence in the Eastern part of the Burlington Peninsula.

Tuach Present Study		Kennedy 1972, 1975 b		Correlation uncertain	DeGrace 1975b	
	Later faults and kinks.		Later faults.		Dm+3	Open to locally close recumbent folds.
D_4	S_4 strain slip fabric open upright warps and F_4 folds.	D_4	S_4 strain slip fabric or crenulation. Open F_4 folds.		Dm+2	Upright folds.
D_3	Widespread S_3 strain slip fabric. Minor and possibly major NE plunging folds.	D_3	S_3 strain slip fabric F_3 isoclinal to open major and minor folds, overturned to south.		Dm+1	Strain slip fabric, south facing recumbent major and minor folds.
D_2	Penetrative L-S fabric locally a strain slip fabric minor and possibly major tight upright F_2 folds.	D_2	S_2 schistosity or L-S fabric, locally a crenulation. Major F_2 isoclinal folds, southward facing. Minor isoclinal to close F_2 folds.		Dm	Penetrative schistosity tight upright to overturned major and minor folds.
D_1	Relict penetrative L-S fabric.	D_{1b} D_{1a}	S_1 schistosity or L-S fabric. Local major F_1 folds. Minor tight to isoclinal F_1 folds Tectonic slides.		Dm-1	Local bedding plane schistosity.

that repeated phases of recumbent folding affected the rocks in the area, and suggests that the major recumbent S.E. facing F_2 structures present along the North coast of the peninsula have been downfolded in the central part of the Brulington Peninsula by later F_3 structures, DeGrace suggests that the major structures were upright and that the limbs of these folds have been vertically shortened to form southward facing recumbent folds along the north coast of the peninsula. The information available from the Rambler Area may fit either of these interpretations.

6.2 Geological Setting Rambler Area

6.2.1 Depositional model - Rambler Area

The available structural information does not suggest that large scale repetition of the stratigraphy in the Rambler Area is present. The apparent general dip of the rocks is towards the N.E. at approximately 30 to 40 degrees, and the available facing criteria suggests that the sequence is younger towards the N.E.. Contacts between the volcanic lithofacies units are gradational and no evidence to suggest the possibility of a major unconformity is present in the area, nor is there evidence to suggest the presence of major fault or slide.

On the basis of the available information, it is possible to construct a simplistic depositional model: -

(a) Deposition of a pillow lava unit. No basement to the pillow lava

sequence is observed in the Rambler Area (lithofacies A, Figure 4).

(b) Onset of proximal vent facies explosive basic volcanism, with deposition of agglomerates, tuffs, waterlain tuffs, and volcanogenic sediment, and extrusion of localised pillow lava units (lithofacies B).

(c) Explosive extrusion of a predominantly rhyolitic magma to form a proximal acid pyroclastic pile (lithofacies D), and a more distal mixed acid and basic pyroclastic terrain (lithofacies C). Deposition of the basic pyroclastic rocks continued during and after the extrusion of the acid material.

(d) Deposition of a thick unit of predominantly basic volcanic sediment and/or waterlain tuff with local extrusion of pillow lava units (lithofacies E), this unit represents a more distal and quieter environment.

The deposition of the volcanic sequence was followed by intrusion of the Burlington Granodiorite in the West, and the Cape Brulé Porphyry in the East. The basic intrusive rocks may have been intruded during build up of the volcanic pile both in the Rambler Area and to the East, and may in part feed the basic lavas.

A schematic pre-deformational reconstruction of the stratigraphy is presented in Figure 9, the continued presence of pillow lavas in the sequence implies that the rocks are marine in origin. The apparent stratigraphic position of mineralisation in the area is shown in Figures 3, 7 and 9 and is further discussed in the following section.

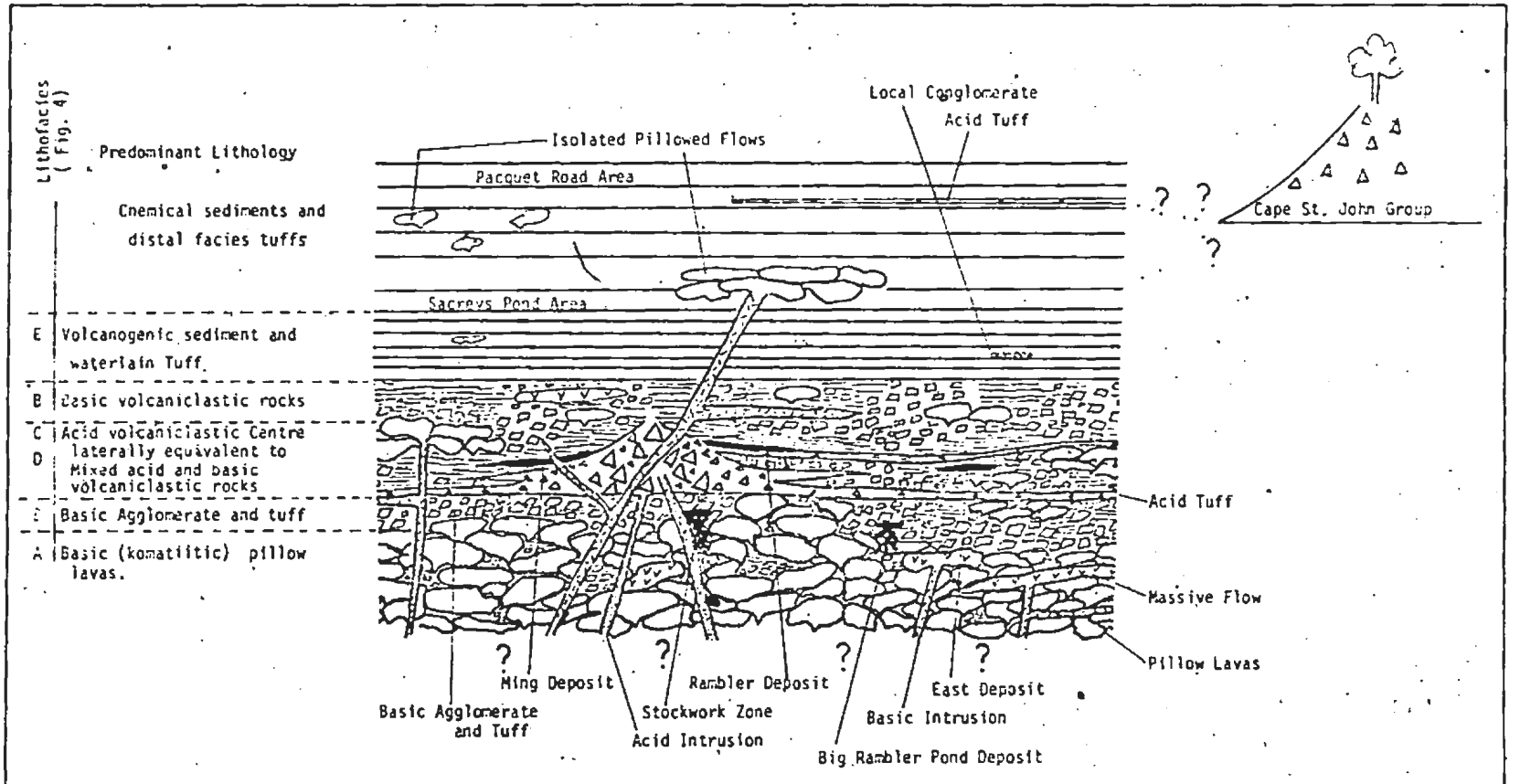


Figure 9. Schematic predeformational stratigraphic succession in the Rambler Area, Baie Verte.

6.2.2 Mineralisation in the Rambler Area

The Ming Ore Deposit (Chapter 5) is shown to lie on the N.E. side of the central acid pyroclastic terrain and at the top of the acid pyroclastic pile. The sulphide horizons exhibit a complex facies relationship with acid and basic tuffaceous and/or sedimentary rocks, and contain very minor gangue minerals; this feature suggests that deposition of the sulphides occurred rapidly, perhaps with the sulphides flowing into the environment.

The Rambler Ore Deposit which was a massive zinc-copper producer, and which was described by Gale (1971), shows gross similarities to the Ming Deposit. The ore body lies within the mixed acid and basic volcanic terrain. The sequence beneath the deposit appears to be truncated by a low angle fault; however, large acid fragments are present in a basic chloritic matrix in the vicinity of the mine, acid tuff units occur in the hangingwall, and silicic rocks and quartz-chlorite schists are present in the footwall of the mine. These factors suggest that the ore body was deposited on the margins of the main acid centre in the Rambler Area. The horizon bearing the Ming Deposit and the Rambler Deposit are probably equivalent, however, faulting and folding (Figure 3, 4 and 7) prevent certain correlation.

The East Ore Deposit was a disseminated and stringer chalcopyrite-pyrrhotite body, defined by cut off grade, and no massive sulphide horizons were noted (Gale, 1971). The deposit is stratiform and conformable to minor thinly bedded acid tuff horizons in the hanging-

wall, and the sulphides occur in a host rock of quartz-chlorite schist. On surface a unit of pyrite and mariposite bearing silic rocks is laterally equivalent to the chalcopyrite-pyrrhotite deposit at depth; locally basic volcanic sediments are recognisable on surface, and a single exposure shows the presence of pyrite-quartz stockwork veins cutting the volcanic sediment. The East Zone Deposit cannot be directly related to the Ming or to the Ramber Deposit; however, its apparent situation in basic sediment, the presence of thinly bedded acid tuffs and the presence of mariposite bearing pyritic silicic rocks may suggest that the mineralisation occurred in relationship to the massive sulphide mineralisation, and may represent a distal facies disseminated sulphide deposit, related to the acid centre. To the south of the East Deposit, the acid pyroclastic rocks are more abundent.

The Big Rambler Pond deposit is comparable to the East Ore Body. The country rock appears to be comprised of basic sediment, and basic pillowed rocks and pyrite and mariposite bearing chert beds are present in the vicinity of the deposit.

Numerous other showings are known in the Rambler Area; they lie predominantly within lithofacies B and C. They are always spatially related to silicic rocks and/or quartz sericite schist horizons.

In conclusion it is probable that the main phase of sulphide mineralisation in the Rambler Area relates to the submarine acid pyroclastic centre, and took place towards the end of the acid volcanism. The massive sulphide mineralisation may represent proximal facies mineral-

isation while the disseminated mineralisation may represent more distal facies deposition in a basin of basic sediment. The stratiform nature of the ore bodies suggest that the larger deposits may have been deposited at the ocean floor/sea water interface. The smaller showings may represent smaller deposits of syngenetic sulphide mineralisation or may perhaps be epigenetic deposits formed from migrating sulphide bearing fluids in the volcanic pile. The presence of mariposite and pyrite bearing chert beds indicates that exhalative activity was definitely taking place during volcanism, and the association of mariposite and pyrite bearing silicic rocks with all the economic deposits in the area, and with many of the showings suggest that mineralisation was exhalative in origin. The difference in sulphide composition of the various ore deposits may perhaps relate to the distance of sulphide migration from the main source, or to different vent sources. To date no definite large stockwork zone of mineralisation has been reported in the Rambler Area in association with the sulphide deposits; if such a zone is present it may be displaced from the sulphide deposits themselves and possibly awaits discovery. If such a zone exists or has not been removed by erosion it has still to be located.

Complex faulting or folding, presently unrecognised, may be responsible for the juxtaposition of the different types of deposits.

6.2.3 Regional Setting

The geological and tectonic setting of massive sulphide deposits

have received much attention in the literature within the past several years, and noteable reviews and publications have been made by Sangster (1972), Constantinou and Govett (1972), Riddler (1973b) Hutchinson (1973), and Lambert and Sato (1974). Within the framework of the ideas expressed by these and many other authors, the rocks in the Rambler Area can be considered to represent the evolution of a small volcanic basin (Fig. 9); mineralisation took place probably as exhalite towards the end of a phase of rhyolitic vulcanism round a rhyolitic centre; the rocks in the immediate Rambler Area represent proximal facies material while the rocks to the N. and N.E. of the area represent more distal facies material in the development of the basin. It seems probable that the Pacquet Harbour Group underlies, or may in part be laterally equivalent to the Cape St. John Group, the author would like to suggest that acid rocks are much more abundant in the Pacquet Harbour Group than is generally recognised, and the exact delineation of the nature of the Pacquet Harbour Group must await detailed studies of the entire Burlington Peninsula.

The nature of mineralisation in the Rambler Area has generally been recognised to be enigmatic (Hutchinson, 1973; Strong, 1973) within the framework of the overall plate-tectonic setting in the Newfoundland Appalachians in that the ore deposits in the area apparently show conflicting evidence of Cyprus type (Gale, 1973) and Kuroko type (Heenan, 1973) origin. Gale (1971, 1973) has analysed the country rocks in the area and has shown the basic rocks to be komatiitic and tholeiitic.

He suggests that the nine tholeiitic analyses are comparable to analyses of modern ophiolitic pillow lava sequences. It is pointed out that no evidence has been reported to suggest the presence of an ophiolite stratigraphy, or a dismembered ophiolite stratigraphy in the Pacquet Harbour Group; oceanic tholeiitic rocks are common within island arcs and in Archean greenstone belts, and furthermore, the complexly deformed, metamorphosed, and altered state of the rocks in the Rambler Area are liable to lead to misleading interpretation without detailed, numerous, and careful chemical analyses. Relatively undeformed sulphide bodies of a similar aspect to the East Ore Deposit are present in the Buchans district (J. Thurlow, pers. comm., 1975), and deformed deposits are present in the Noranda district (D.F. Sangster, pers. comm, 1973); these deposits are interpreted to represent stockwork mineralisation in association with chloritisation and silicification of the country rocks and are not immediately associated with massive sulphides. The deposits are uneconomic and as such have received little attention in the literature.

The presence of acid volcanic rocks in the hangingwall of the East Ore Deposit, and the abundance of acid rocks in the Rambler Area, the lack of ophiolite stratigraphy in the area, and the apparent contemporaneity of all the sulphide deposits in the Rambler Area do not support the contention that the East Ore Deposit has a Cyprus type origin. The conclusion is that the deposits are more akin to Archean and/or Kuroko type deposits.

It is interesting to note that komatiitic volcanics are abundant in Archaean volcanic terrains, and are thought to result from unstable crustal conditions, and large scale partial melting of mantle material. Hutchinson (1973), has pointed out the metal abundances (Cu-Zn) in the mineralisation in the Rambler Area is indicative of "primitive" crustal conditions as were present in Archaean terrains, and this observation is in agreement with Gale's analyses.

If it is accepted that the rocks in the Rambler Area are representative of primitive crustal conditions, the problem exists as to which particular tectonic environment produced these conditions. Within the framework of currently proposed models (Section 1-5) that of Hutchinson (1973) appears to be a front runner. Hutchinson suggests that the rocks in the Rambler Area were deposited during the initial stages of development of an island arc system, whether the island arc will prove to be related to initial development of a Pre-Burlingtonian island arc (Kennedy 1973, 1975b) or whether they relate to initial development of a central Newfoundland Ordovician island arc system (Strong, 1974; DeGrace et al., 1975b), or whether their origin may fall within some other tectonic hypothesis must await detailed structural, stratigraphic, and chemical studies of the entire Burlington Peninsula.

6.3 Outstanding Problems

The following topics are suggested for further work within the Pacquet Harbour Group:

(a) Detailed lithological and structural mapping in the Pacquet Harbour Group outside the immediate area of Rambler Mines.

(b) Whole rock geochemical studies of regional extent and in the immediate vicinity of the mines.

(c) Co-ordination of all currently available and future data obtained from geological, geochemical and geophysical surveys and from diamond drilling in order to permit a realistic geological analyses throughout the Pacquet Harbour Group.

(d) Investigation of the co-existing sulphide phases in the Ming Mine, and a field study of the relationship between sulphide and silicate minerals during repeated deformation.

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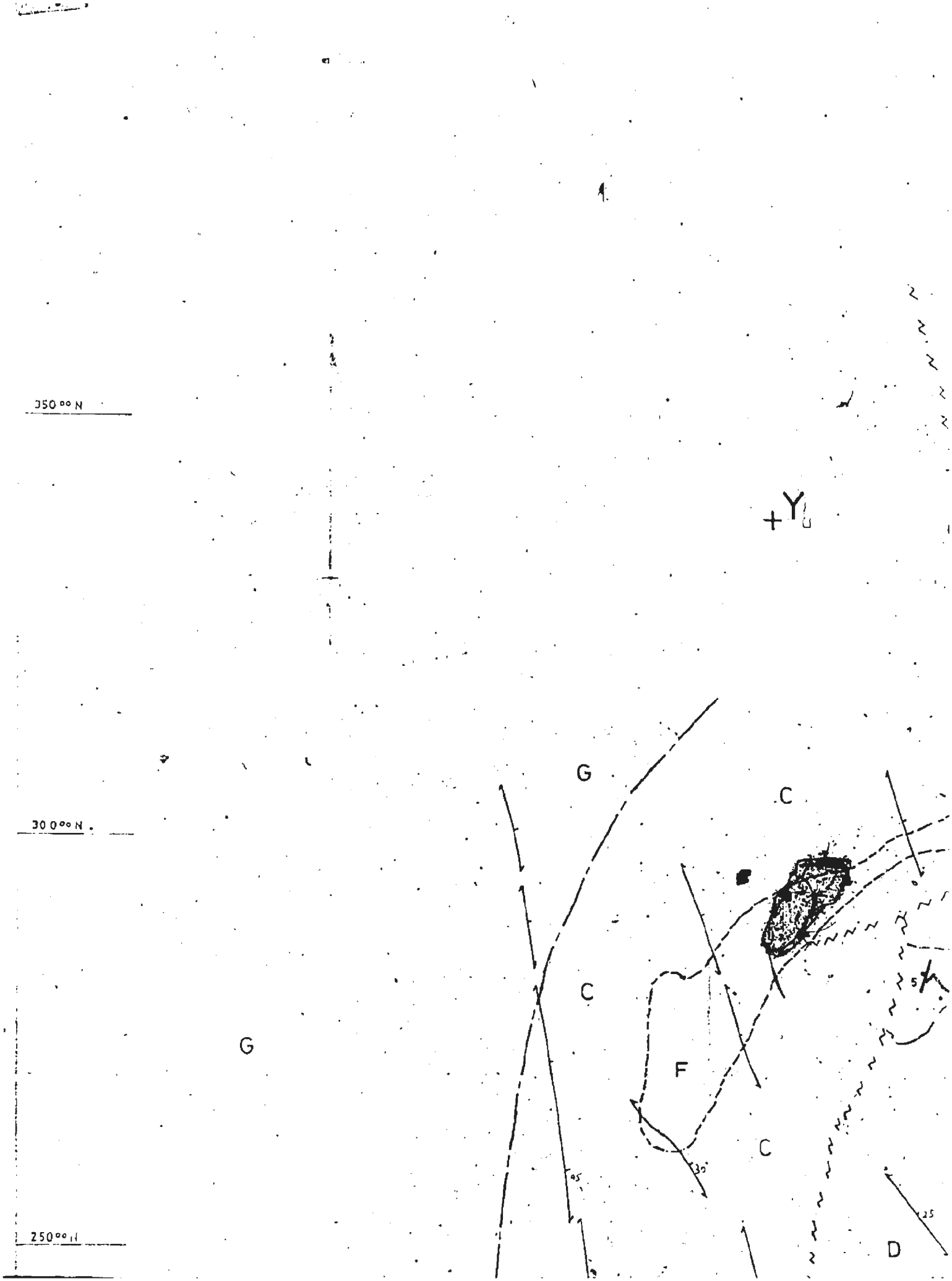
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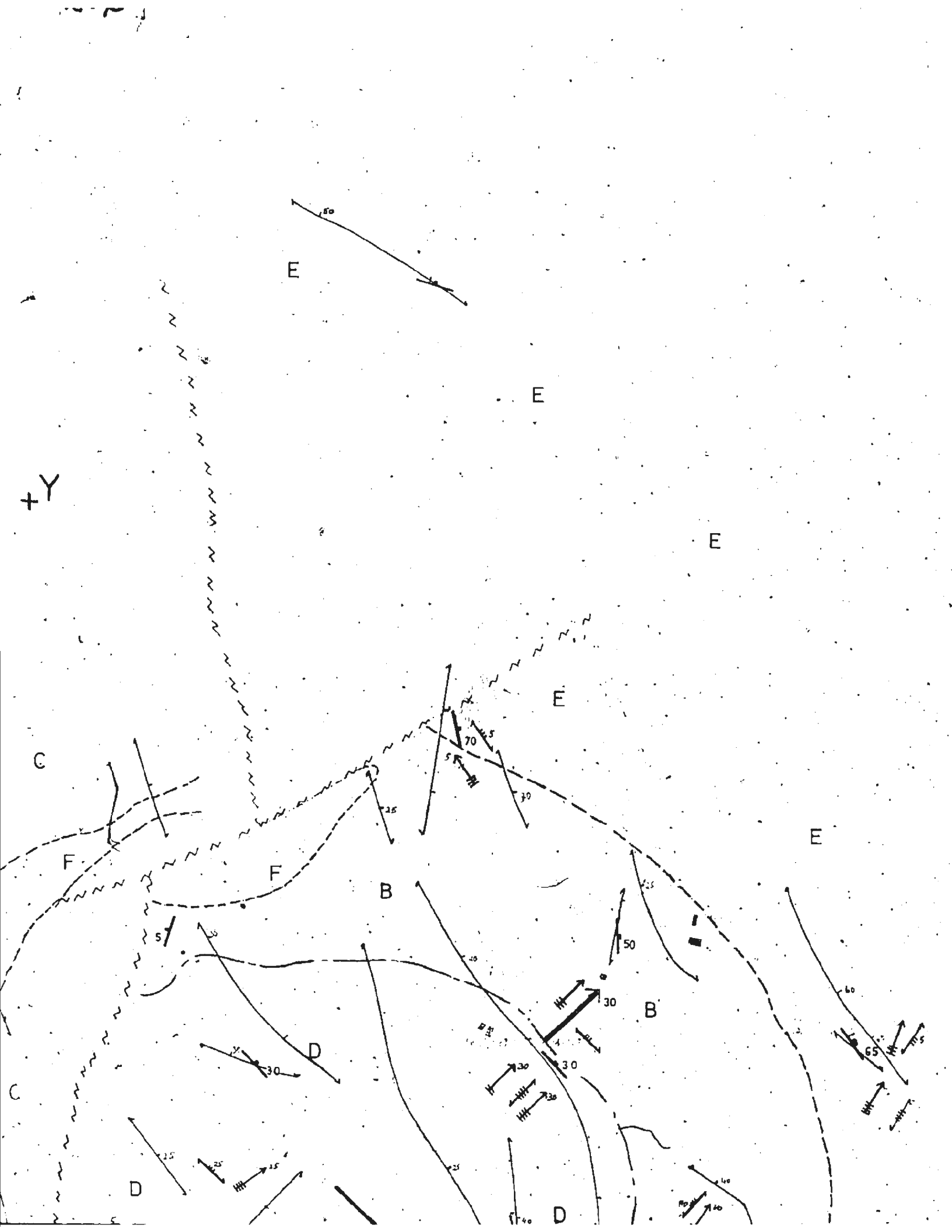
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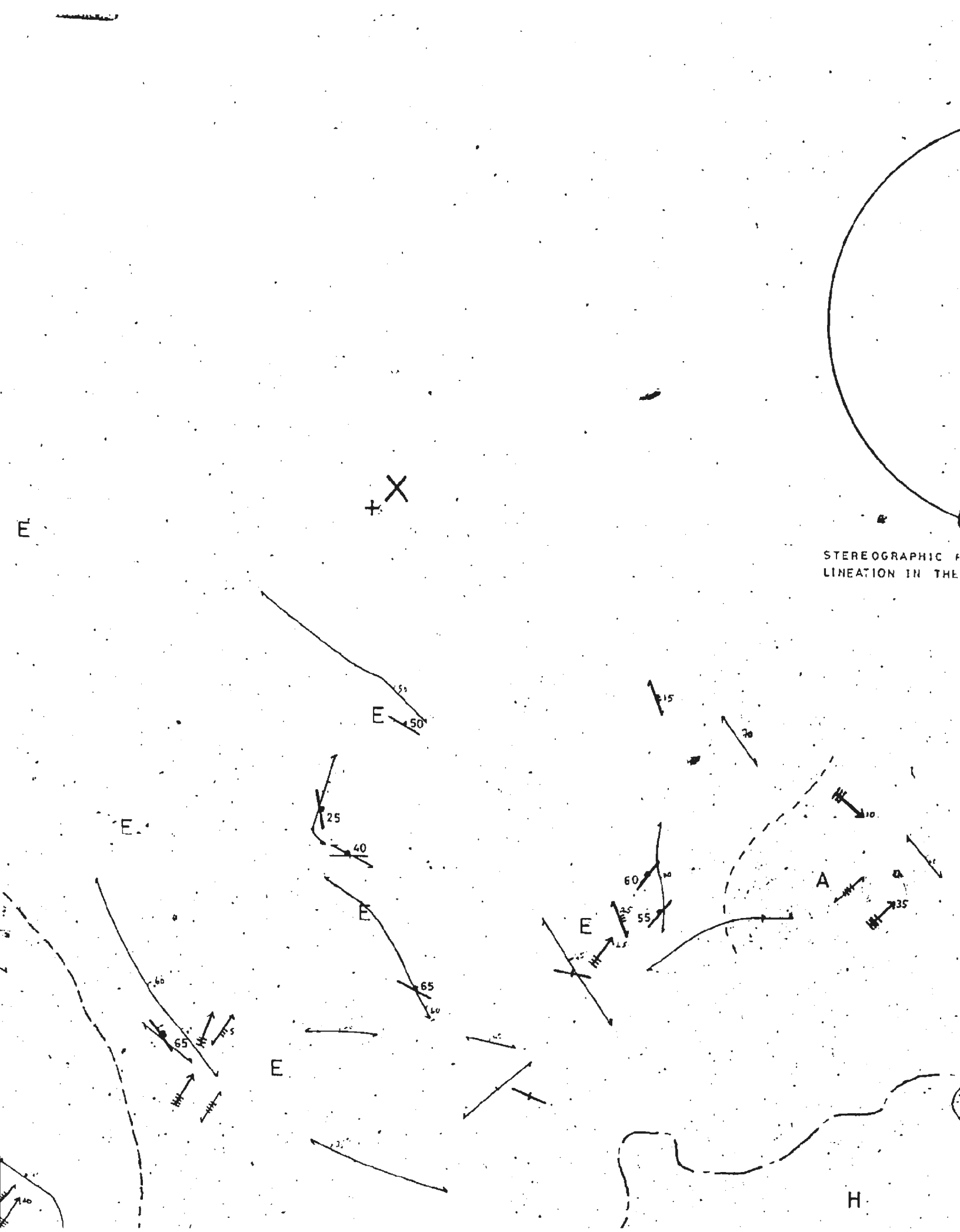
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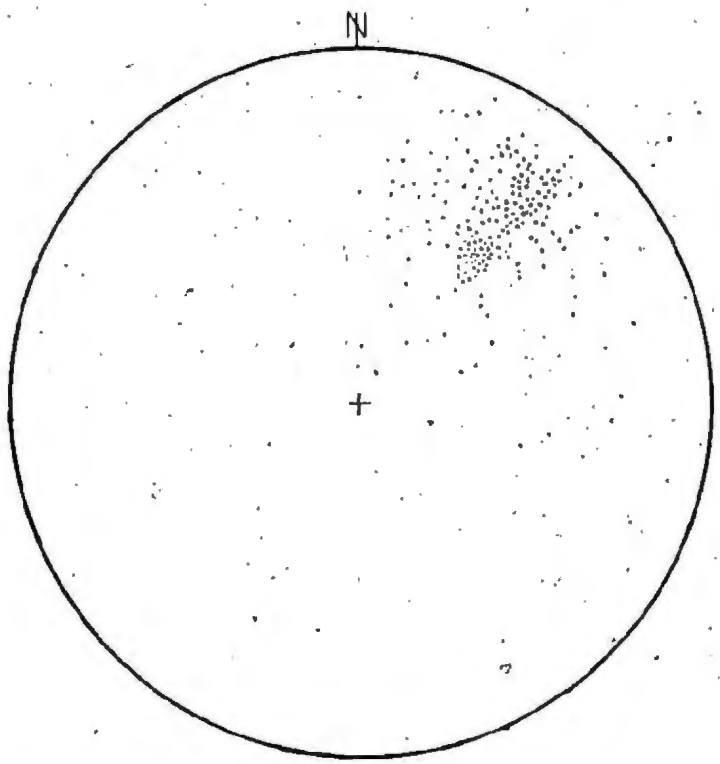
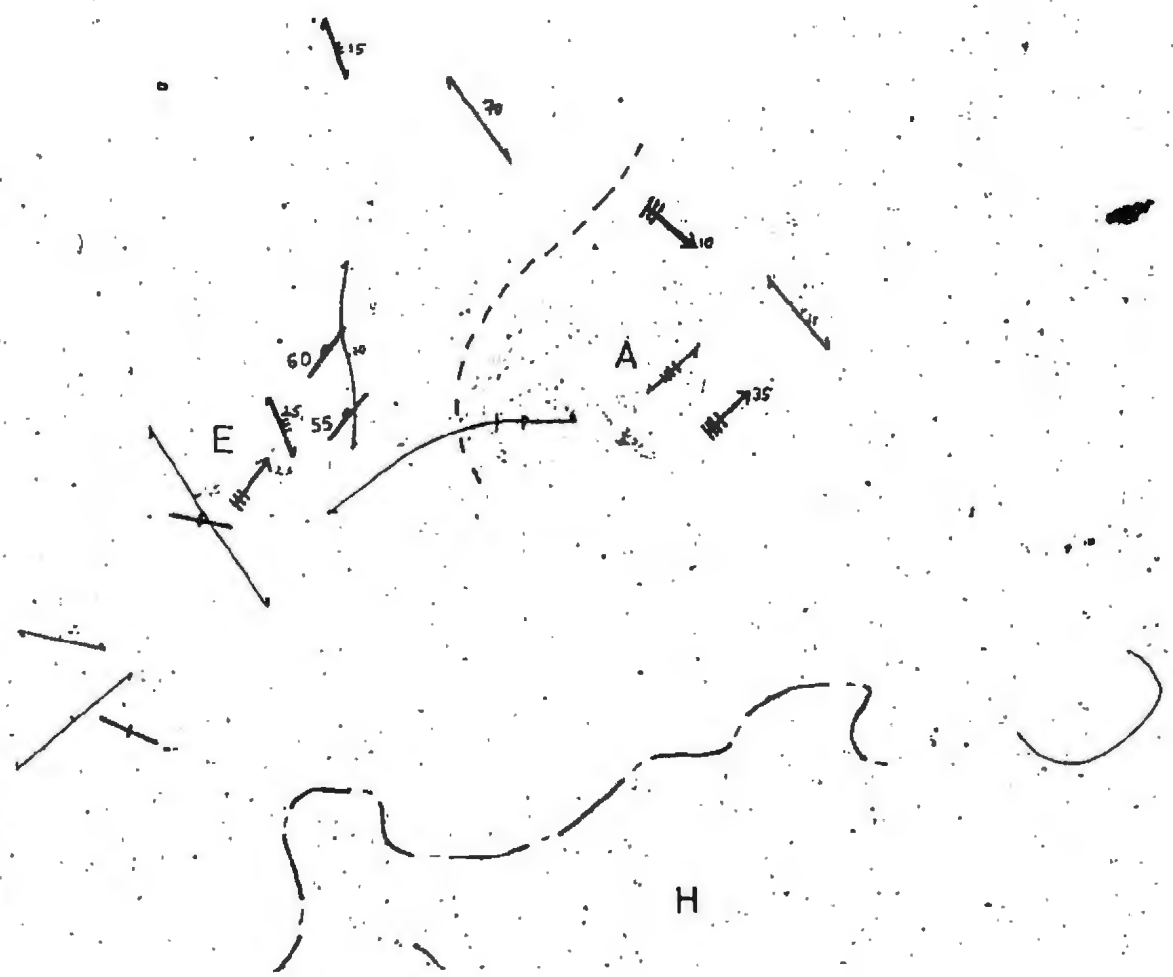


STEREOGRAPHIC PROJECTION OF MINERAL AND PARTICLE LINEATION IN THE RAMBLER AREA (L_1? + L_2)



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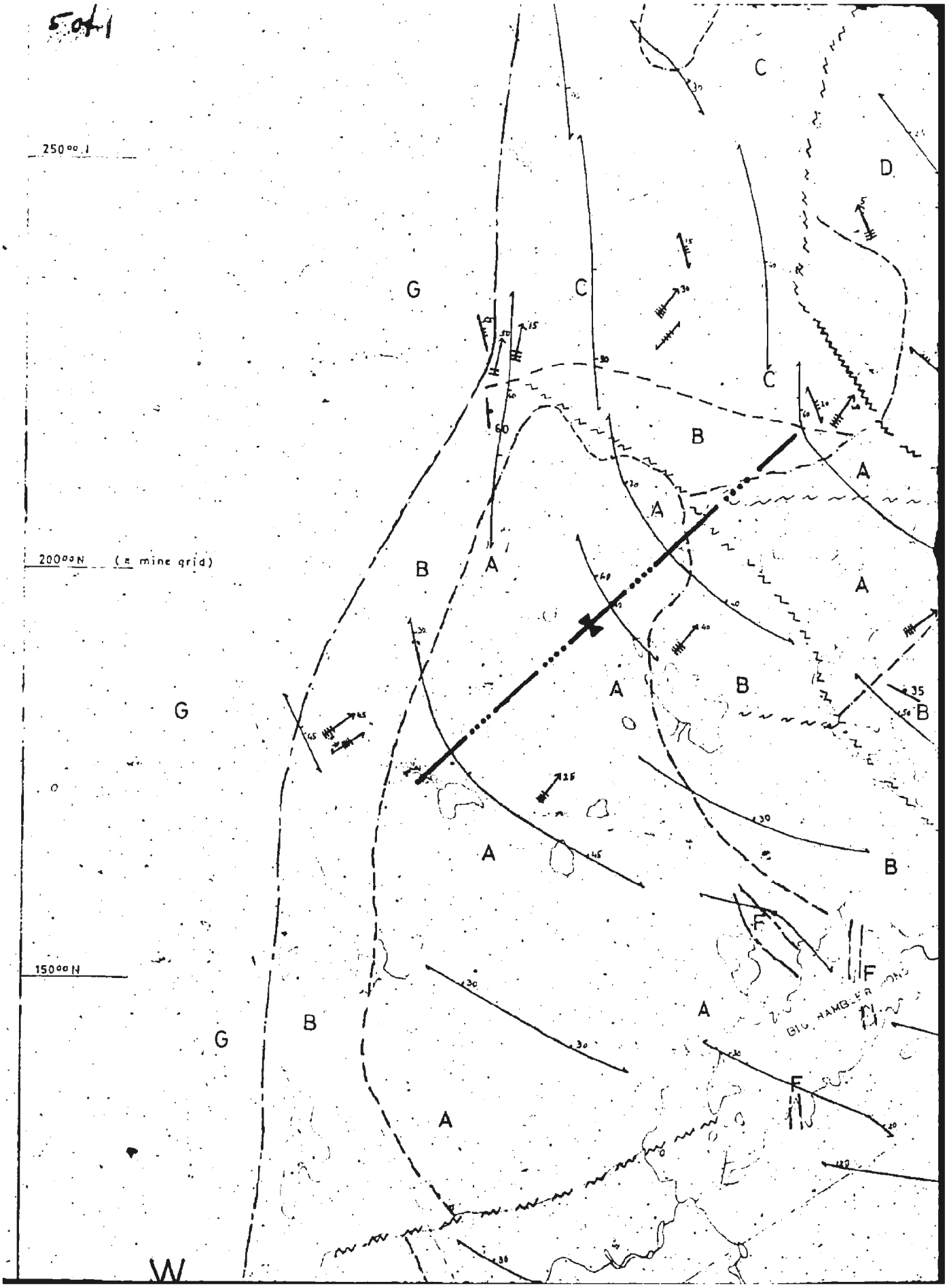

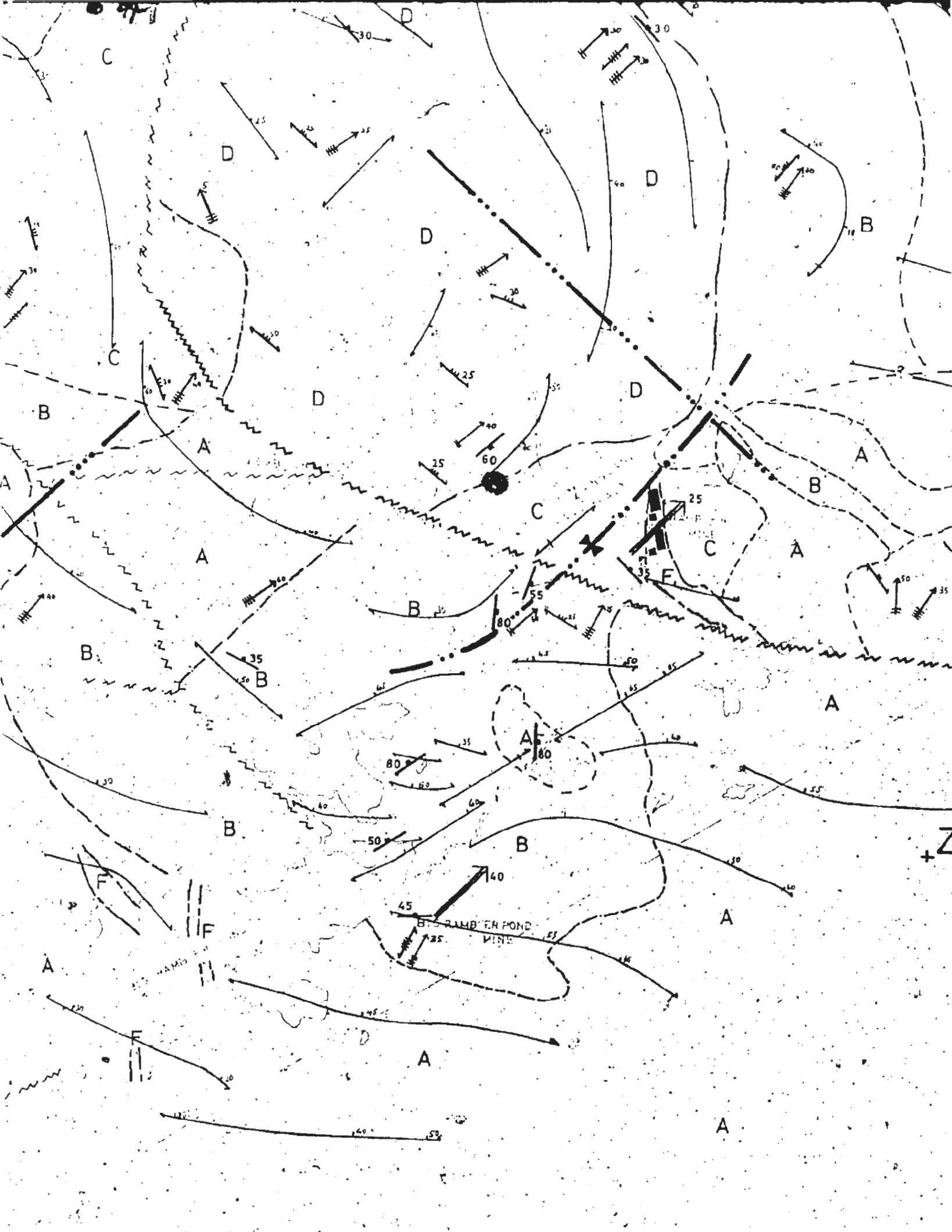
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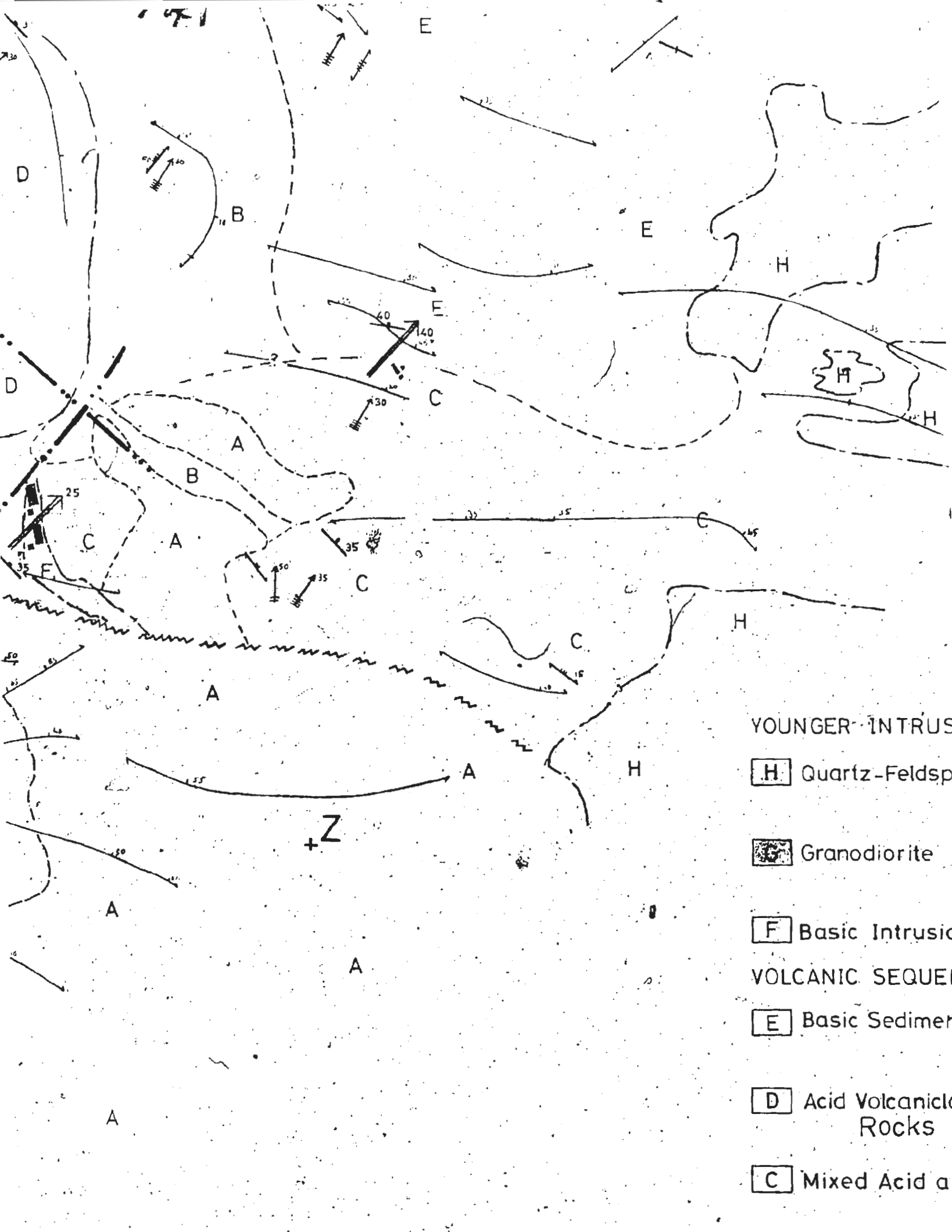
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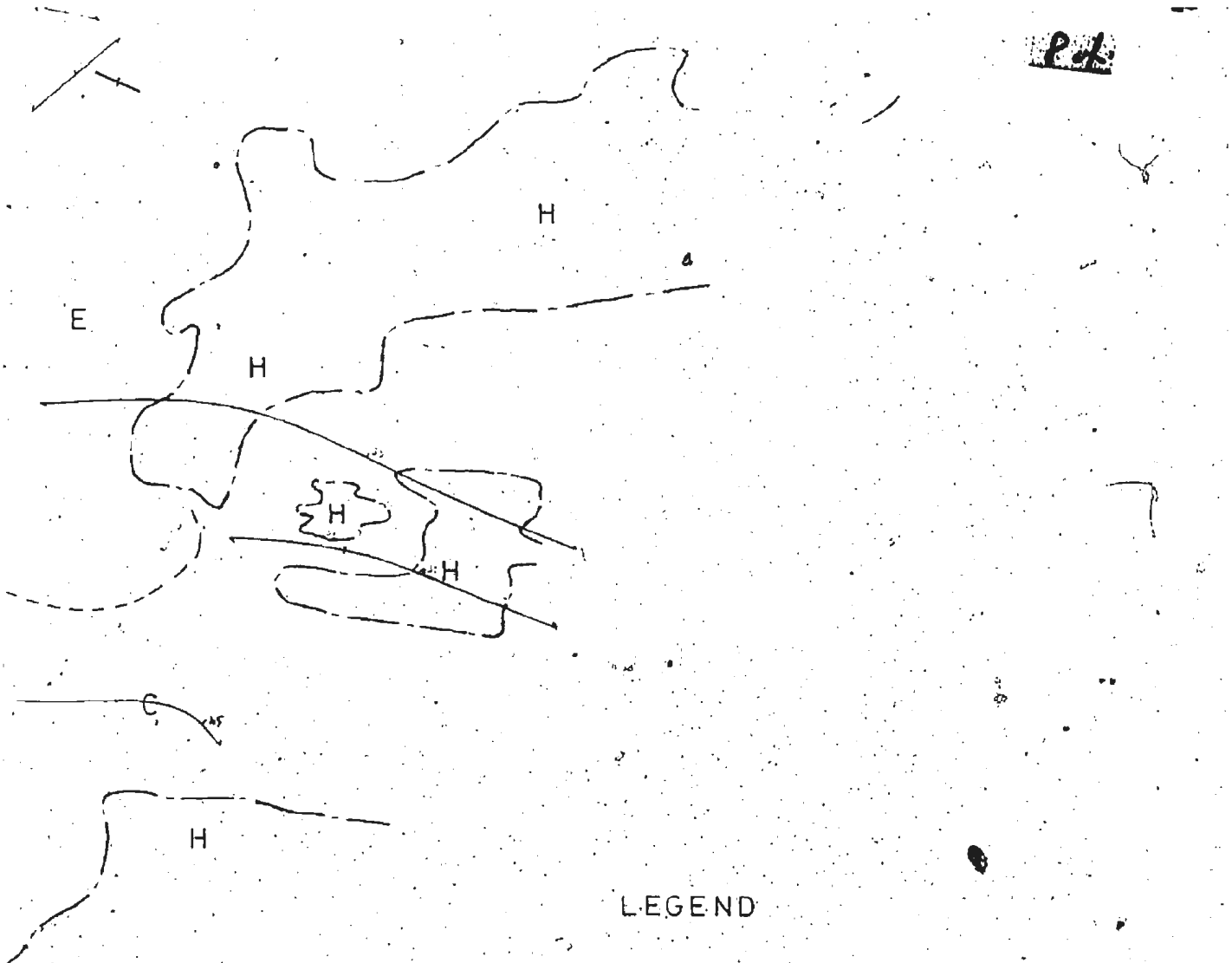
C Mixed Acid a



LEGEND

YOUNGER INTRUSIONS

H — Quartz-Feldspar Porphyry

G — Granodiorite

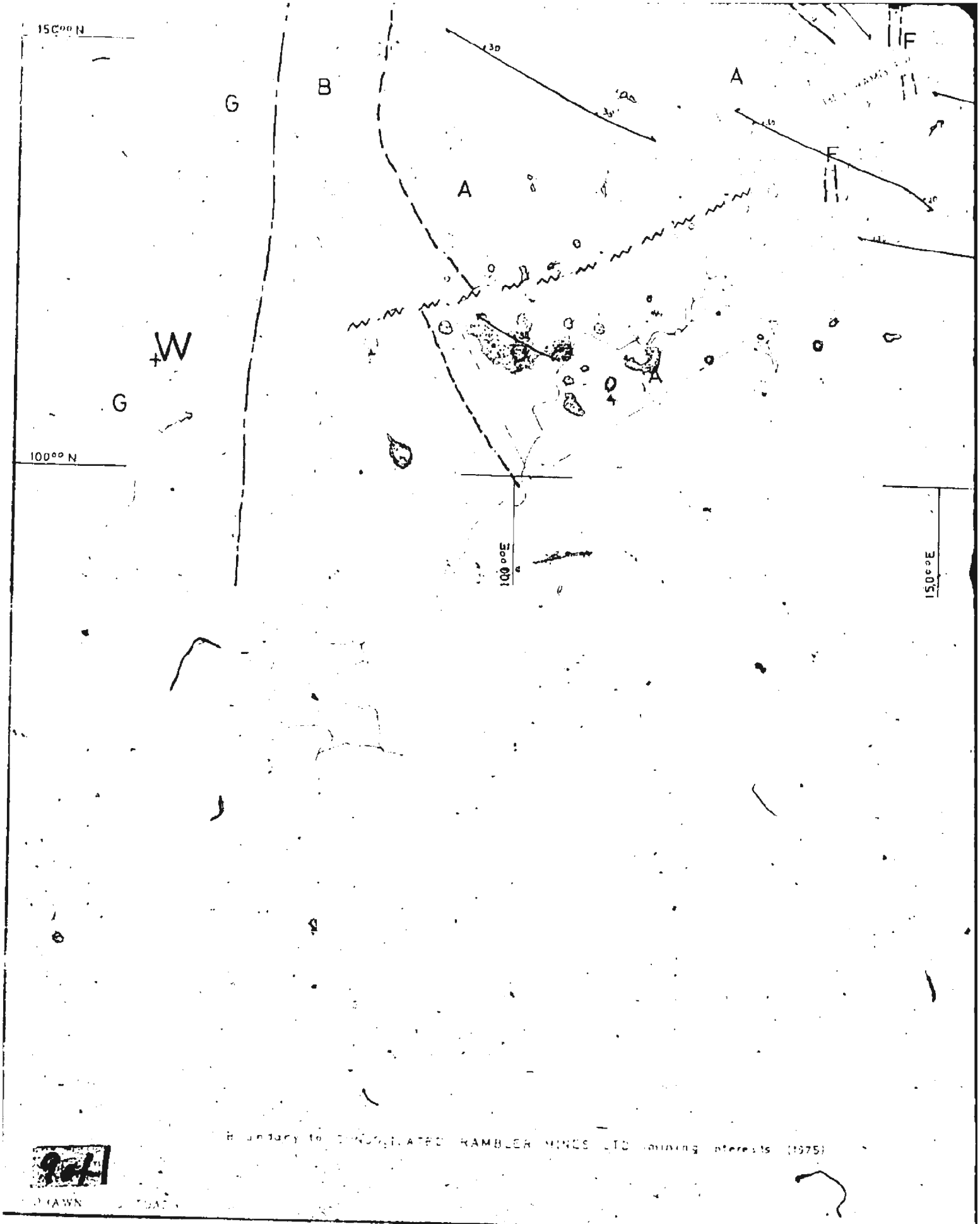
F — Basic Intrusion — METADIABASE AND METAGABBRO

VOLCANIC SEQUENCE

E — Basic Sediments — PREDOMINANTLY BEDDED AND LAMINATED GREYWACKES, WATERLAIN BASIC TUFFS, AND REWORKED BASIC TUFFS; MINOR CONGLOMERATE, AND CHERT HORIZONS; MINOR BASIC VOLCANIC FLOWS.

D — Acid Volcaniclastic Rocks — PREDOMINANTLY DACITIC AND RHYOLITIC AGGLOMERATE, MINOR RHYOLITIC TUFFS AND / OR FLOW, MINOR BASIC TUFFS AND FLOWS, MINOR CHERT, AND QUARTZ SERICITE SCHIST.

C — Mixed Acid and Basic Rocks — INTERCALATED ACID AND BASIC VOLCANICLASTICS, BASIC FLOWS, MINOR QUARTZ-SERICITE SCHIST, MINOR CHERT HORIZONS.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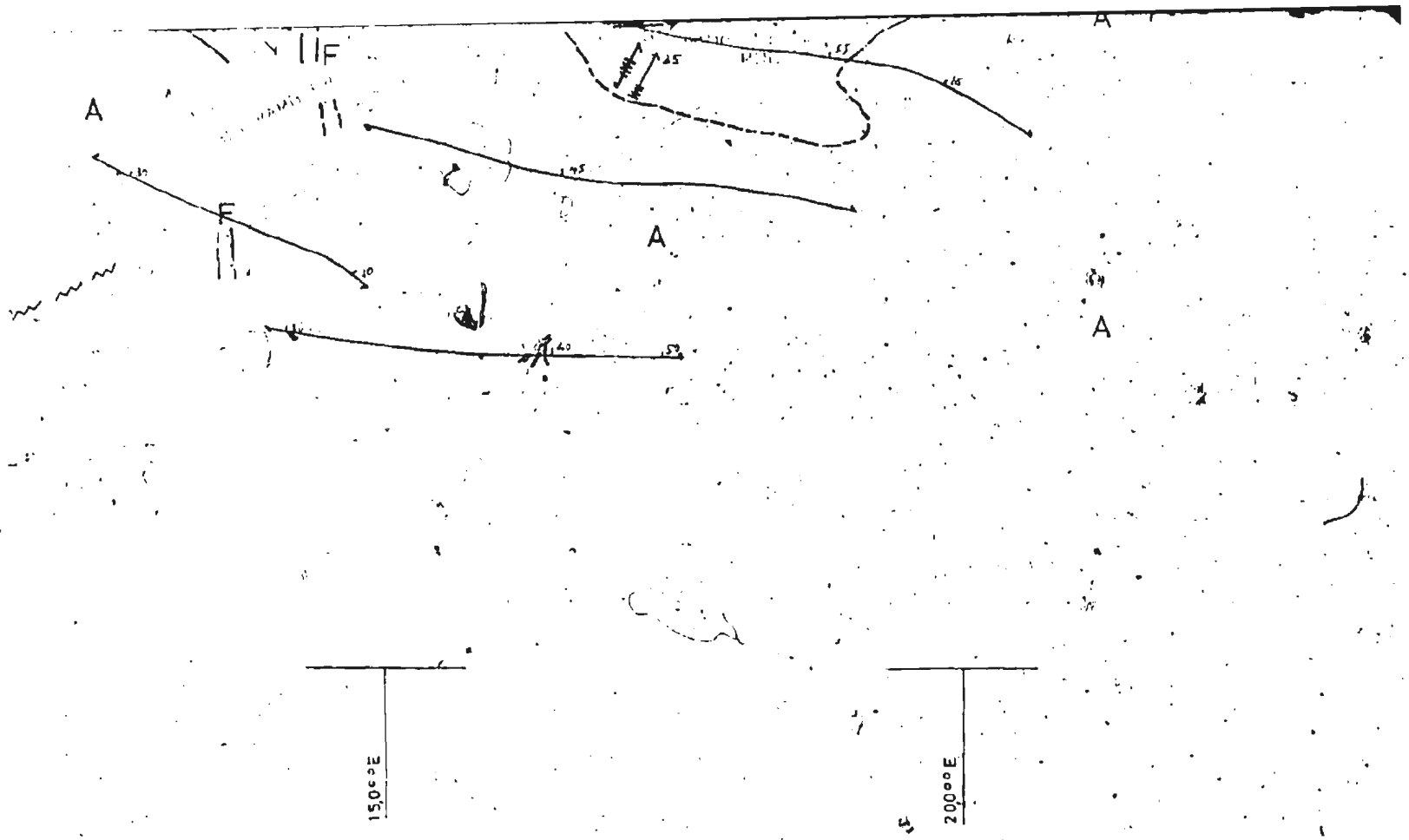

FIGURE 4 - GEOLOGY

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F Basic Intrusion

VOLCANIC SEQUENCE

E Basic Sediments

D Acid Volcaniclastic Rocks

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A Basic Flow

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F Basic Intrusion — METADIABASE AND METAGABBRO

VOLCANIC SEQUENCE

E Basic Sediments — PREDOMINANTLY BEDDED AND LAMINATED GREYWACKES, WATERLAIN BASIC TUFFS, AND REWORKED BASIC TUFFS; MINOR CONGLOMERATE, AND CHERT HORIZONS, MINOR BASIC VOLCANIC FLOWS

D Acid Volcaniclastic Rocks — PREDOMINANTLY DACITIC AND RHYOLITIC AGGLOMERATE, MINOR RHYOLITIC TUFFS AND / OR FLOW, MINOR BASIC TUFFS AND FLOWS, MINOR CHERT, AND QUARTZ SERICITE SCHIST

C Mixed Acid and Basic Rocks — INTERCALATED ACID AND BASIC VOLCANICLASTICS, BASIC FLOWS, MINOR QUARTZ-SERICITE SCHIST, MINOR CHERT HORIZONS

B Basic Volcaniclastic Rocks — PREDOMINANTLY AGGLOMERATE, FLOW AND BASIC TUFF AND / OR SEDIMENT, MINOR QUARTZ SERICITE SCHIST, CHERT HORIZONS, AND MINOR RHYOLITIC INTRUSIONS.

A Basic Flow — PREDOMINANTLY PILLOWED AND MASSIVE FLOWS, MINOR BASIC AGGLOMERATE AND TUFF, MINOR RHYOLITIC INTRUSIONS.

NB APPROXIMATELY 25% OF THE AREA UNDERLAIN BY THE VOLCANIC SEQUENCE IS COMPRISED OF BASIC INTRUSIVE ROCKS

BEDDING (inclined, top known; inclined, top unknown; vertical, top unknown)

TREND OF MAIN (S_2) SCHISTOSITY (inclined; vertical)

LATER SCHISTOSITIES (S_3 inclined; S_4 inclined; S_4 vertical)

PLUNGE OF FOLD (F_2; F_3; F_4)

PLUNGE OF ORE DEPOSIT

LITHOFACIES BOUNDARY (approximate, inferred)

FAULT (defined; approximate; inferred)

AXIAL PLANE TRACE (approximate) OF F_2 SYNFORM

AXIAL PLANE TRACE (approximate) OF F_3 FOLD.

AXIAL PLANE TRACE (approximate) OF F_4 FOLD

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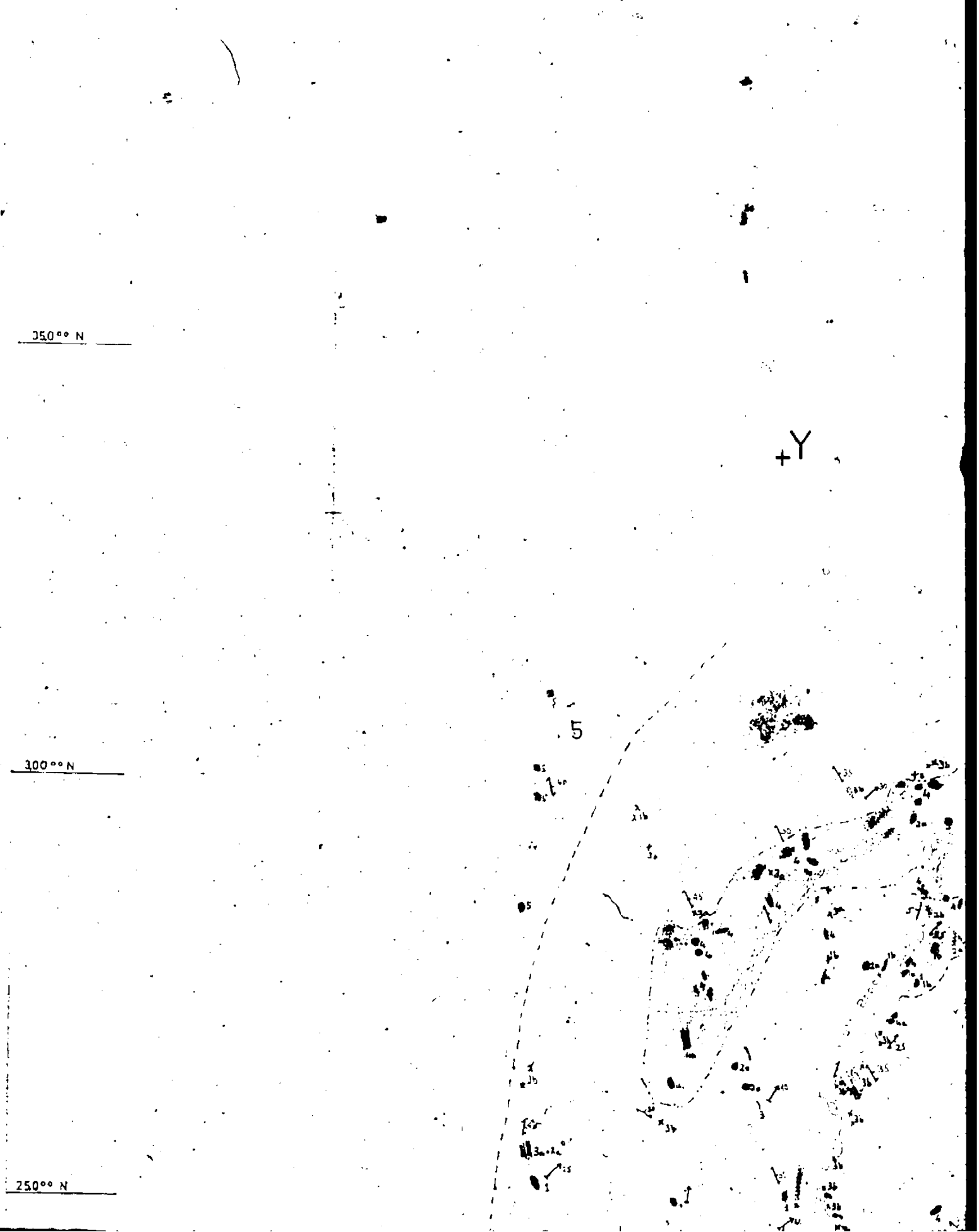

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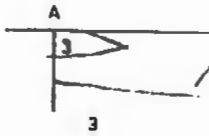

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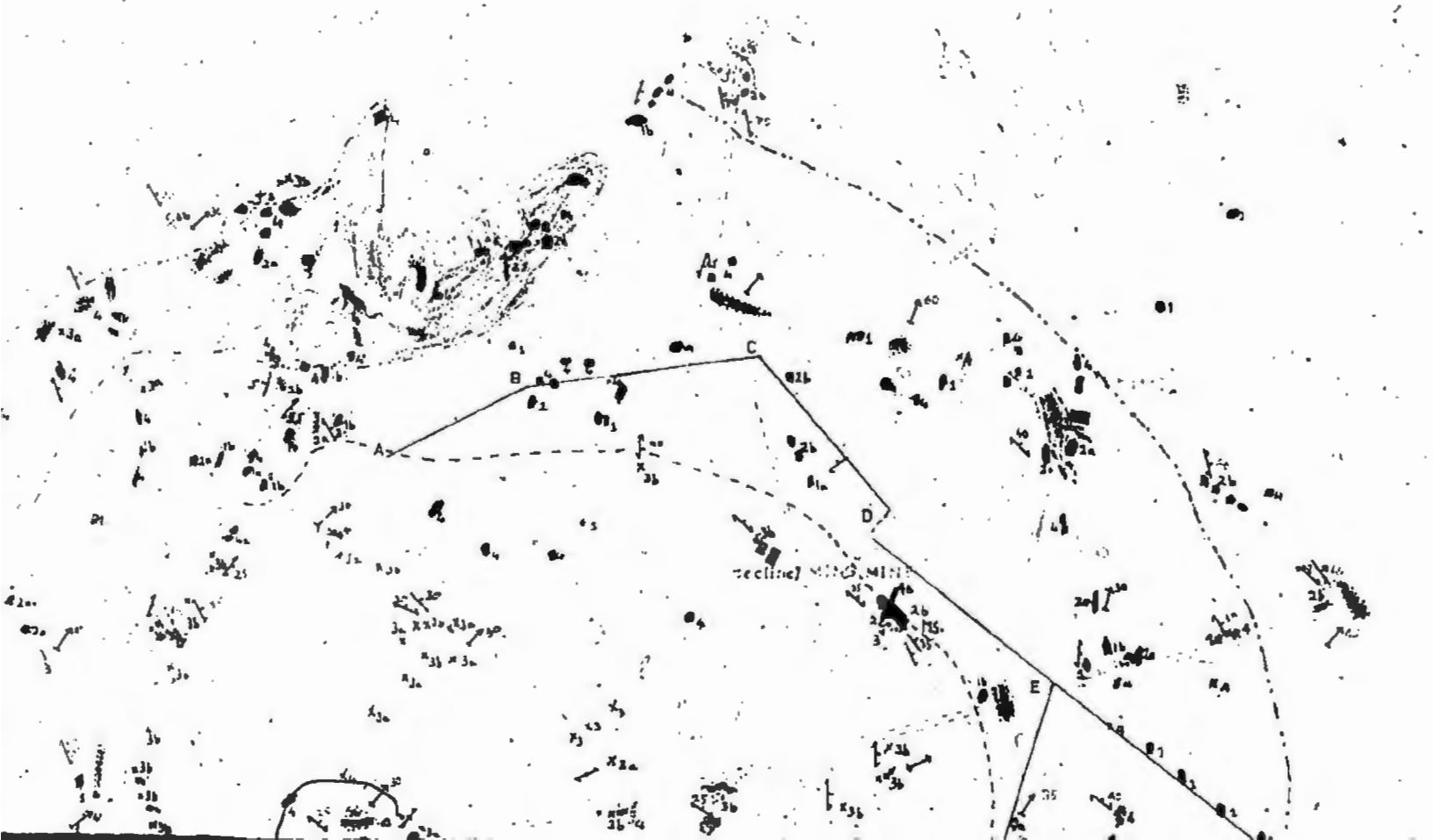

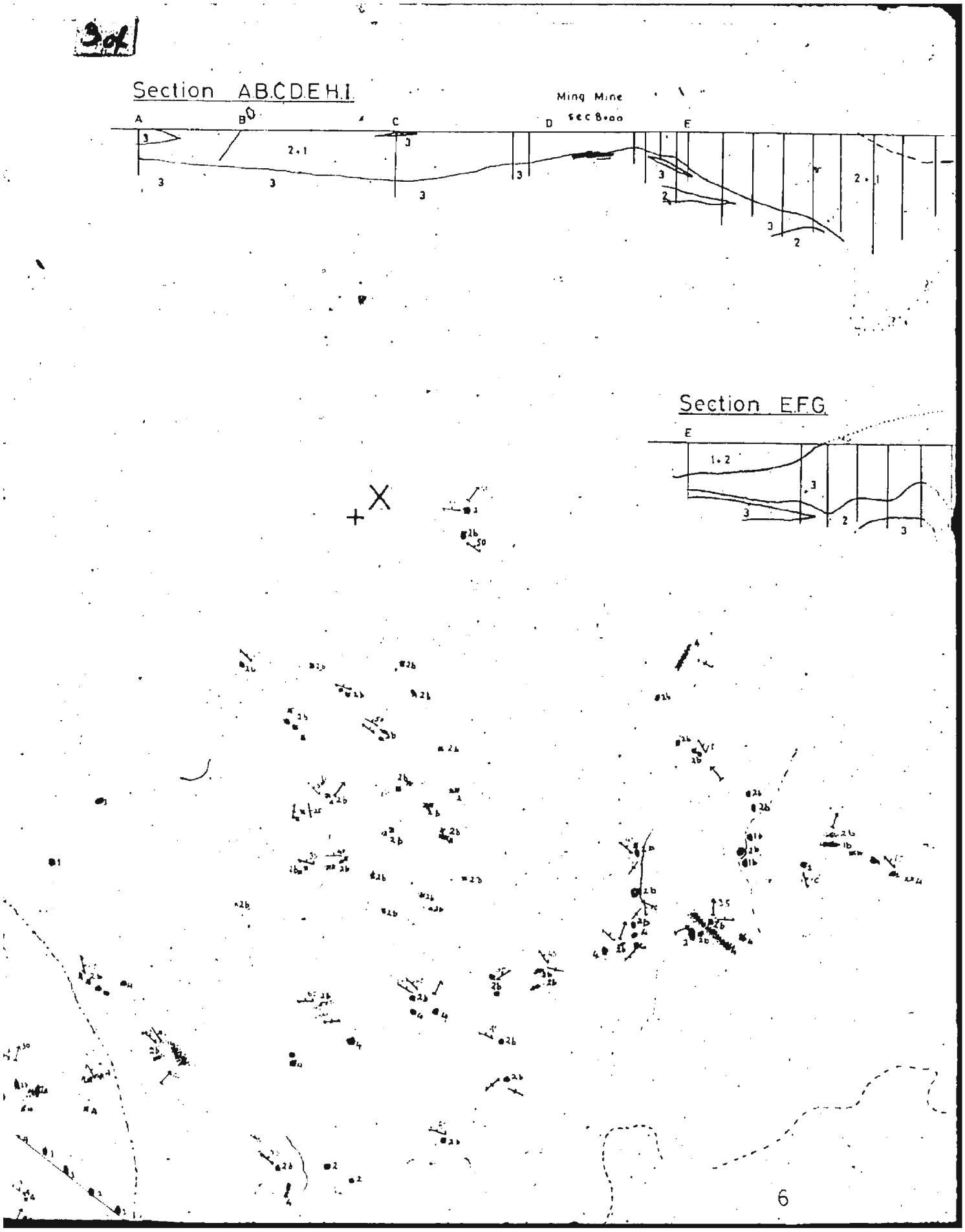
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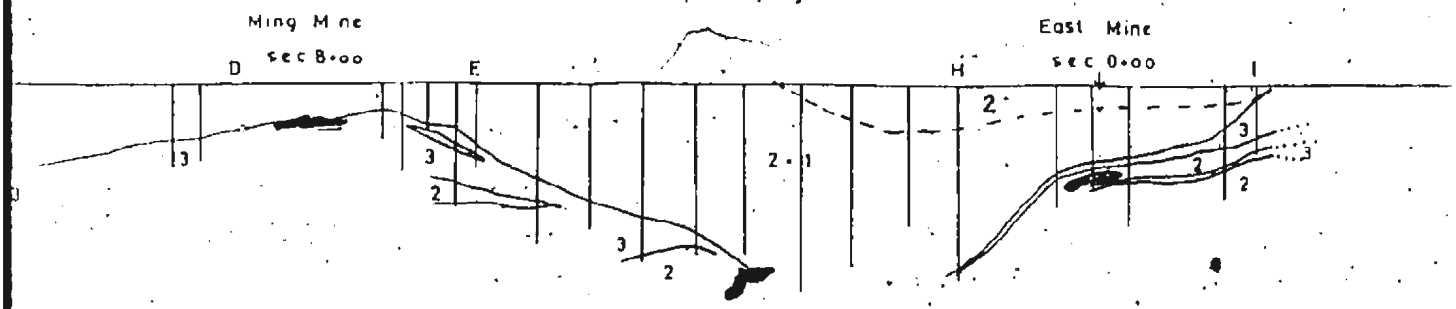
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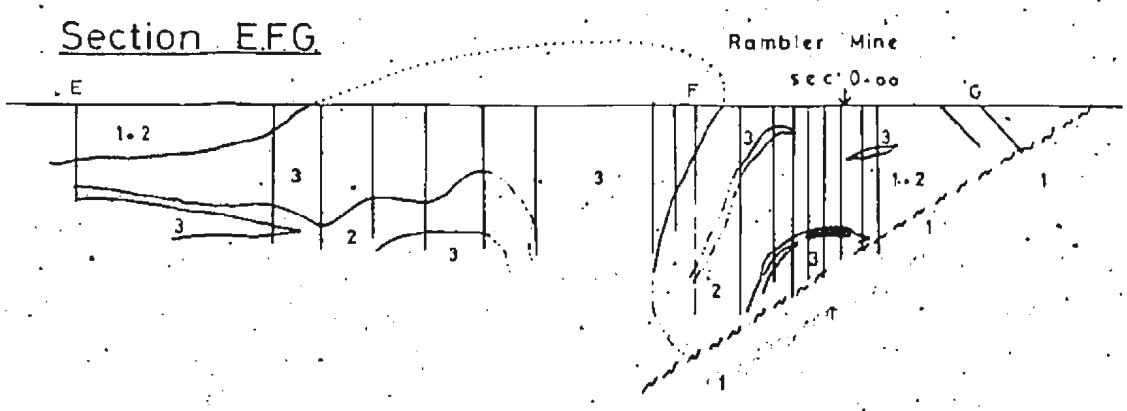
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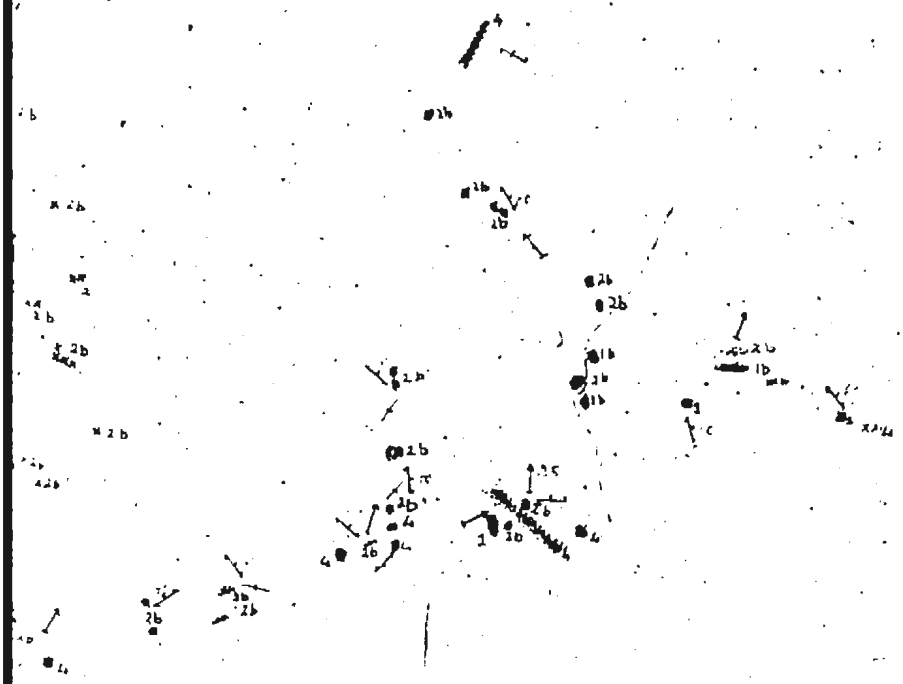

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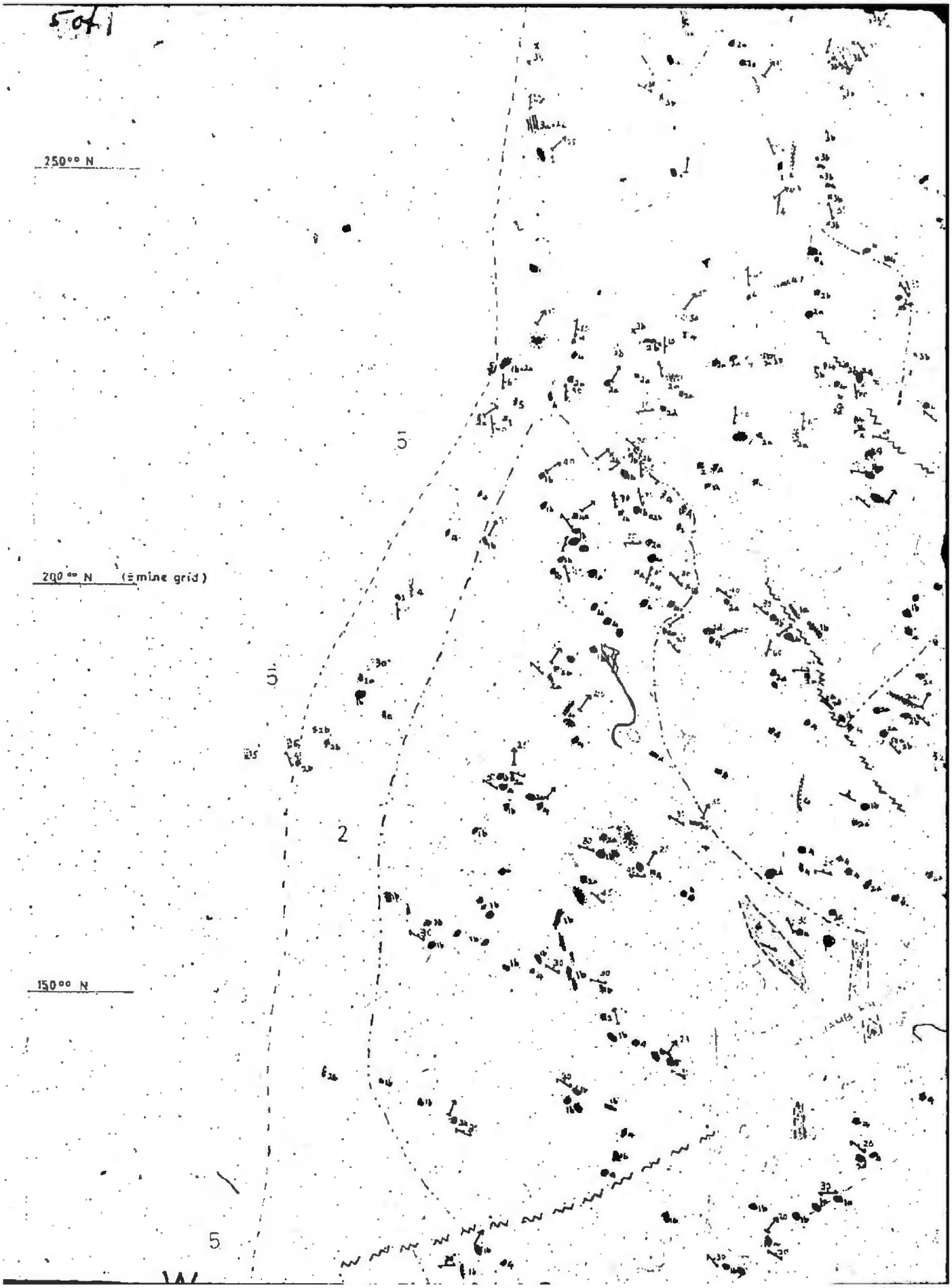

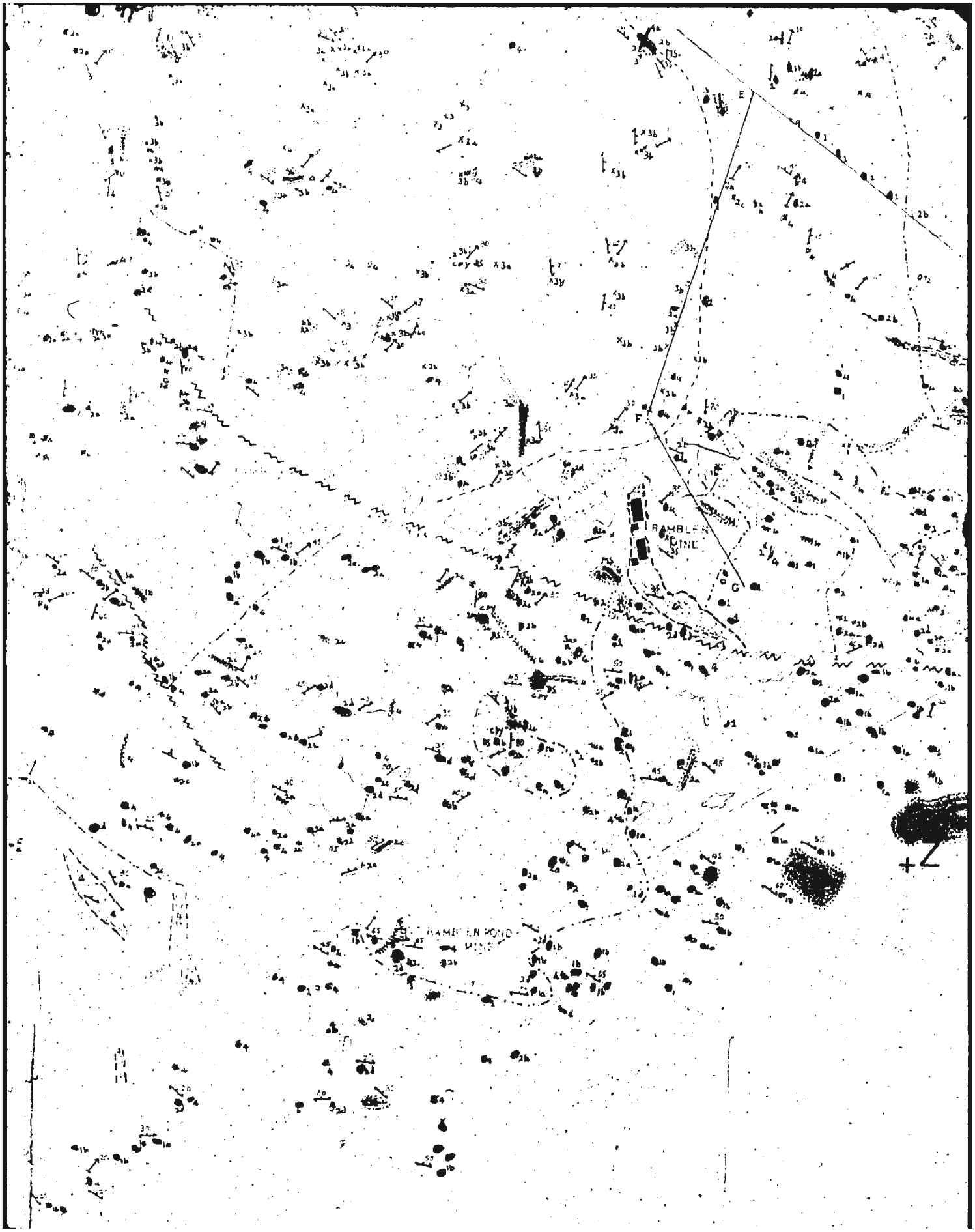
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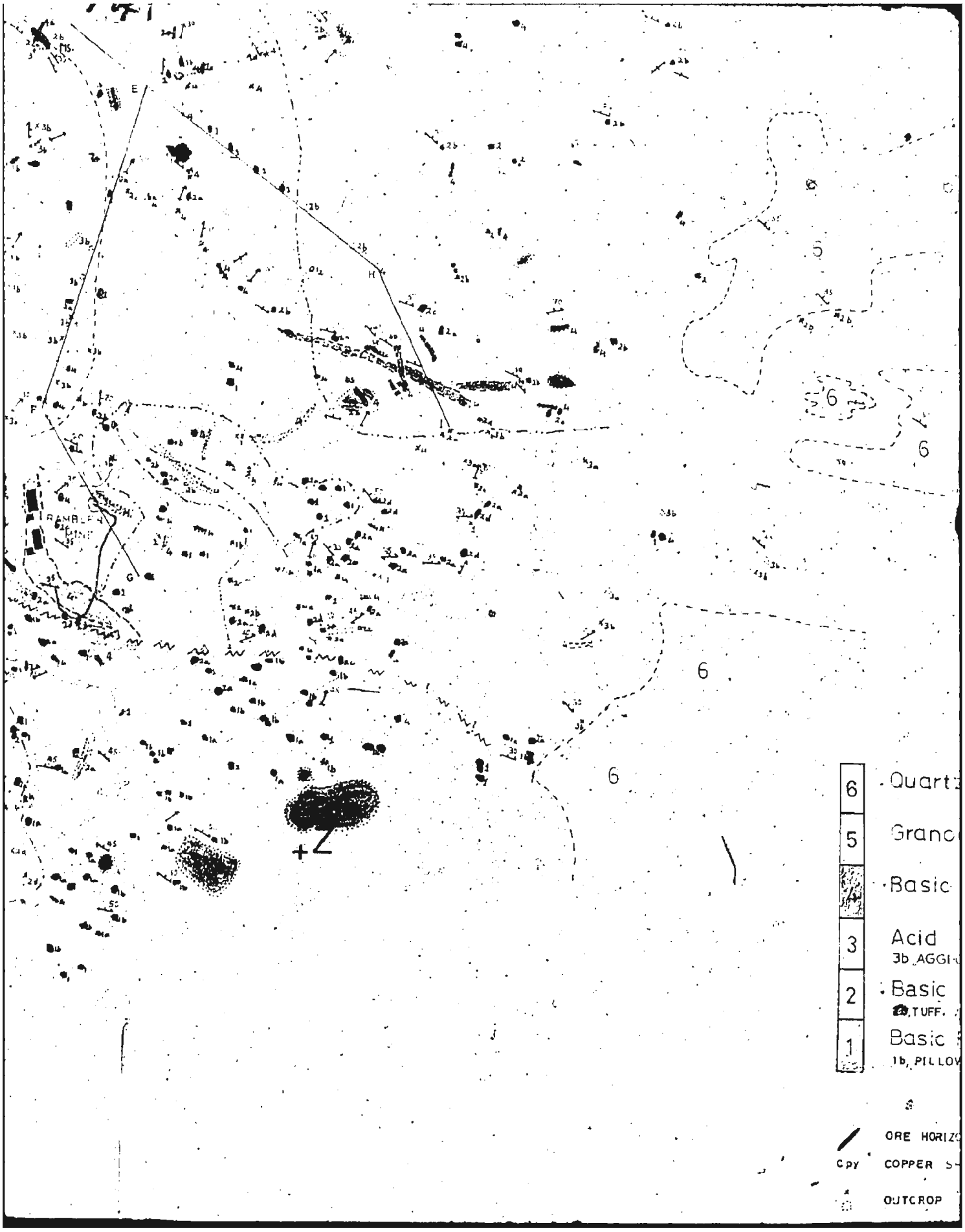
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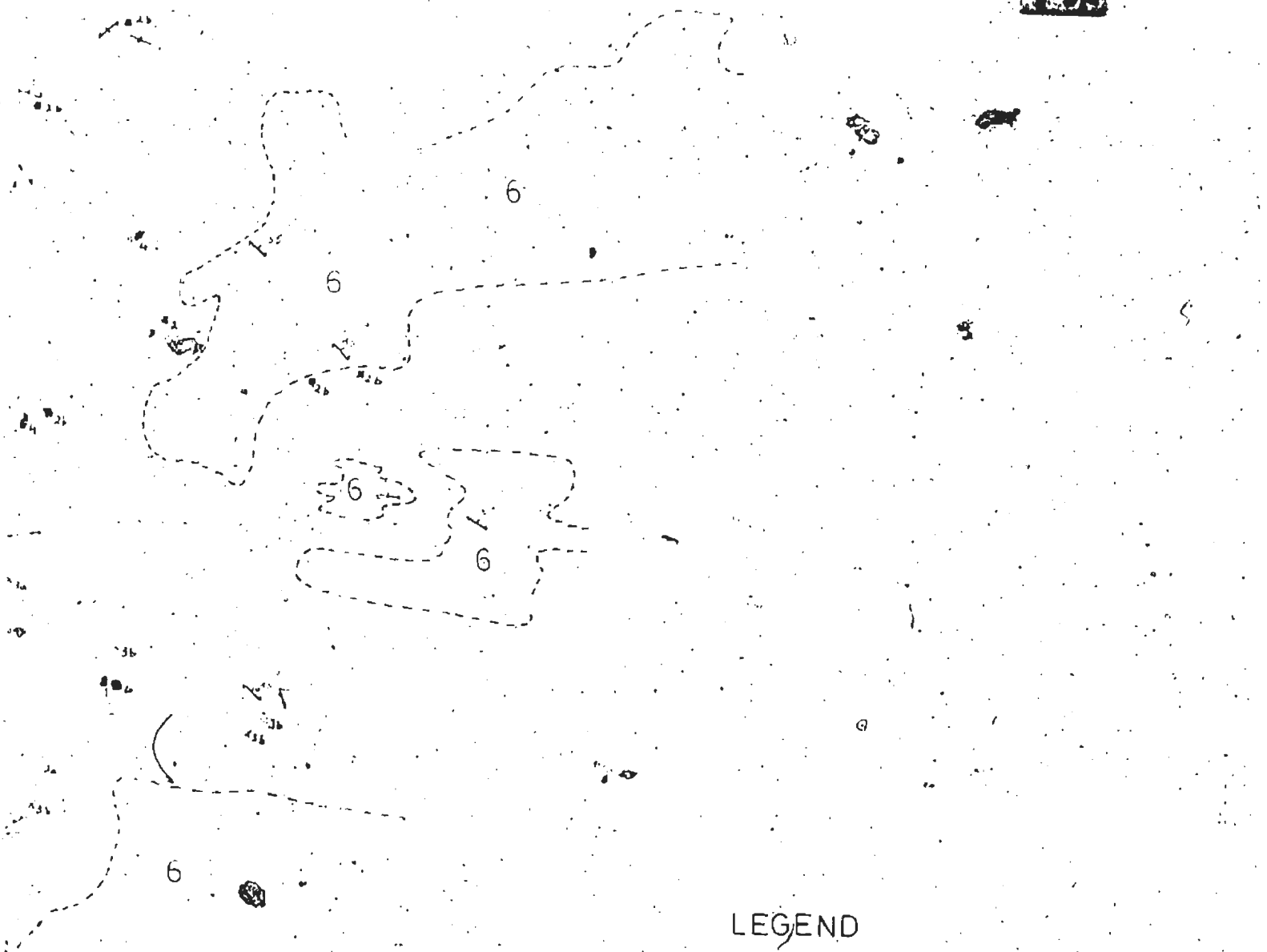

LEGEND

6	Quartz Feldspar Porphyry
5	Granodiorite
4	Basic Intrusive Rocks
3	Acid Volcaniclastic Rocks : 3a, MASSIVE ; 3b AGGLOMERATE and TUFF
2	Basic Volcaniclastic Rocks : 2a, AGGLOMERATE ; 2b, TUFF, VULCANOGENIC SED ; 2c, CHERT, SILICIFIED ROCKS ; 2d, CHLORITE SCHIST
1	Basic Flows : 1, UNDIFFERENTIATED, 1a MASSIVE FLOWS ; 1b, PILLOWED FLOWS.

ORE HORIZON = M.S., MASSIVE SULPHIDES ; D.S., DISSEMINATED SULPHIDES.

Cpy COPPER SHOWING

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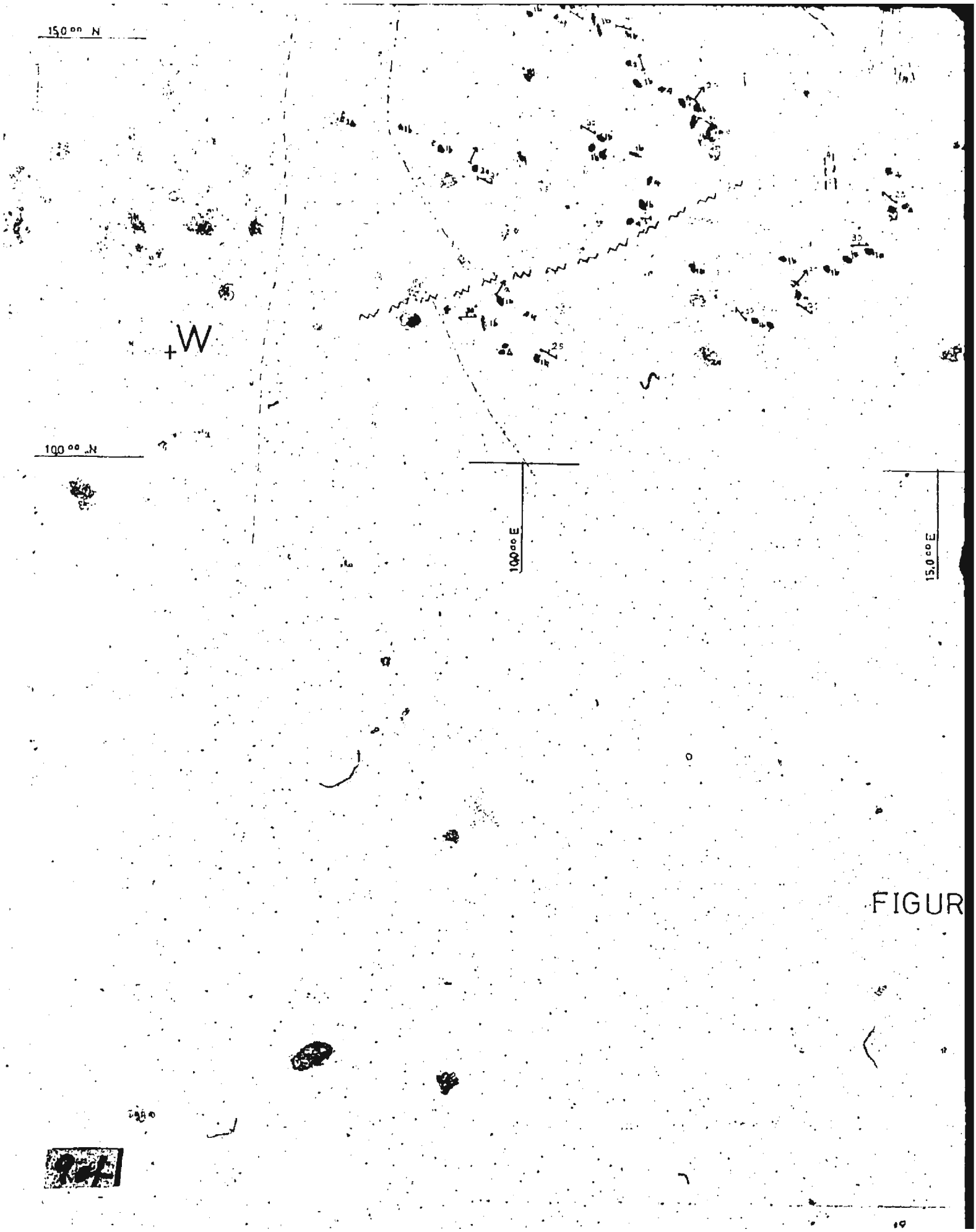


FIGUR

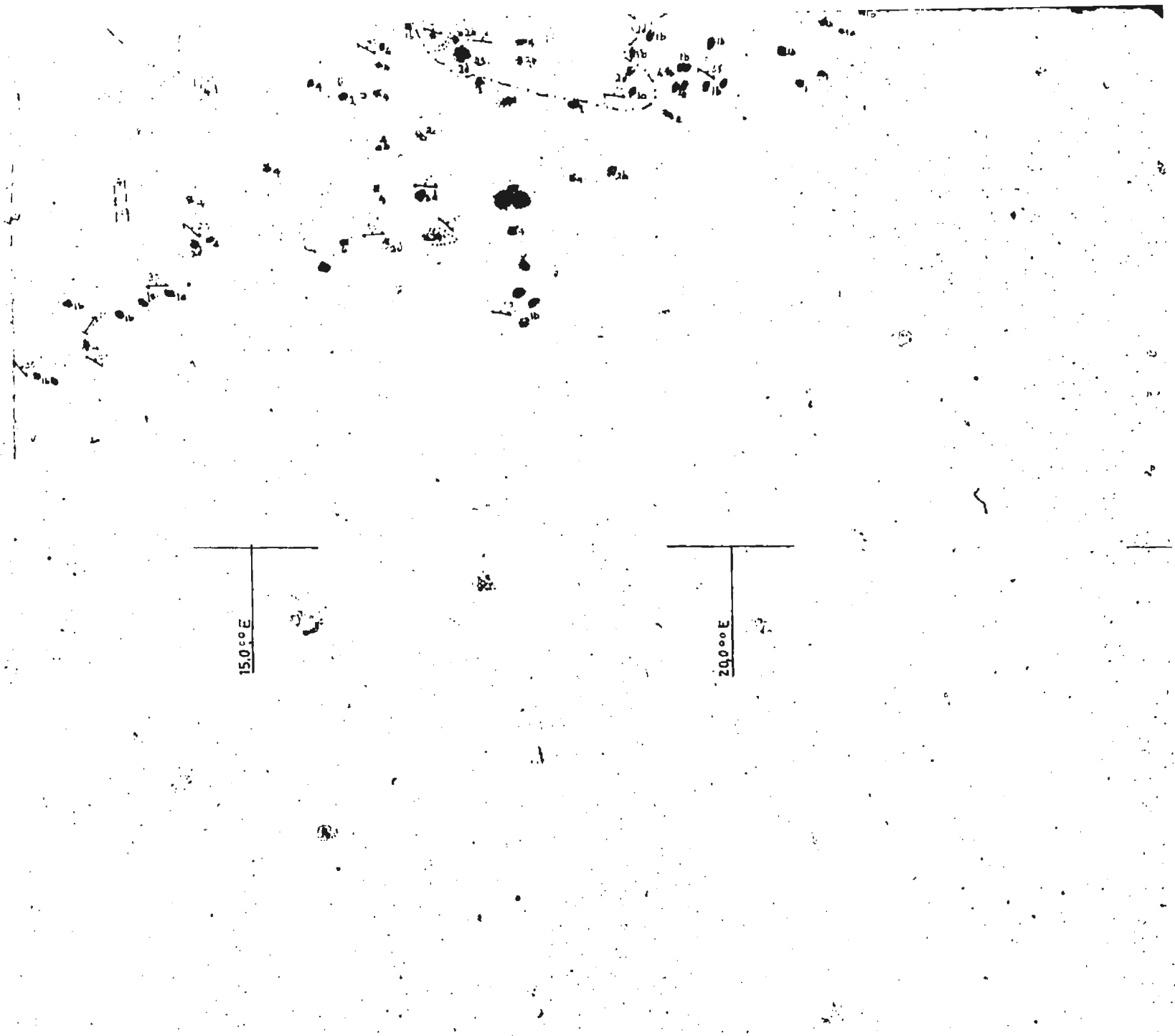


FIGURE 3 - GEOLOGICAL OUTCROP MAP

CONS. RAMBLER MINES AREA - BAIE VERTE,

miles
0 1/2 1

kilometres
0 1

2 Basic Vol
2b, TUFF, VOLCAN
1 Basic Flo
1b, PILLOWED F

ORE HORIZON

Cpy COPPER SHOWIN

OUTCROP

GEOLOGICAL CO

BEDDING ;

PILLOW LAVA

SCHISTOSITY (S

MINERAL and PA

FAULT

250°E

300°E

L OUTCROP MAP

AREA - BAIE VERTE, NFLD.

1/2 1

ilometres
1 2

[illegible] Volcaniclastic Rocks : 3a, MASSIVE ;
3b, AGGLOMERATE and TUFF

2 Fasic Volcaniclastic Rocks : 2a, AGGLOMERATE ;
2b, TUFF, VOLCANOGENIC SED ; 2c, CHERT - SILICIFIED ROCKS ; 2d, CHLORITE SCHIST

1 Basic Flows : 1, UNDIFFERENTIATED ; 1a MASSIVE FLOWS ;
1b, PILLOWED FLOWS

ORE HORIZON : M.S., MASSIVE SULPHIDES ; D.S. DISSEMINATED SULPHIDES.

Cpy COPPER SHOWING

OUTCROP (<100 ft in length)
(> " " ")

GEOLOGICAL CONTACTS (Known)
(Approx)
(Assumed)

BEDDING ; BEDDING (Showing Direction to Top of Bed)

PILLOW LAVA (Showing Direction to Top of Flow.)

300 m

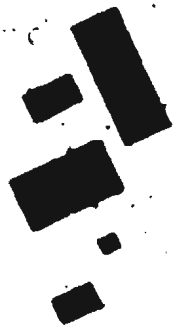
SCHISTOSITY (S_2)

MINERAL and PARTICLE LINEATION

FAULT

M.U.N. M.Sc. THESES : J. TUACH (1976)

A - PLAN

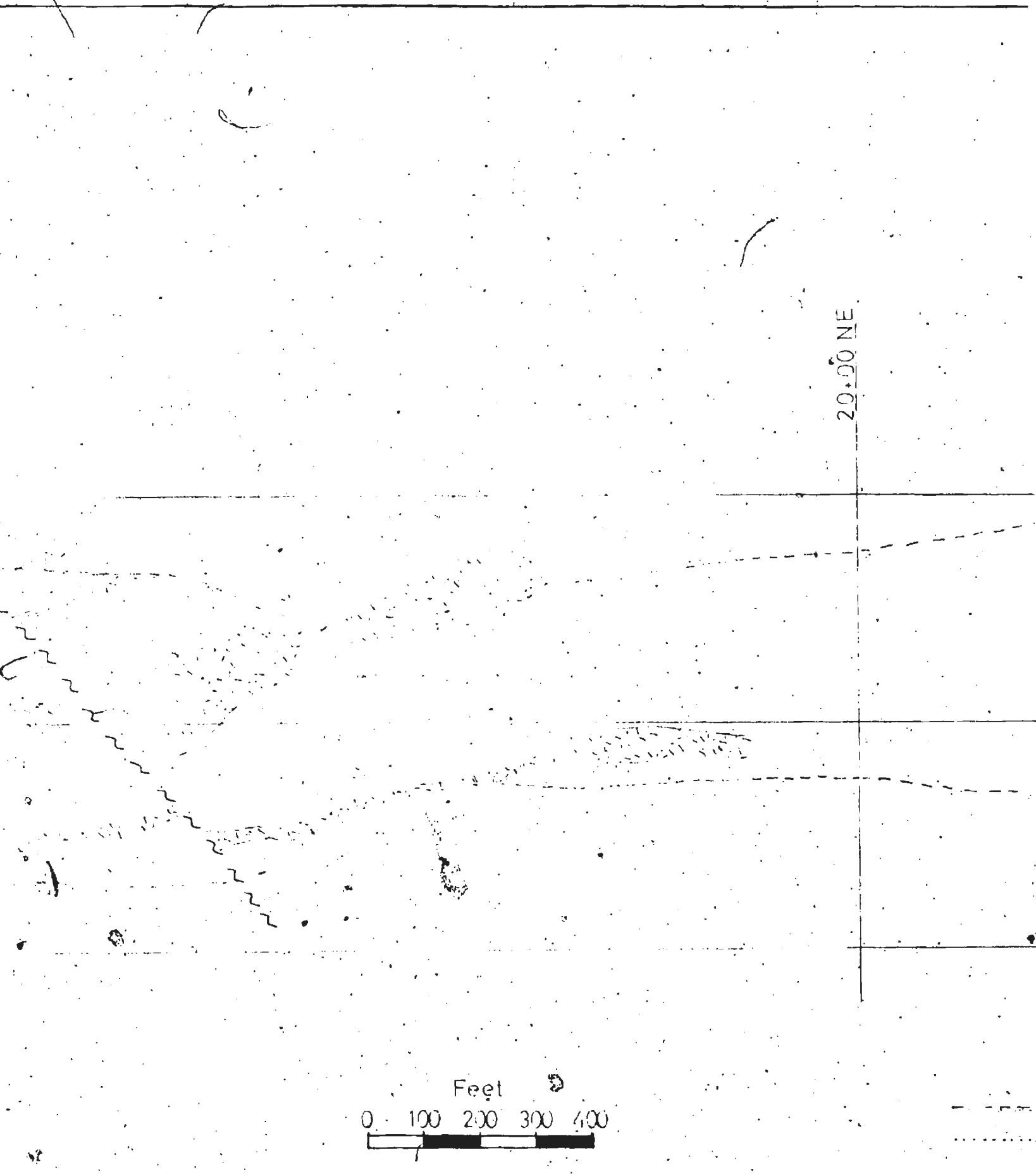


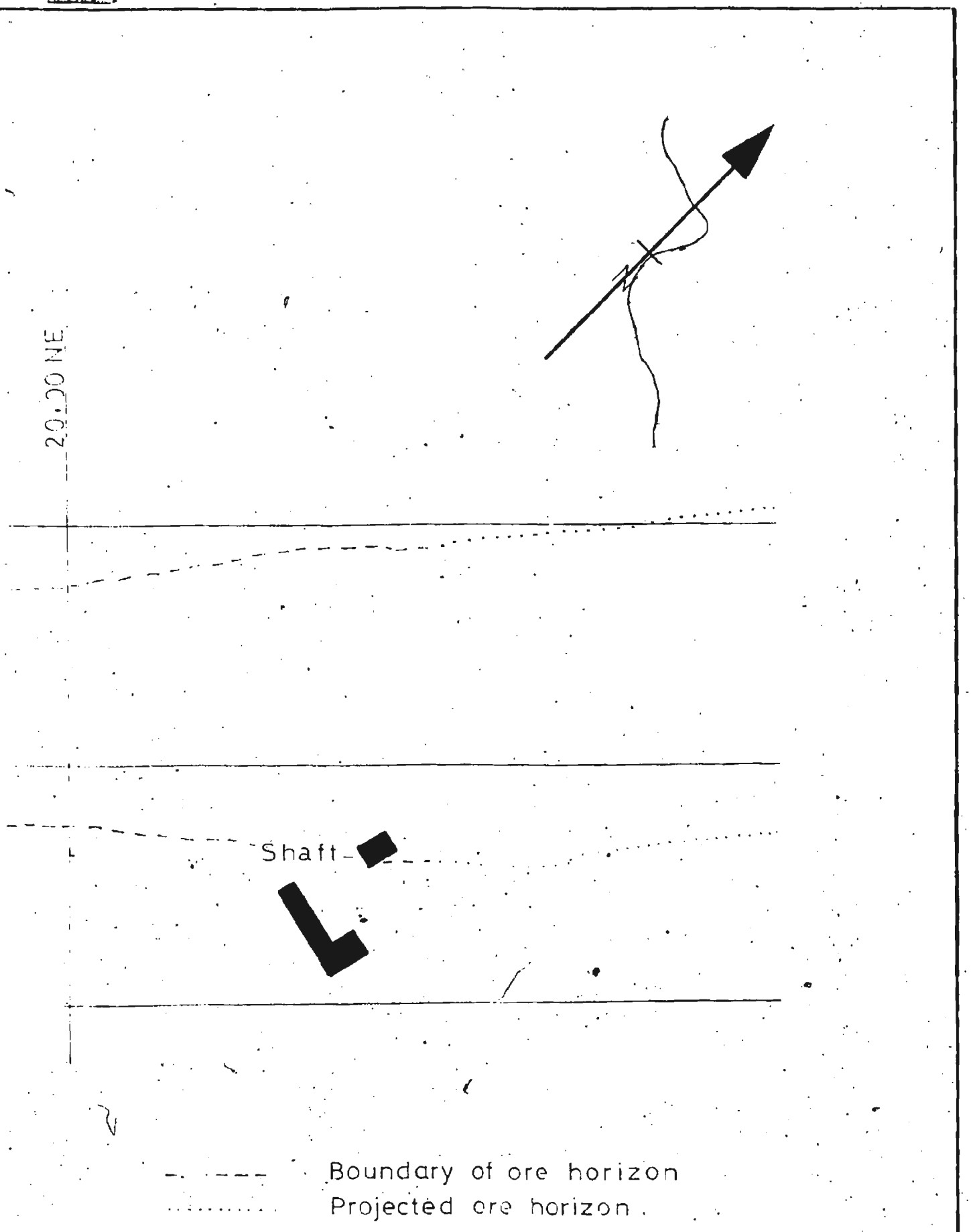
SECTION 12.00 NW

SECTION 8.00 NW

SECTION 4.00 NW

2 of



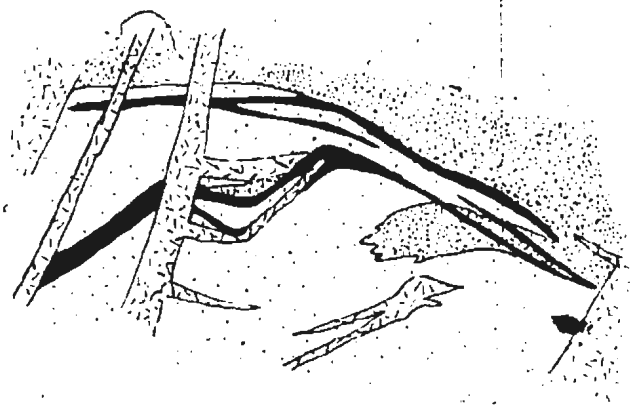

20.00 NE
Shaft
Boundary of ore horizon
Projected ore horizon

4of.

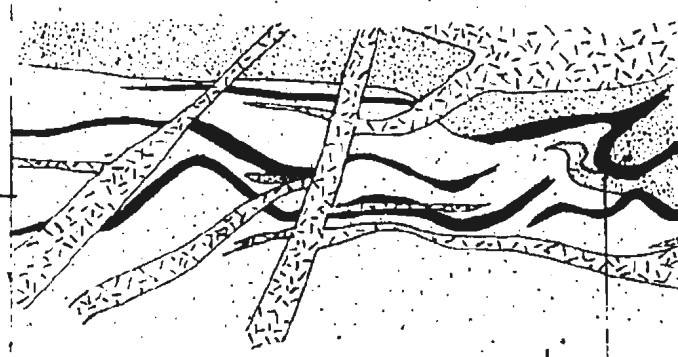
C - SECTIONS PARALLEL TO STRIKE

(i) SEC 7+50 NE

(ii) SEC 9+50 NE

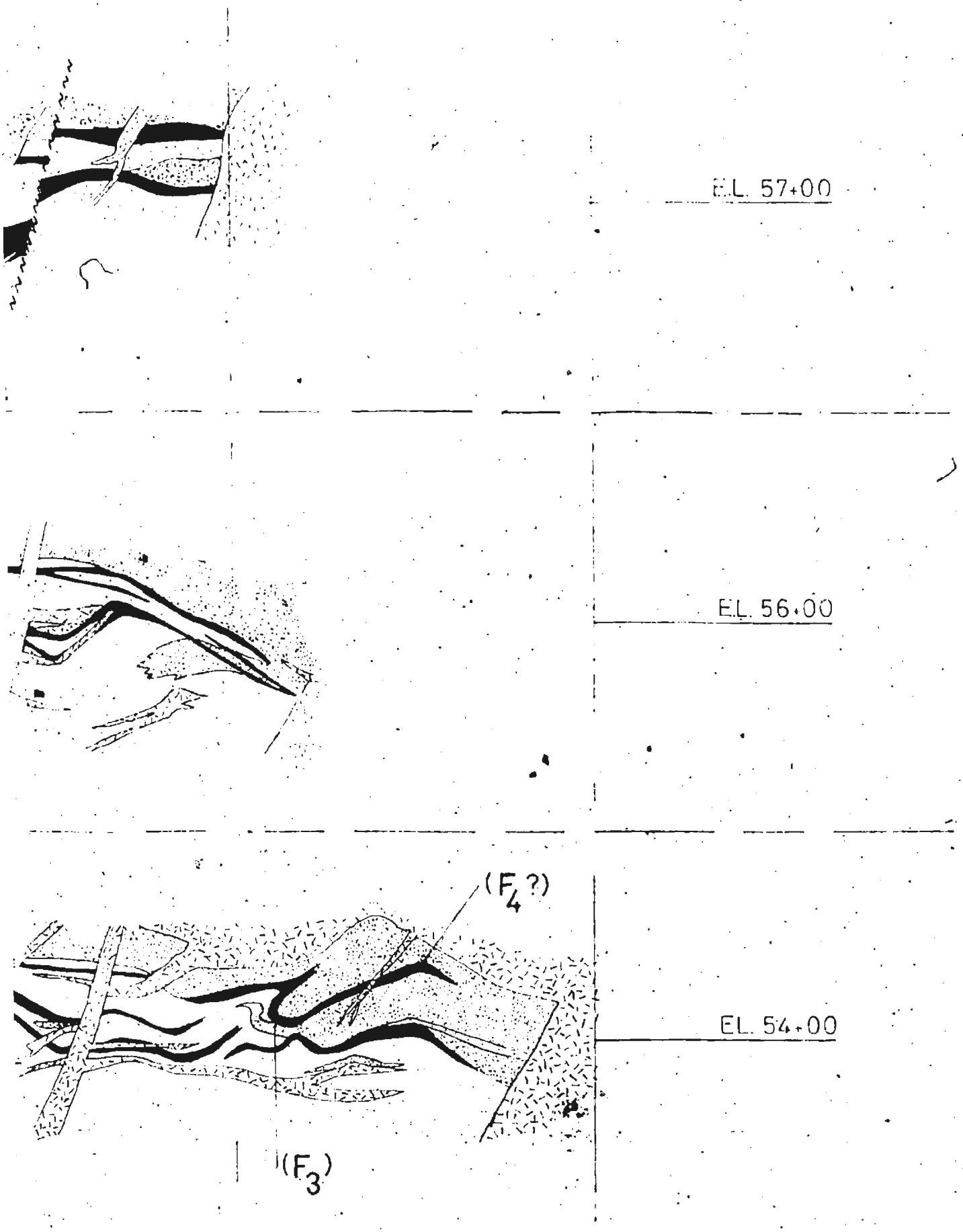


(iii) SEC 12+00 NE



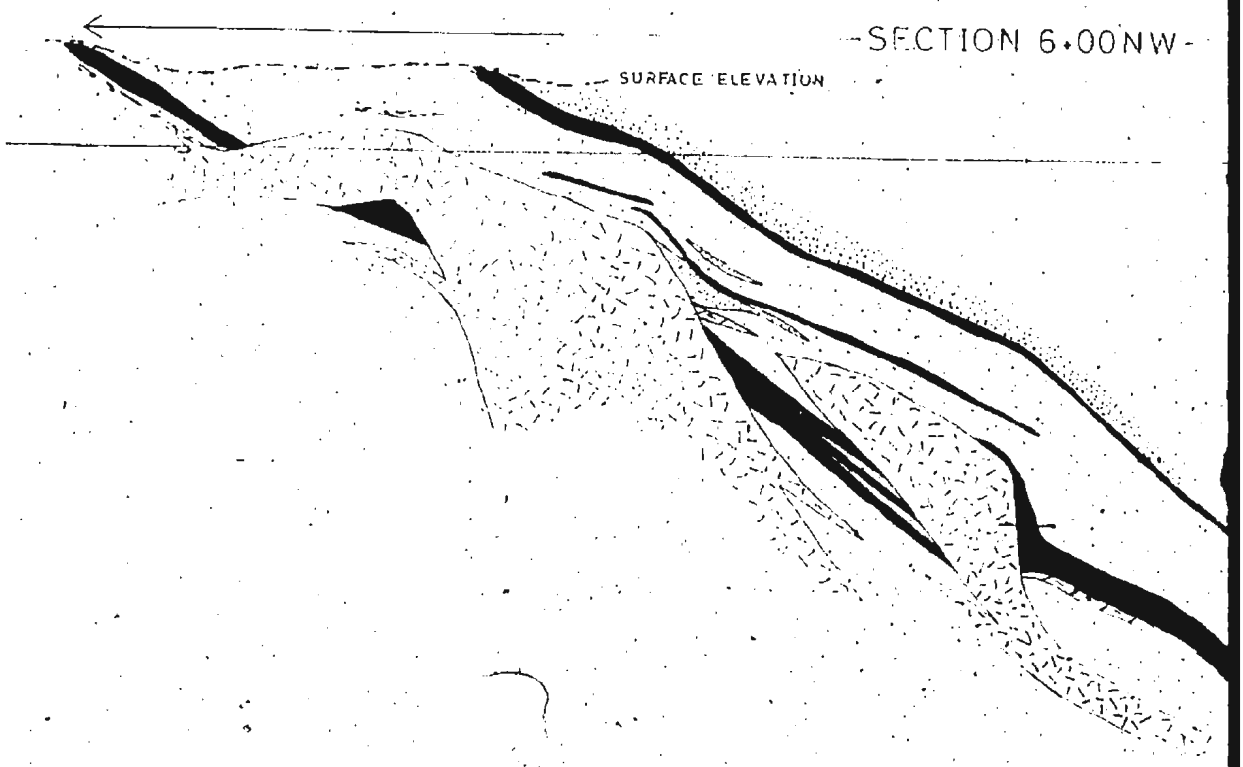
(F3

TO STRIKE



6 of 1

B - SECTION(S) PARALLEL TO PLUNGE

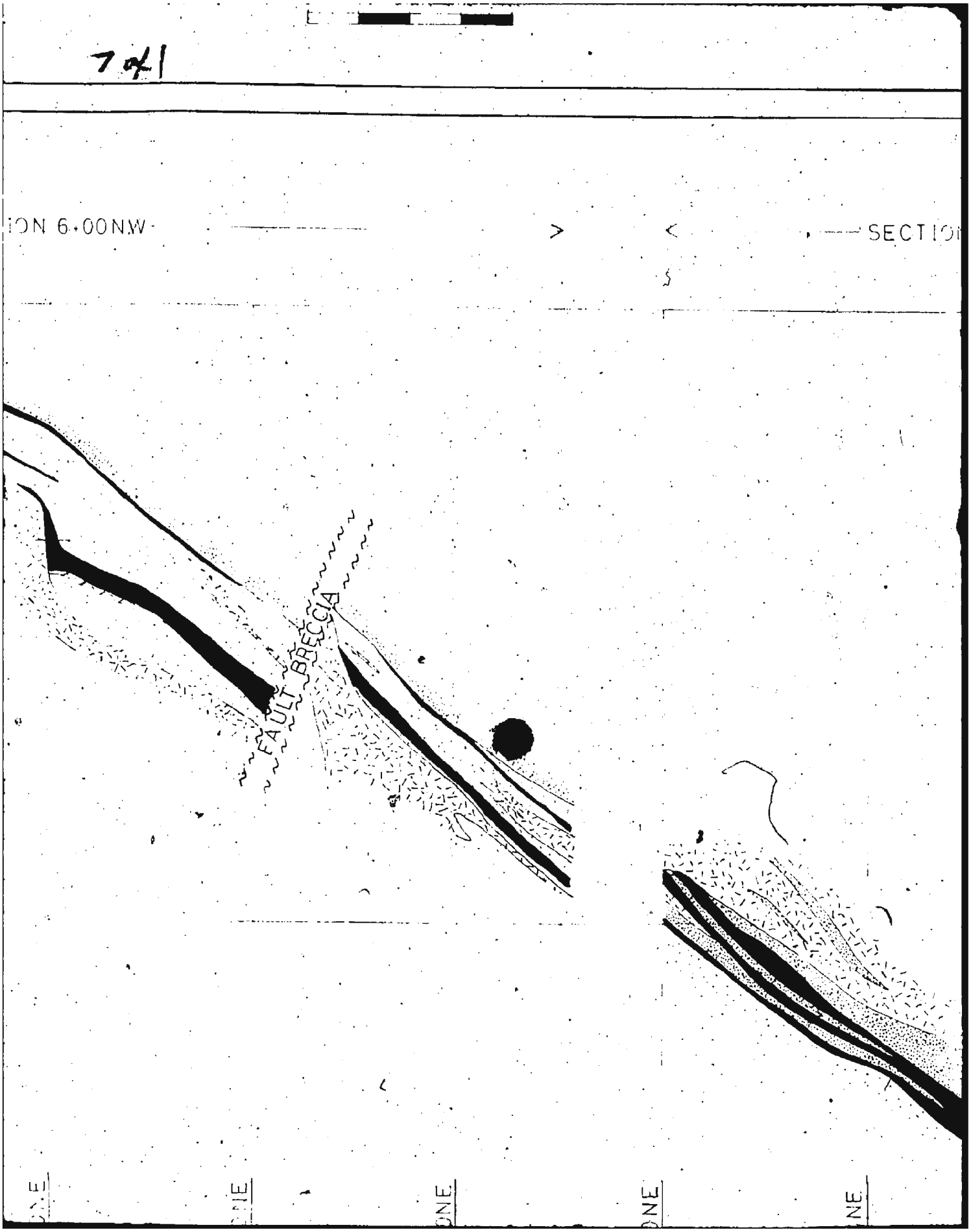


NE

NE

NE

7 of 1



Projected ore horizon

Pl. 1

SECTION 9+00NW

(iv) SE

EL 60+00

EL 58+00

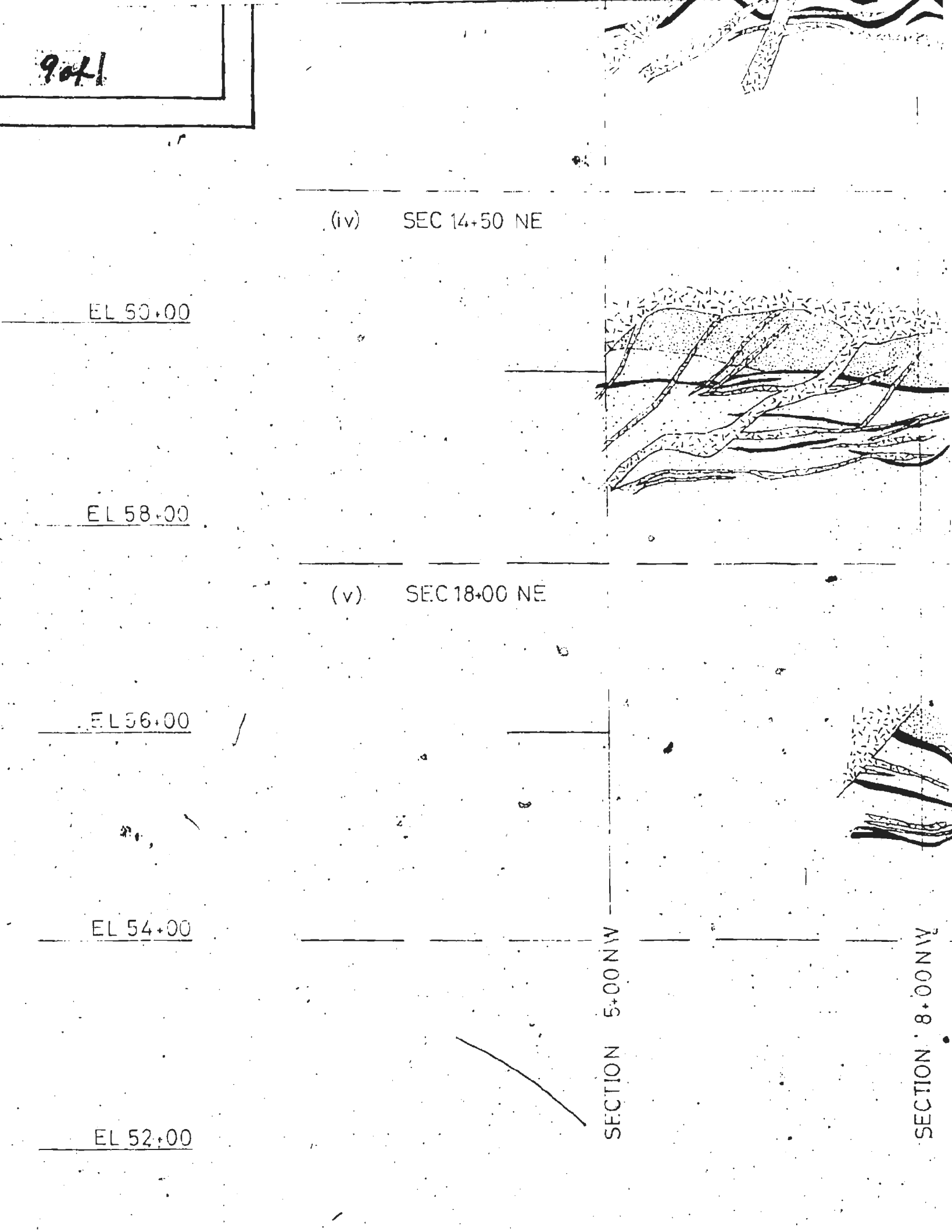
(v) SE

EL 56+00

EL 54+00

EL 52+00

NE


(iv) SEC 14+50 NE
EL 60+00
EL 58+00
(v) SEC 18+00 NE
EL 56+00
EL 54+00
EL 52+00
SECTION 5+00 NW
SECTION 8+00 NW

(F3)
EL. 53+00
EL 51+00
SECTION 8+00NW
SECTION 11+00NW

SEC 0+00

SEC 2+00NE

SEC 4+00NE

SEC 6+00NE

FIGURE 5 - GEOLOGICAL PLAN AND SECTIONS

MING ORE DEPOSIT

BAIE VERTE, NFLD

DRAWN J. TUACH

Sept 1975

SEC 6+00NE

SEC 8+00NE

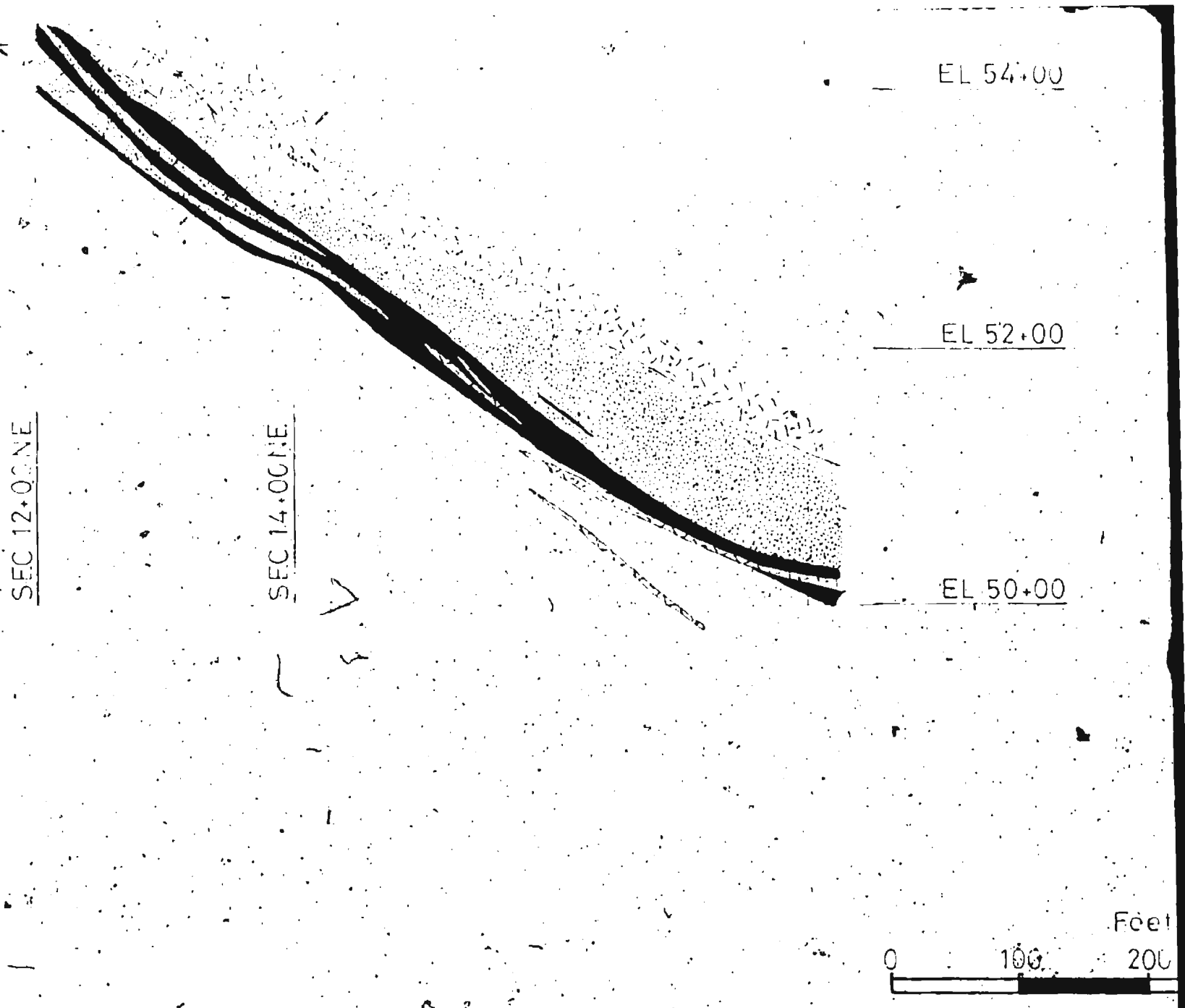
SEC 10+00NE

SEC 12+00NE

N AND SECTIONS

)SIT

LD



13-1

EL 54+00

EL 52+00

EL 50+00

SECTION 5-CONN-V

SECTION 8-CONN-V

ULTRAMAFIC S

METADOLERITE

BASIC VOLCANO

MASSIVE SULP

ACID VOLCANIC

FAULT

Feet

0 100 200 300 400

SECTION 3+00NW

SECTION 1+00NW

LEGEND.

ULTRAMAFIC SILL

METADOLERITE INTRUSION — PREDOMINANTLY SILLS

BASIC VOLCANOGENIC SEDIMENT — BEDDED and LAMINATED ACTINOLITE-CHLORITE-ALBITE BIOTITE RICH SCHIST

MASSIVE SULPHIDE

ACID VOLCANICLASTIC ROCKS — COMPLEX ASSEMBLAGE OF RHYOLITIC AGGLOMERATE & TUFF, QUARTZ-SERICITE SCHIST, CHERT, AND THIN BEDS OF PYRITE

FAULT

MUN MSc THESES J. TUACH (1976)