THE GEOLOGY OF
THE STIRLING COPPER PROPERTY
SPRINGDALE, NEWFOUNDLAND

JOHN GILBERT McARTHUR

THE GEOLOGY OF
THE STIRLING COPPER PROPERTY
SPRINGDALE, NEWFOUNDLAND

BY

JOHN GILBERT McARTHUR

a thesis submitted in partial fulfilment of the
requirements for the degree of Master of Science

Department of Geology, Memorial University of Newfoundland

September, 1973

ABSTRACT

The Stirling property at Springdale in north-central Newfoundland is one of many pyritic copper prospects found in the dominantly pillowed Lower Ordovician Lush's Bight Group. The nearby Whalesback and Little Bay mines within the Group are recent past-producers of copper.

The map-area is underlain by a 3800-foot thick sequence of Lush's Bight Group volcanics which has been divided into four mappable units: tuffaceous schists and siliceous tuffaceous schists; chloritic metabasalts; volcanic breccia; and epidote basalt and isolated pillow basalt. Numerous mafic intrusives are considered to be feeder dykes and sills to the volcanic pile. Ten whole rock analyses support the interpretation that the Lush's Bight Group is a low-potash tholeiite that formed in the upper part of layer two of ancient oceanic crust.

The volcanic units and the related intrusives have been metamorphosed to the greenschist facies and have one good penetrative, steeply dipping S_1 fabric produced by the main regional deformation - D_1. This deformation produced very large-scale folds such that the entire map-area is underlain by part of one limb of a major F_1 fold. Small-scale kink bands and crenulations are evidence for a locally developed D_2 deformation. Two sets

of faults trending 030° and 060° have been recognized in the subsurface drilling and they correspond to strong topographic linears.

Two separate zones of pyrite and chalcopyrite mineralization with minor pyrrhotite and sphalerite have been designated "A" and "B". The sulphides occur as massive or nearly massive lenses, pods and as a stockwork of stringers. Disseminated sulphides are common throughout the zones. In the "A" zone, the sulphides occur in the chloritic metabasalts similar to many of the pyritic copper deposits in the Group. In the "B" zone, the sulphides occur in the siliceous tuffaceous schists and to a lesser extent in the chloritic metabasalts. The mineralized zones are steeply dipping and generally conformable with the stratigraphy and structure. Primary sulphide textures are absent due to recrystallization and remobilization during the D_1 deformation. The present distribution of sulphides resembles the disseminated stockwork zone in the 'Cyprus type' ophiolite mineralization.

CONTENTS

CHAPTER III

GEOLOGY OF THE STIRLING PROPERTY

CHAPTER IV

STRUCTURAL GEOLOGY

CHAPTER V

ECONOMIC GEOLOGY

CHAPTER VI

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Location and access

The Stirling property of British Newfoundland Exploration Limited (Brinex) is located about one mile northwest of the town of Springdale (population 3,500) on Halls Bay, Notre Dame Bay, Newfoundland. This property is an original Fee Simple grant optioned by Brinex. The area studied is about 9,000 feet long and 5,000 feet wide (Figure 3). There are two distinct mineralized zones - 'A' and 'B' that have been extensively tested by diamond drilling. The 'A' zone lies approximately 600 feet north of Stirling Pond and the 'B' zone is immediately north of Lower Twin Pond.

Access to the property is by several footpaths and tractor roads from the Brinex Base Camp and from the town of Springdale.

Topography

Maximum relief in the study area is about 300 feet. The hills and valleys are strongly aligned in an east-northeasterly direction, although in the central part of the area this grain is transected by a strong photolinear, trending north-northeastward. This alignment reflects the general strike of the volcanic rocks. The low areas, such as lakes

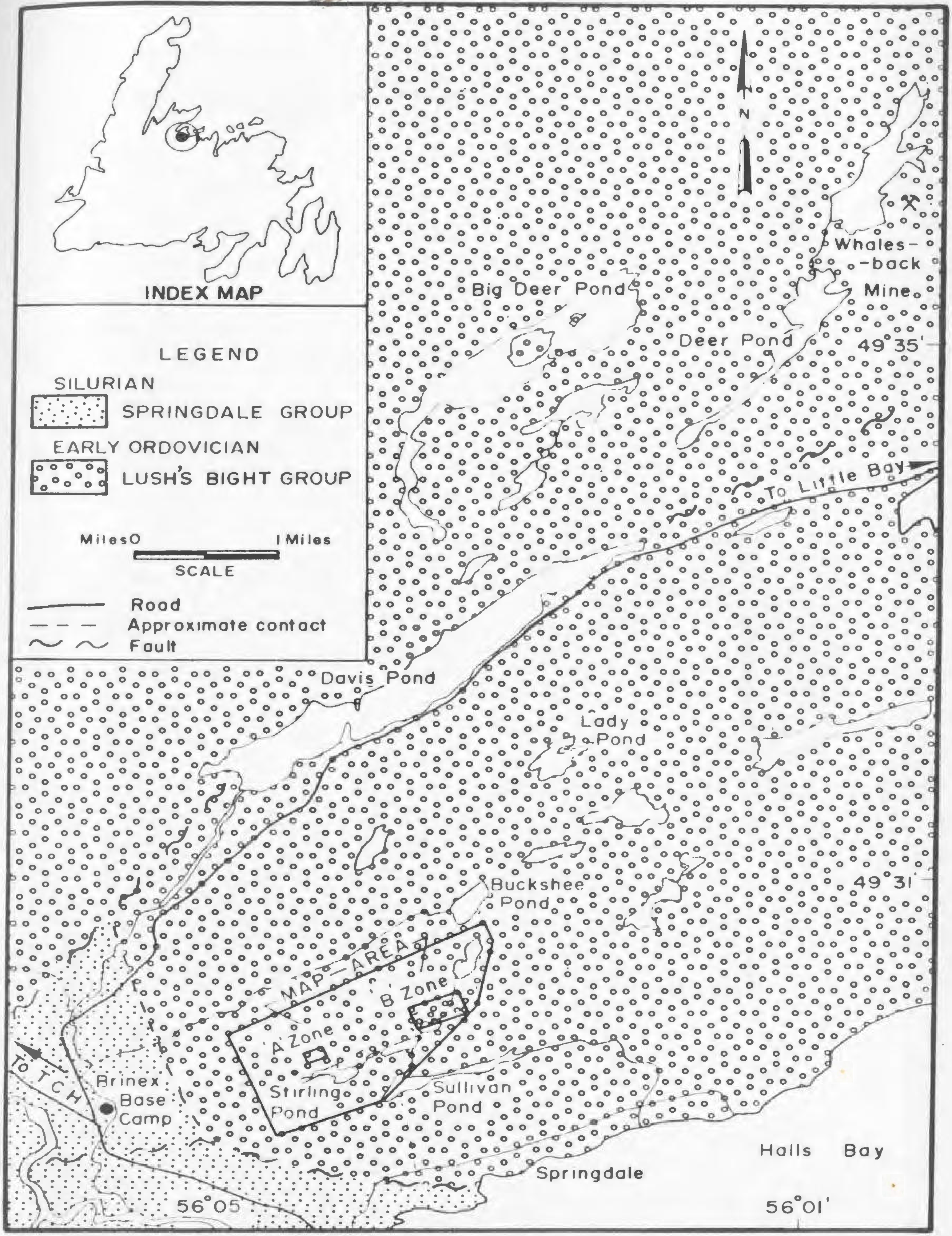


FIGURE 3 INDEX MAP

A Looking north from 9600E, 8500N. Stirling Pond is on the right. Small white tent near main shaft on the 'A' zone.

B Assistant C.Whalen looking east from 9500E, 8500N. Sullivan Pond can just be seen through the trees in the foreground. Middle right is Halls Bay and the islands in Notre Dame Bay.

and swamps are underlain by non-resistant schists and fault zones. The ridges and hilltops are underlain by more massive and resistant volcanic rocks and epidotized pillow lavas. Drainage is generally from west to east with Stirling Pond draining into Upper Twin Pond. Along the above mentioned photolinear, however, drainage is southwestward from Island Pond to Lower Twin Pond and then to Upper Twin Pond. Upper Twin Pond drains into Sullivan Pond which eventually drains into Halls Bay (Figure 1). The map-area contains numerous swamps.

The best bedrock exposures are on the hills and on the shores of the ponds. Overburden is generally less than ten feet thick.

Mining in the Halls Bay Area

The Little Bay mine was the main copper producer in the Halls Bay area prior to 1900. This mine produced continuously for fifteen years form 1878 to 1893. Numerous other smaller copper deposits have had sporadic production over the same period. In 1961, the Little Bay mine was re-opened by Atlantic Coast Copper Corporation Limited and produced until 1969. In 1965, Brinex's Whalesback mine came into production at a rate of about 2,000 tons per day. This mine closed in June, 1972. The Gullbridge mine, twenty miles south of Springdale, produced from

1966 to 1971 at a rate of 2,000 tons per day.

History of the Stirling property

During the period from 1880 to 1882 the Betts Cove Company sank two mine shafts and four test pits and produced 240 long tons of copper ore concentrate. Interest in the property waned until the early 1960's when Brinex began the process of acquiring exploration privileges from the present fee simple owners.

In 1967, Brinex carried out a geochemical soil survey on the property. Several anomalies were delineated and have since been tested by drilling. In 1968, Sander Geophysics Limited (Sander, 1969) was contracted to carry out a combined helicopter-borne electromagnetic (E-M) and magnetic survey. The E-M survey showed only a few positive in-phase anomalies approximately overlying some of the magnetic anomalies. The E-M anomalies are probably caused by mafic rocks, rather than sulphide mineralization. The magnetic anomalies were interpreted as indicating structural changes, probably block faulting, which transgress the general easterly strike of the rock units.

In July, 1968, Inspiration Limited was contracted by Brinex to begin diamond drilling on the property. A total of 31,816 feet of core was recovered from 51 drill holes. The holes range from 186 to 1500 feet in length and give

Plate II

A Diamond drilling at hole SP-69-41 "Pulling rods"

B Diamond drilling at hole SP-69-41 "Lowering rods" a maximum vertical intersection of about 900 feet. H.R. Peters, J.E.S. James and T.N.N. Murthy, Brinex staff geologists, logged most of the core during 1968 and early 1969. In 1972, Brinex dropped the option on the property.

Principal geological investigations of the Halls Bay area

Early geological studies were made by A.H. Murray and J.P. Howley (1881, 1918) between 1864 and 1909, by M.E. Wadsworth (1884) on the Little Bay Mine, and by A.F. Buddington, Edward Sampson and W.M. Agar on the Princeton Geological Expeditions between 1915 and 1919. Later, G.H. Espenshade (1937) mapped the Pilley's Island area and first defined the Lush's Bight Group. In 1938 and 1939, MacLean (1947) mapped the Little Bay area and examined many copper deposits with the help of Douglas, Williams and Rove.

Regional mapping by E.R.W. Neale (Neale, Nash and Innes, 1960; Neale and Nash, 1963; and Neale in preparation) in the King's Point Map-area (on a scale of 1 inch to 1 mile) included the Stirling property. H. Williams (1962) mapped the Botwood (west half) Map-area (on a scale of 1 inch to 4 miles) which lies east of the Stirling property. H.R. Peters (1967) summarized the geology and history of the mineral deposits in the Halls Bay area.

V.S. Papezik and J.M. Fleming (1967) distinguished the Whalesback type and St. Patricks type volcanic rocks near the Whalesback and Little Bay mines. A study of the ore mineralogy and textures at the Whalesback mine by K. Kanehira and D. Bachinski (1968) showed the sulphides have undergone structural deformation and regional metamorphism.

Recently, Memorial University graduate students have studied a wide range of problems in the Lush's Bight Group. G. Gale (1970) studied the primary dispersion patterns of copper, zinc, manganese and sodium in the wall rocks of three sulphide deposits: the Lady Pond prospect, Little Deer mine and Little Bay mine. B.E. Marten (1971) mapped the Western Arm area of Green Bay, and defined the Western Arm Group previously considered to be part of the Lush's Bight Group. U.A. Sayeed studied the tectonic setting of the Colchester plutons on Southwest Arm. J.R. DeGrace (1971) noted that sulphide deposits near King's Point occur in chlorite schist zones that have a composite schistose fabric. J.M. Bird and J.F. Dewey (1970) proposed a model for the evolution of the Appalachian orogen based on the new concepts of the Plate Tectonic Theory. In their model the Lush's Bight Group was considered to be oceanic crust. W.G. Smitheringale (1972) presented the results and interpretations of 81 chemical analyses of Lush's Bight volcanics. The exploration effort of Brinex and other mining companies in the area has contributed much geological information about the Halls Bay area in the form of unpublished assessment reports and maps.

Previous studies of the Stirling Pond area

MacLean (1947, p. 35) described the Stirling deposit as a quartz-sulphide vein replacement in a chlorite schist lens which strikes 070° and dips 75° north in a sheared, metabasalt pillow lava country rock. He observed pyrite, chalcopyrite and sphalerite in the ore and quartz and calcite as gangue minerals. MacLean noted that the pyrite grains are rounded and intensely fractured, and that the large grains crushed at their margins indicate post-pyrite deformation. He also stated that there is no evidence of any commercial quantity of ore, and that most of the chlorite schists in the vicinity are barren at the surface.

In 1967, W.G. Smitheringale carried out preliminary mapping of the present map-area and the surrounding area at a scale of 1 inch to 400 feet. His initial interpretation favoured gently dipping volcanic strata, possibly some type of stratigraphic control of mineralization, and pyritiferous zones of greater lateral dimensions than vertical dimensions .

H.D. Lilly, J.E.S. James (1967, 1967a), and D. Morris (1965) have mapped areas adjacent to the Stirling property for Brinex.

Purpose and scope of the present study

This study was undertaken to attempt to define and correlate volcanic-stratigraphic units in the vicinity of the mineralized zones and to elucidate the structure, especially the scale of folding. The problem was suggested to the writer by Mr. H.R. Peters of Brinex who considered stratigraphy and structure to be the keys to understanding the control and history of mineralization in the area. He observed that the diamond drill holes intersected a number of tuffaceous units and that these units were sufficiently distinct from the common pillow lavas to make feasible an attempt to establish a stratigraphic succession.

Method of study

The writer mapped the Stirling property at a scale of 1 inch to 400 feet, from July to October, 1969, using air photographs and a grid for base control. Also, more than 20,000 feet of diamond drill core were examined and appropriate samples collected (Figures 1 and 2).

Most of the holes were drilled at inclinations between 45° and 65° south at a bearing of 155° north. Most collar locations have been surveyed and the flattening of the drill holes has been determined by acid dip test or by Tropari surveying, generally at 100-foot intervals.

At Memorial University of Newfoundland, the writer examined thin sections, polished thin sections and polished sections of the samples collected. As well, some of the drill core samples were sawn, lightly polished, and varnished and examined under a zoom stereoscopic microscope. Ten whole-rock chemical analyses were made using an atomic absorption spectrophotometer.

Acknowledgements

The writer most gratefully acknowledges support for this study from British Newfoundland Exploration Company Limited, especially Dr. A.P. Beavan and Mr. H.R. Peters. Numerous discussions of various geological problems and helpful suggestions from Brinex staff geologists are also gratefully acknowledged. The writer was assisted in the field by Mr. L. Hicks and Mr. C. Whalen who deserve special thanks. Drs. E.R.W. Neale, M.J. Kennedy and J.S. Sutton visited the author in the field. Dr. W.G. Smitheringale acted as over-all supervisor for the study. The writer was financially supported at Memorial University for four semesters by a Departmental Fellowship and from Dr. W.G. Smitheringale's National Research Council Operating Grant No. A-2678. Mrs. G. Andrews performed the whole rock chemical analyses. Mr. F. Thornhill and the technical staff of the Geology Department prepared thin sections and polished sections, and assisted the

writer in other ways. Messers K. Byrne and H. Butt helped the writer with some of the drafting. Mr. Ben Hansen and Mr. Jack Martin of the Memorial University E.T.V. Photographic studio provided 'last minute' colour printing of some of the plates, after commercially produced prints proved unacceptable. Their co-operation and assistance has been invaluable. Mr. and Mrs. I.H. Stewart provided room and board and much encouragement during the preparation of this thesis during the spring of 1972. Typing of the drafts and final copy of this thesis has been willingly done by my wife, Cindy, and her help and encouragement is greatly appreciated.

CHAPTER II

REGIONAL GEOLOGY AND COPPER DEPOSITS

The Stirling property is entirely underlain by volcanic rocks of the Lush's Bight Group. This group forms a part of the Central Mobile Belt of Newfoundland.

Lush's Bight Group

Definition

This group was first defined by Espenshade (1937, p. 13) in the Pilleys Island area. MacLean, (1947, p.3,4) mapping in the Little Bay map-area to the west of Espenshade's area, recognized similar lithologies and subdivided the Lush's Bight Group into three "sections": the Little Bay Head section, the Western Arm section, and the Halls Bay Head section. The latter two were correlateable and overlay the Little Bay Head section. Recently, Marten(1971) defined the Western Arm Group as including all but the lowermost basalt member of MacLean's Western Arm section. This basalt member is placed by Marten in the Lush's Bight Group. It is believed that the Halls Bay Head section is lithologically similar to the Western Arm Group and therefore it also should no longer be included in the Lush's Bight Group. Hereafter, in this thesis the terminology of Marten (1971) will be used unless otherwise specified.

Distribution and thickness

The Lush's Bight Group occurs on the Springdale Peninsula between Southwest Arm and Halls Bay and on parts of Sunday Cove Island, Pilleys Island, and Triton Island. MacLean (1947, p.4) estimated the thickness of the Little Bay Head section to be 15,000 feet, despite the fact that the group outcrops on the Springdale Peninsula for approximately 10 miles across strike.

Lithological description

The Lush's Bight Group has been described as consisting of great thicknesses of greenschist facies, pale to dark green, pillowed, mafic to intermediate volcanics and some interfingering lenses and thin beds of tuffs and agglomerates.

The pillow lavas and pyroclastics are intruded by a wide range of dykes, sills and plutons, many of which may be comagmatic with the extrusives (compiled from MacLean, 1947; Neale in preparation; Smitheringale, 1972).

Structure and structural relationships

In most places these pillow lavas strike northeast and dip steeply from 70° to 80° northwest. Using carefully selected pillow tops, Neale stated that isoclinal folding produced a repetition of the strata and that the true thickness of the group was probably considerably less than MacLean's estimate of 15,000 feet. Numerous high-angle faults subdivide the group into several blocks which show structural discordance with adjoining blocks.

The base of the group is not known. The group is conformably overlain by the recently defined Western Arm Group (Marten, 1971) which is briefly described below. The group is faulted against suspected Silurian rocks in several places and the contact is commonly intruded by sills and dykes of rhyolite and feldspar porphyry (Neale in prep.). The Lobster Cove fault (defined by Espenshade, 1937, p. 20) is a high-angle fault that separates the relatively undeformed Silurian (?) Springdale Group from Lush's Bight Group volcanic rocks. This fault appears to be offset 2½ miles (right-handed lateral displacement) by the Davis Pond fault (Neale and Nash, 1963). The Lobster Cove fault is part of the Lukes Arm Fault system extending from eastern Notre Dame Bay. Along its length, this fault system separates mainly Lower Ordovician volcanics on the northwest from Middle Ordovician to Silurian rocks on the southeast.

Age and origin

There are no known fossil occurrences in the group, however the age is inferred to be Early Ordovician or older, as the base of the conformably overlying Western Arm Group has been dated on the basis of one brachiopod shell (MacLean, 1947, p. 4). Bird and Dewey (1970, figure 5) interpret the age as Precambrian.

Traditionally, the group has been considered to be the product of subaqueous volcanism due to the predominance of pillow lavas. With the recent developments in plate tectonics, a more precise statement of the environment of origin is desired. Bird and Dewey (1970, p. 1045) interpreted this group as layer 2 of the oceanic crust. Much later in the Early Ordovician, a complex island arc was formed and the Lush's Bight Group was upthrust as wedges behind a trench which is postulated to be delineated by the Lukes Arm fault.

The analytical results presented by Smitheringale (1972) show the group chemically to be mainly a low-potash tholeiite typical of mid-ocean ridge tholeiites. A few alkalic analyses allow an alternative suggestion that the group may be related to the formation of an island arc.

Western Arm Group

This group has recently been defined by Marten (1971). It conformably overlies the Lush's Bight Group. The Western Arm Group consists of three formations, a lower tuff formation (2,400 feet), a middle pillow basalt formation (2,200 feet), and an upper formation (3,600 feet), subdivided into a lower tuff and an upper agglomerate.

Gabbroic sills and a small quartz diorite plug are believed to be genetically related to the volcanism. The degree of alteration, deformation and metamorphism is considerable less intense in the Western Arm Group than in the Lush's Bight Group. MacLean (1947) dated the Western Arm Group as Early Ordovician, Canadian, based on the identification of a single brachiopod shell - Discotreta - from a shale lens near the base of the group. The Western Arm Group may be equivalent to the Snooks Arm Group and to part of the Cutwell Group on Pilleys Island (Marten, 1971).

It is thought that the base of the Western Arm Group marks the change from deep-water oceanic volcanism to explosive island arc volcanism of dacitic and andesitic composition. This volcanism took place in much shallower water with some periods of emergence indicated by probable ignimbrites (Marten, 1971, p.22).

Copper deposits

Metallogenic province

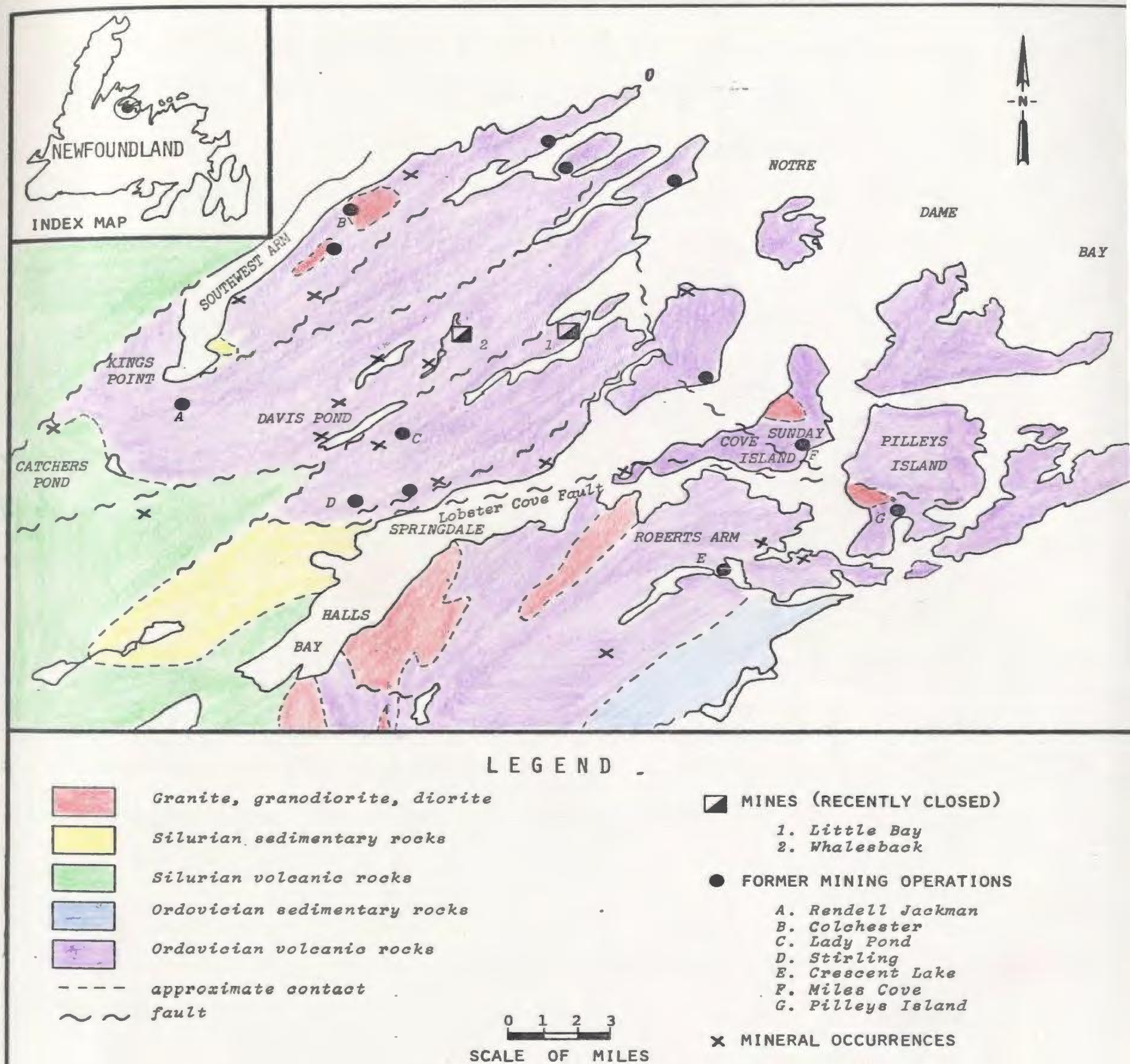
It has long been recognized that there is an unmistakable spatial relationship between the numerous pyritic copper sulphide occurrences and volcanic host rocks in the Notre Dame Bay area (Snelgrove and Baird, 1953, p.37) such that the area may be described as a copper metallogenic province. The mines and mineral occurrences in the Halls Bay area of Western Notre Dame Bay are shown on figure 4. It should be noted that most of the deposits occur north of the Lobster Cove-Lukes Arm fault zone as does the Stirling deposit. There appear to be characteristic differences in the mineral deposits on each side of the fault system. To the north the deposits, such as Whalesback, are typically small, simple, pyrite-chalcopyrite mineralized zones in Lower Ordovician, mafic, tholeiitic pillow lavas and pyroclastics.

To the south of the fault the deposits have a more complex polysulphide mineralogy in a host of more acidic and calc-alkaline composition. The main deposits south of the fault are Buchans, Gullbridge and Pilleys Island. These types of deposits will not be considered furhter in this thesis.

Description of pyritic copper deposits

Most of the deposits and occurrences have the following common characteristics:

1. Simple pyrite-chalcopyrite mineralogy predominates with locally minor concentrations of pyrrhotite, sphalerite, magnetite and marcasite with quartz, calcite, chlorite and epidote as the gangue minerals.



COPPER MINERAL DEPOSITS, HALLS BAY AREA, NEWFOUNDLAND

McArthur, MSc. Thesis, 1973 FIGURE 4 *(Redrawn from Peters, 1967)*

2. The mineralized zones consist of lenses of low-grade disseminated sulphides, stringers and veinlets, as well as a few higher grade, massive bodies.

3. The mineralized zones typically occur in 'chlorite schists' or 'shear zones' which are derived from pillow lavas and pyroclastics.

4. Most mineralized zones are steeply dipping as are the host rocks.

5. Mineralized zones are cut by numerous dykes of a wide compositional range.

6. The deposits, in general, do not have a close spatial relationship to plutonic rocks, however, the Colchester and Whalesback deposits are exceptions to this. (MacLean, 1947; Peters, 1967; Fogwill, 1970; Smitheringale, 1972).

Origin of the deposits

H. Williams (1963) briefly summarized the early ideas on the genesis of these occurrences such as being deposited by magmatic hydrothermal fluids from dioritic intrusions (Snelgrove, 1931), granitic intrusions (Heyl, 1936; Baird, 1948),and being deposited in faults and shear zones (MacLean, 1947, Baird, 1956). Williams noted the widespread distribution of the pyrite-chalcopyrite type deposits so consistently found in Ordovician volcanic rocks. He suggested that the base metal mineral deposits and volcanic rocks were genetically related and that the sulphides originated with the volcanism. He further suggested that the local features noted by the earlier authors controlled the latest emplacemnt or remobilization of the sulphides as a consequence of structural deformation.

Peters (1967), in a summary paper of the sulphide deposits of Halls Bay area, also stated that the sulphides were probably directly related to the volcanism but later were remobilized into structural and stratigraphic traps, possibly in conjunction with emplacement of granodiorite plutons.

In a detailed study of the ore mineralogy and textures in the Whalesback deposit, Kanehira and Bachinski (1968, p. 1391) described primary colloform pyrite textures and the replacement of pyrite by chalcopyrite. " The present distribution of sulphides post-dates the formation of the host volcanic rocks and is a consequence of structural deformation. Sulphide mineralization and shearing overlapped, in part at least, with chalcopyrite re-deposition continuing to later stages. Porphyritic dykes cut the shear zone and sulphide ore, with the whole being regionally metamorphosed." They concluded that the sulphide mineralization must be post-volcanic lavas, in part pre-shearing and pre-regional metamorphism.

Although in the case of Whalesback and other deposits the evidence for the exact relationship of the sulphides to the volcanic host rocks has been obscured by deformation and metamorphism, the mid-ocean ridge environment is considered a likely environment for the formation of sulphide deposits. Ore fluids may be expelled by volcanic exhalations or produced by magmatic hydrothermal or metamorphic hydrothermal processes and sulphides deposited in stratigraphic traps formed by aquagene tuffs, pillow breccias and volcanically derived sediments (Smitheringale, 1972).

DeGrace (1971) and Kennedy and DeGrace (1972) concluded that the often mineralized chlorite schist zones in the Lush's Bight Group represented early shear belts in which an early foliation has been folded and transposed by the later, regional, penetrative deformation. The sulphides are pre-tectonic to the development of the schist zones and were later remobilized into these zones during subsequent folding.

CHAPTER III

GEOLOGY OF THE STIRLING PROPERTY

General Statement

It is difficult to map distinct stratigraphic volcanic units in many portions of the Lush's Bight Group. In the Stirling area, the difficulties lie in distinguishing or recognizing individual flows and their associated features such as brecciated or vesicular flow tops or flow bottoms. It is also difficult to determine in the field whether or not a given greenish-grey, fine-grained, cleaved volcanic rock is an andesite or basalt, and in some cases whether the rock is intrusive or extrusive. Chlorite is present in almost all the rocks in this area and whether it is 10 per cent or 50 per cent, the dark green chloritic colour appears to mask other minerals and textures.

Both in field mapping and core logging the writer used both primary and secondary features such as colour, metamorphism, hydrothermal alteration, banding, brecciation, cleavage, schistosity, and pillow structure as criteria for separating the units in the volcanic sequence. Amygdules, on the other hand, despite numerous minor occurrences, were not given much consideration as they were interpreted to be restricted to localized pockets. In general, it is easier to identify rock types in the drill core than in weathered field samples.

Description of Map-units

In the Stirling map-area, the Lush's Bight Group is divided into four mappable volcanic units (Table III - 1). Some of these are subdivided into sub-units mainly on the basis of alteration and primary structures, Unit 1 consists of tuffaceous schists some of which are highly siliceous. Unit 2 consists of several types of chloritic metabasalts. Unit 3 is a localized but highly distinctive magnetic, purple and greenish volcanic breccia. Unit 4 consists of 2 sub-units: an epidote basalt and an epidote-rich isolated pillow basalt.

The main cleavage or schistosity (S_1) is usually steeper than or parallel to the lithological contacts, therefore the volcanic sequence is believed to be upright and unit 1 is considered to be the oldest unit in the map-area. This will be further discussed in Chapter IV.

Unit 1 Tuffaceous schists

Distribution and thickness

This unit underlies the low-lying areas in a belt from Stirling Pond to Lower Twin Pond. It has been recognized extensively in the drill core from the 'B' zone and to a minor extent in the 'A' zone. The outcrops

TABLE III - I TABLE OF MAP-UNITS

<table>
<tr><th>ERA</th><th>PERIOD</th><th colspan="2">MAP-UNIT and THICKNESS (feet)</th><th>LITHOLOGY</th></tr>
<tr><td>Mesozoic ?</td><td>Jurassic or Early Cretaceous</td><td>Intrusive</td><td>unit 7</td><td>7, Lamprophyre</td></tr>
<tr><td rowspan="13">Paleozoic</td><td rowspan="4">Ordovician and Younger</td><td>Intrusives</td><td>unit 6</td><td>6c, Fine-grained diorite and diabase
6b, Medium-grained gabbro and diorite
6a, Feldspar porphyry</td></tr>
<tr><td colspan="3">Intrusive contacts</td></tr>
<tr><td>Intrusive ?</td><td>unit 5</td><td>5, Rhyolite, felsite</td></tr>
<tr><td colspan="3">Relations unknown</td></tr>
<tr><td rowspan="9">Early Ordovician</td><td rowspan="9">Volcanic Sequence - Lush's Bight Group</td><td>sub-unit 4b
1300 ±</td><td>4b, Isolated pillow basalt</td></tr>
<tr><td colspan="2">Gradational contact</td></tr>
<tr><td>sub-unit 4a
800 ±</td><td>4a, Epidote basalt</td></tr>
<tr><td colspan="2">Conformable contact (?)</td></tr>
<tr><td>unit 3
700 ±</td><td>3, Volcanic breccia</td></tr>
<tr><td colspan="2">Conformable contact (?)
(partly interfingering)</td></tr>
<tr><td>unit 2
400 ±</td><td>2b, Schistose chloritic basalt
2a, Chloritic basalt</td></tr>
<tr><td colspan="2">Gradational or interfingering contact</td></tr>
<tr><td>unit 1
600 ±</td><td>1a, Tuffaceous schists, 1b Siliceous tuffaceous schists</td></tr>
</table>

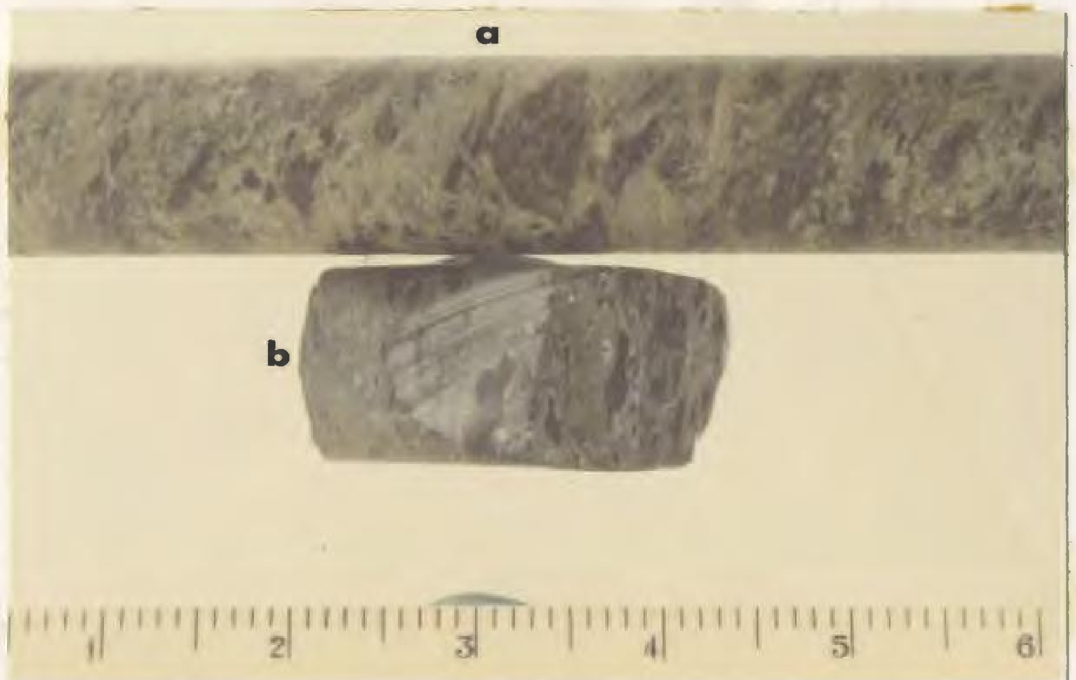
of this unit are mainly confined to small exposures on the shores of the ponds. This unit is approximately 600 feet thick.

Lithology

Unit 1 is sub-divided into 2 sub-units:1a, tuffaceous schists and 1b, a texturally similar zone of siliceous tuffaceous schists. These sub-units are readily distinguishable in the drill core although gradational varieties exist. In outcrop, sub-unit 1b is recognizable, however, sub-unit 1a, being similarly chloritic to unit 2, may not be clearly separated from unit 2 in the area north of the Twin Ponds.

Sub-unit 1a is greyish to greenish in colour. It is typically finely schistose, but there are a few coarser fragmental or streaky varieties of schists (Plate III - A). Small amygdules may occur in this unit but they are rare. Sub-unit 1b is much greyer and less green in colour than 1a. This is due to the higher quartz content which is readily seen in the hand specimen.

This unit as a whole consists of widely varying proportions of the following main minerals: plagioclase, chlorite, quartz, sericite, calcite, and relatively minor amounts of disseminated epidote, magnetite, and sulphides (mainly pyrite). Plagioclase (albite An_6) laths are



A Drill core samples from unit 1 showing coarse fragmental and tuffaceous textures.

a: from sub-unit 1b with a highly siliceous matrix.
b: from sub-unit 1a with chlorite in both fragments and matrix.

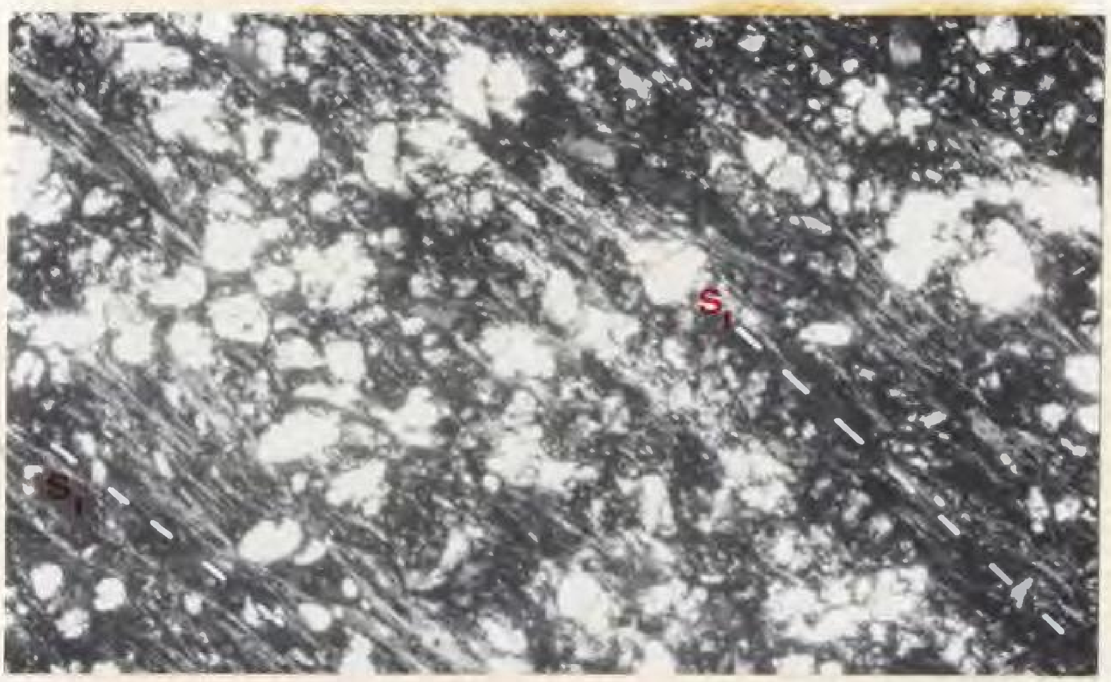
B Photomicrograph of bottom sample in above picture showing the tuffaceous texture; (X30), X-nicols.

A Photomicrograph of relict quartz phenocrysts in a quartz-sericite schist (sub-unit 1b). Matrix quartz is chert-like; (X48), X-nicols.

B Photomicrograph of laminations in tuff (unit 1); (X 48), Plane light.

quite rare but they do occur as large relict phenocrysts and as very fine microlites. Albite also probably occurs in its typical metamorphic anhedral form in which it is very difficult to visually distinguish from quartz. Quartz has been readily identified where it is medium- to coarse-grained. In some rocks there are large isolated relict phenocrysts (Plate IV-A). There is also abundant, aphanitic, chert-like quartz in the matrix, sometimes occurring as quite distinct laminations (Plate IV-B). Chlorite grain size is variable. The finest grain size is suggestive of volcanic ash. Chlorite typically occurs as micaeous flakes that bend around coarse quartz grains. Chlorite also occurs as coarse, irregular shaped patches that may be tuff fragments. In places the chlorite is massive and coarse grained with some inclusions of quartz. Sericite occurs with chlorite in some rocks and without chlorite in others, especially in sub-unit lb. In a few thin sections, it was noted that sericite in the form of thin, widely-spaced flakes defines a possible early fabric (pre-S_1). The angle between the two fabrics is approximately 35° (Plate V-B). Carbonate alteration commonly occurs in coarse patches, disseminated grains and in amygdules.

All rocks in this unit have one good penetrative fabric (S_1), usually defined by the parallel or augen



A A quartz chlorite-schist from unit 1 showing only one fabric; (X48),X-nicols.

B A quartz-sericite schist from unit 1 showing 2 fabrics; (X48),X-nicols.

growth of chlorite and sericite (Plate V). The age of much of the quartz present in these rocks is believed to be pre-main deformation as the S_1 fabric often wraps around the coarser quartz grains. The chert-like quartz grains have a preferred orientation parallel to the chlorite and sericite (S_1) fabric. Both types of early quartz have a 'dirty' appearance due to numerous fine inclusions. The quartz also shows uneven extinction. Mutual grain boundaries are very irregular and show a considerable degree of embayment. There is some minor evidence for a pre-S_1 silicification in the form of quartz veinlets that have subsequently been deformed, possibly cataclastically. Minor syn-tectonic growth of quartz is mainly seen in pressure shadows around large pyrite grains or other fragments (Plate VI-A). The quartz has a feathery columnar impingement texture (Spry, 1969, p. 161). Minor post-tectonic quartz occurs in small patches and cross-cutting veins. Both the syn- and post- tectonic types have a 'clean' appearance with only rare inclusions. The grain boundaries are straighter and less embayed.

<u>Contact relations</u>

Unit 1 is believed to be the oldest unit in the map-area. Although rocks of both units 2 and 4 occur to the south, it is not known whether they are actually stratigraphically lower or are repeated by faulting and/or

A. Photomicrograph showing feathery quartz in a pressure shadow; (X30), X-nicols.

B. Photomicrograph of an altered sericite schist of sub-unit lb; (X30), X-nicols.

folding. Unit 1 grades upward into unit 2. The contact between 1a and 1b is gradational and is arbitrarily taken in hand specimen by the writer where a siliceous appearance is more dominant than a chloritic appearance. Subunit 1b in general underlies 1a and therefore is considered to be older but this relationship is not consistent everywhere.

Origin

The evidence for a tuffaceous origin is based on:

1. A few samples with textures consisting of coarse fragments of volcanic ash or ragged patches of laminated tuff.
2. Relic phenocrysts of quartz and plagioclase.
3. In a few drill holes there are bands generally less than 2 feet thick, composed of almost pure chlorite of extremely fine grain size and not showing intense shearing, possibly representing thin beds of volcanic ash.
4. Numerous irregular shaped patches of mainly chlorite and other distinct compositions that may be tuffaceous in origin.

The origin of the peculiarly abundant quartz in subunit 1b is unknown except that it is mostly pre-S_1.

There are several possible origins for the quartz:

1. The primary chemical composition of this unit may have been rhyolitic favouring the crystallization of abundant free quartz.

2. Chert may have been precipitated from sea water and interbedded or incorporated with the pyroclastics during their diagenesis.

3. Hydrothermal silicification, rising in the complex fault zone underlying Stirling, Upper and Lower Twin and Sullivan ponds, may have been acitve before the main regional deformation.

The writer prefers either the second or third mentioned possible origins.

Unit 2 chloritic metabasalts

This unit is sub-divided into two sub-units: 2a, chloritic basalt and 2b, schistose chloritic basalt. The dominating characteristic of this unit is the abundance of chlorite.

Distribution and thickness

Unit 2 occurs in a belt about 400 feet thick, lying between sub-unit 4a and Stirling and Upper Twin Ponds and south of unit 3. In the 'A' zone it occurs in inter-fingering lenses within sub-unit 4a. A few small out-crops southeast of Stirling Pond may indicate a second belt of this unit or, alternatively, additional inter-fingering lenses.

Lithology

The basalts and schists of this unit are typically fine-grained and dark green to greyish-green in colour. The chloritic basalts of sub-unit 2a (Plate VII-A) have a good penetrative cleavage but do not have mineralogically distinct layers as do the schistose chloritic basalts of sub-unit 2b (Plate VII-B).

This unit consists of mainly plagioclase (albite, An_6) laths (50%) and chlorite (30%). In places, fine, interstitial quartz, similar to quartz occurring in unit 1, is moderately abundant. Calcite is the main alterat-ion mineral occurring in both sub-units but it is more abundantly developed in sub-unit 2b within the chlorite-poor layers. Sericite and epidote are extremely rare in this unit. Magnetite and leucoxene occur as disseminated, fine grains and massive stringers. Zones of ore grade and near ore grade chalcopyrite are associated with highly chloritic host rocks.

The plagioclase laths are well preserved and albite twinning is very common. The grain boundaries of the

A Photomicrograph - Typical chloritic basalt (unit 2a) with plagioclase laths (white) set in a chlorite groundmass (dark grey) and disseminated pyrite grains (black); (X48), Plane light.

B Photomicrograph - Schistose chloritic basalt (unit 2b) showing possible flow banding. Dark chloritic layers contain very fine-grained, aligned plagioclase laths, whereas, the alternate layers contain abundant coarser plagioclase; (X30), X-nicols.

plagioclase may be strongly altered giving a fuzzy appearance. Fine inclusions are abundant in the plagioclase. Chlorite is the most common matrix mineral filling the interstitial spaces around the plagioclase. In sub-unit 2a it has grown with a preferred orientation but rarely does it form a schistosity or banding as in sub-unit 2b. The schistosity in sub-unit 2b consists of alternating chlorite-rich layers with chlorite-poor and calcite-plagioclase-rich layers that range in thickness ness from 0.5 - 2.0 mm. In places the plagioclase laths within the chlorite bands may be smaller and have a preferred orientation whereas the laths in the other calcite-plagioclase-rich layers are larger and have a more random orientation.

Within unit 2 are narrow lenses ranging from a few inches to several feet thick of dark green chlorite schist consisting almost entirely of chlorite. The chlorite schist in the drill core tends to break easily into thin wafer-like pieces. Pyrite-chalcopyrite mineralization occurs within the chlorite schist.

Contact relations

Unit 2 is in gradational contact with units 1 and 3. In the 'A' zone it occurs as interfingering lenses within unit 4.

Origin

This unit was probably formed by a succession of massive to finely flow-banded basaltic flows. The fine-grained and often mineralized narrow zones of chlorite schist within this unit may be minor tuff beds or interbedded volcanic sediments.

Unit 3 Volcanic breccia

This unit contains distinctive, reddish, magnetic, volcanic fragments. These fragments are not similar to any other volcanic rock in the map-area.

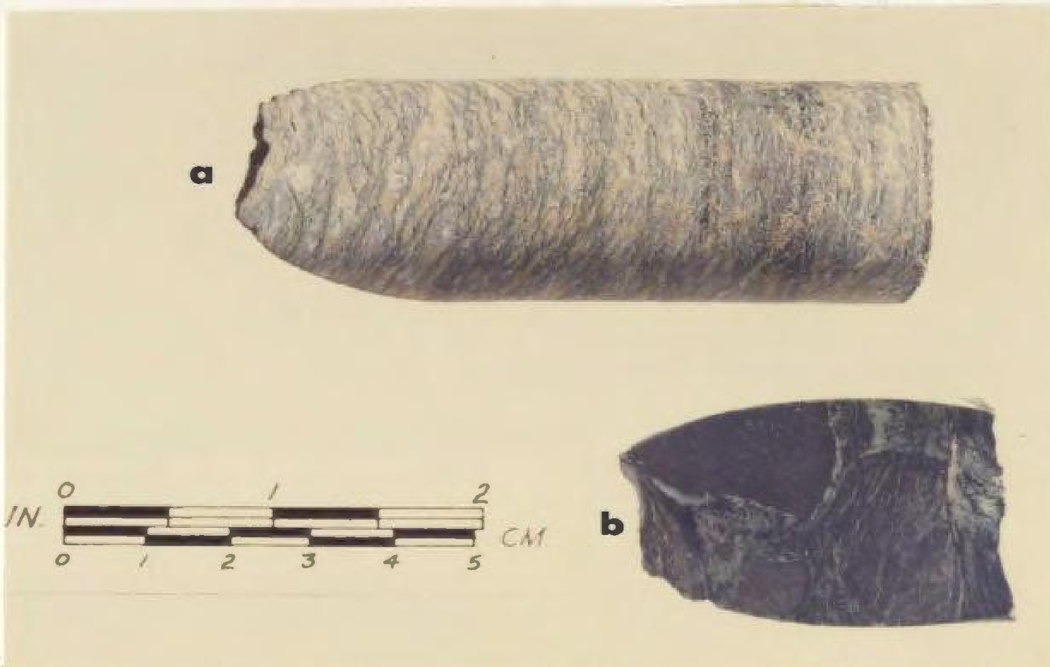
Distribution and thickness

This unit has been recognized southwest of Island Pond in drill holes SP-26,30,31,37,39,40 and 45. This unit has not been positively recognized in outcrop, however, some of the schistose outcrops on the shores of Island Pond may be part of this unit. This unit has been traced along strike for about 800 feet. The thickness is about 700 feet.

Lithology

The volcanic breccia consists of up to 70 per cent reddish and purplish volcanic fragments ranging up to two inches in diameter set in a schistose quartz-chlorite matrix. The fragments vary from angular and quite undeformed to highly deformed with an augen shape (Plate

Plate VIII



Drill core samples of unit 3.

a: augen schist.

b: volcanic breccia with coarse, magnetic, amygdaloidal fragments that are dark red in hand specimen (day light).

VIII-a). Small quartz amygdules are weakly scattered in some of the coarser fragments. In drill hole SP-37-69 an unusual variety of this breccia had coarse but highly irregular patches of epidote alteration mostly confined to the matrix. The fragments in this case were greyish-green rather than reddish or purplish.

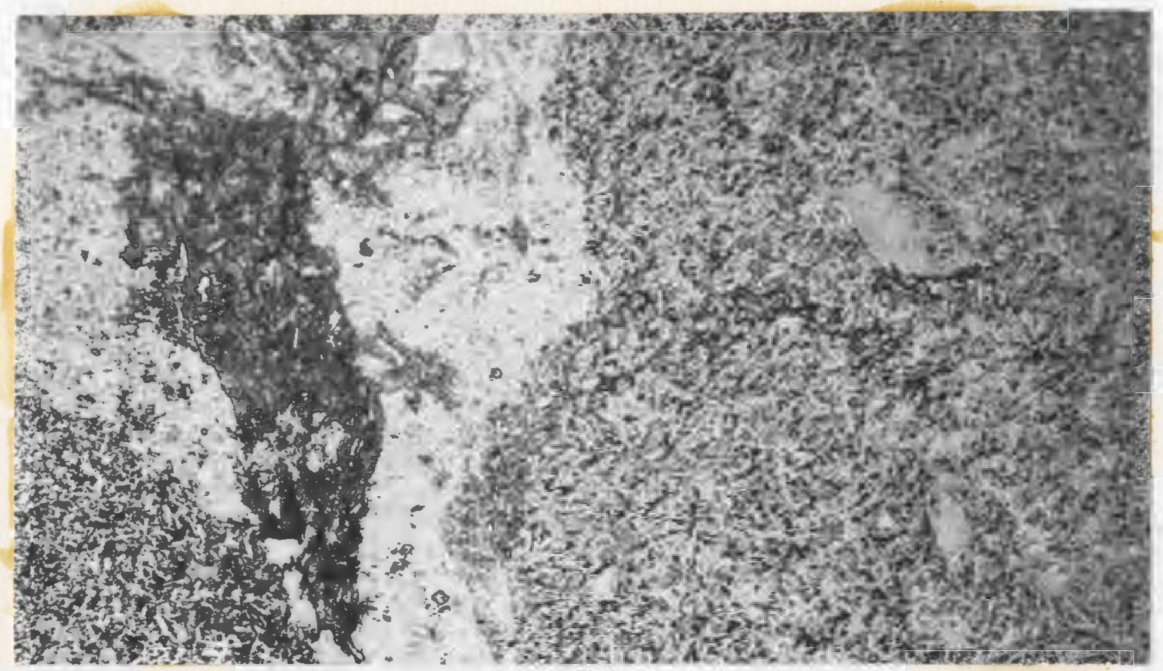
The typical reddish and purplish fragments, especially the coarser ones (Plate IX), consist of well preserved ophitic plagioclase microlites (75%) from 0.1 to 0.2 mm. in length, interstitial chlorite (15%) and relatively abundant, fine, disseminated euhedral grains of magnetite (10%). The matrix of the breccia consists of very fine-grained aggregates of chert-like quartz patches and streaks of chlorite and patches and grains of secondary calcite, thin flakes of sericite, disseminated magnetite and minor pyrite.

Both chlorite and sericite have grown in the planes of schistosity that mainly wrap around the fragments. In a few rocks the sericite fabric is well developed through the fragments. The matrix quartz in places shows a slight preferred orientation.

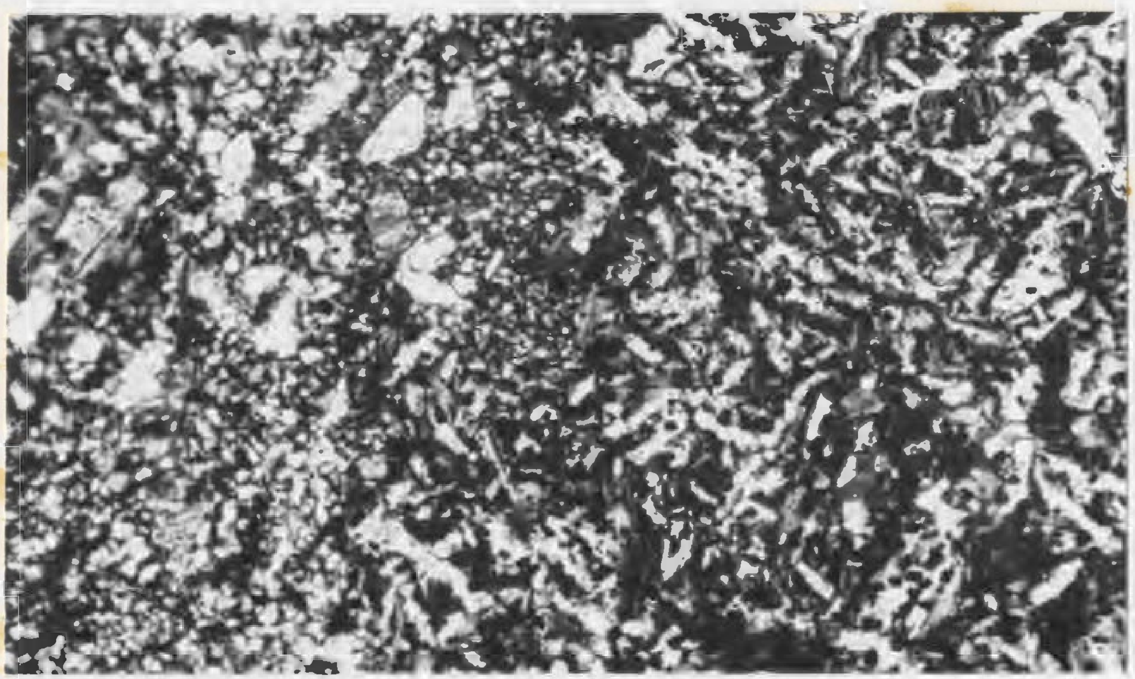
Contact relations

The lower contact zone of this unit rapidly grades from augen schists and schists into basalts and schists of unit 2 over an interval of two to three feet. The

Plate IX



A Photomicrograph - Typical volcanic breccia with magnetite-rich fragments. Unit 3;(X40),Plane light.



B Photomicrograph - Similar to above at higher magnification to show siliceous matrix and magnetite-rich fragments;(X120),X-nicols.

nature of the upper contact is not known as it is obscured by dykes. As this unit was not positively identified in outcrop, its relationships with the other units along strike are not known.

Origin

The occurrence of coarse, volcanic breccia suggests close proximity to an explosive, submarine, volcanic centre. Alternatively this unit may be a pillow breccia.

Unit 4 Epidote basalt and isolated pillow basalt

Unit 4 is a distinctive, epidote-rich, mafic, volcanic rock. It has been sub-divided on the basis of the presence or absence of possible pillow structures into epidote basalt (Sub-unit 4a) and isolated pillow basalt (sub-unit 4b).

Distribution and thickness

Sub-unit 4a outcrops in a belt north of Stirling and Upper Twin Ponds. Its thickness is approximately 800 feet. In a belt parallel to sub-unit 4a, sub-unit 4b is well exposed, underlying the resistant hills on the north side of the map-area. It is also well exposed on hills south of Stirling and west of Sullivan Ponds. In drill holes SP-41 and SP-42, a 530-foot thick section of 4b (down the hole) was intersected. It is believed that this sub-unit outcrops for a considerable distance

Plate X

A Hand specimens of unit 4:

a: heavily disseminated epidote alteration in a basalt.

b: part of an epidosite body.

B Epidosite bodies in outcrop (P) that are interpreted to be isolated pillows.

north of the area mapped and its thickness is unknown. Maximum thickness in the map-area is about 1,300 feet.

Lithology

Unit 4 is typically a fine-grained, faintly cleaved, mafic, volcanic rock. Its colour ranges from greenish-grey to green to yellowish-green. Epidote alteration occurs in a wide range of forms from a pervasive fine-grained dissemination throughout the basalt to veins, patches, clots and occasional amygdule fillings (Plate X-A).

Within sub-unit 4b are distinctive greenish-yellow epidosite* bodies (Plate X, A and B). They have a bun shape and are generally about 12 inches in maximum dimension. It is thought that these bodies represent replaced isolated pillows or pillow cores. Typically, they are quite widely separated (1-20 feet) and rarely are two of these bodies ever in contact, thus pillow tails are not seen. Also they are invariably rounded rather than angular and thus they are probably not a pillow breccia. An alternative interpretation that is not favoured by the author is that they may be volcanic bombs replaced by epidote and quartz.

Chert and jasper occur as small patches and lenses ranging from a few inches to 2 feet long. Jasper was seen in drill holes SP-32 and SP-45.

* Epidosite is defined as a "rock composed essentially of epidote and quartz" (from A.G.I. Glossary of Geology and Rel. Sci.).

In the field the epidote basalt (sub-unit 4a) has the same appearance as the matrix of the isolated pillow basalt (sub-unit 4b).

Sub-unit 4a and the matrix of 4b consist of chlorite (40%), plagioclase (20-30%), epidote, sphene, leucoxene, ilmenite and/or magnetite (25% but quite variable) and minor actinolite, calcite, pyrite (each generally 5% or less). Chlorite is the dominant mineral occurring around and interstitial to thin altered phenocrysts. The microlites are typically small, about 0.1 mm. long. Generally, the primary texture is still recognizable as ophitic or sub-ophitic. Epidote, sphene and leucoxene are generally more abundant in this unit than in any other. The epidote may be either typically yellow or very cloudy and granular and ranges from less than 0.1 mm. to several mm. Dark brown to blackish sphene is usually abundant and is often altered to leucoxene. Fine, black, granular inclusions occurring within the sphene are probably ilmenite or magnetite. Actinolite is present as small, greenish, fibrous grains that are usually highly altered along their margins. They are usually interstitial to the plagioclase microlites. Carbonate alteration occurs in fine veinlets and as very fine grains scattered throughout the matrix. Pyrite is disseminated as fine, anhedral grains, generally less than 0.3 mm.

In hand specimen this unit has a fine cleavage that is spaced 1-3 mm. apart. It is most easily seen on the weathered surfaces. In thin section this cleavage is in places only faintly developed, but where it is developed it consists of irregular cracks that are marked by a fine growth of chlorite and minor rusty staining in near surface samples. The pillows are flattened in the plane of the fabric.

Contact relations

Unit 4 is in contact with units 1, 2 and 3. The contacts between units 1 and 4, and 3 and 4 are probably sharp but they are very poorly exposed. The contact between units 2 and 4 is more gradational and in places interfingering. No volcanic unit has been recognized to lie stratigraphically above this unit within the map-area. The contact between sub-unit 4a and 4b has been arbitrarily drawn by the writer where pillow structures become rare or absent.

Origin

It is thought that this unit was extruded in submarine conditions because of the presence of the epidosite bodies interpreted as pillows. Similar structures clearly are pillows or related to pillows elsewhere in the Lush's Bight terrain. The wide distribution of pillows in the Lush's Bight Group has led many workers to conclude that ~~the group~~ as a whole is submarine in origin.

Unit 5 Rhyolite

Distribution and thickness

Rhyolite is a rock unit of very minor importance in the map-area. Only a few, apparently unrelated occurrences were noted in the drill core. In drill hole SP-10-68, rhyolite was intersected from 103 to 179 feet (measured down the hole). Three drill holes on a section 100 feet to the east failed to intersect this unit. This may indicate that it pinches out abruptly or it is faulted off. Thus the true thickness of this unit cannot be determined.

Lithology

In the drill core the rhyolite is light grey, massive, aphanitic and very hard. It is moderately fractured with fine coatings of calcite and chlorite filling the fractures. Pyrite occurs as fine veinlets and disseminated blebs. A visual estimate of the minerals present in thin section is as follows:

feldspar	10-15%
quartz	10-15%
chlorite	10%
felsic groundmass - mainly quartz	60%
calcite and minor white mica	2-3%
pyrite	1-2%

Microphenocrysts (1 mm.) of feldspar and quartz are scattered throughout an aphanitic groundmass of probably devitrified glass, with minor inclusions and intergrown patches, threads and specks of chlorite. Very minor carbonate alteration is disseminated throughout. Disseminated anhedral pyrite grains are generally 1-2 mm. There is a weak indication of a fabric consisting of a preferred orientation of inclusions and the groundmass quartz. It is also possible that the main deformation has produced the fine, chlorite-filled fracturing.

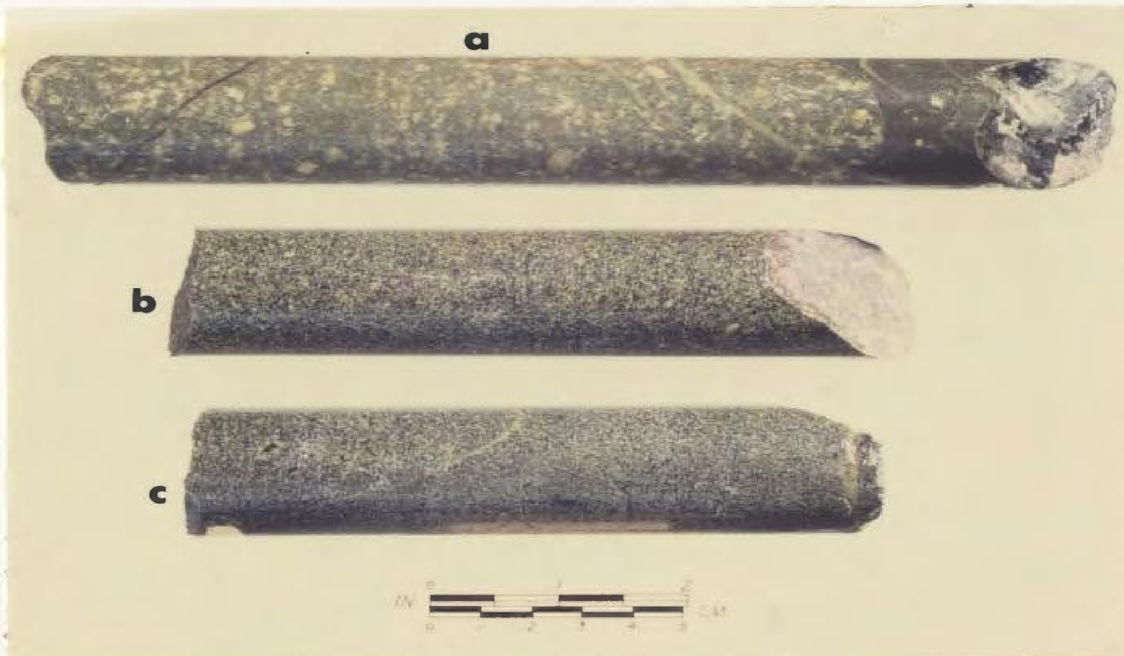
Origin

Due to the restricted nature of the occurrence of this unit it is very difficult to discuss its origin. It is not known whether this unit is extrusive or intrusive. As it is compositionally quite different from other volcanic units, its behaviour during deformation would be expected to also be different. The faint fabric possibly indicates that it is pre-deformation (D_1). It may represent a small local centre of silicic volcanism within the Lush's Bight Group or it could represent post-Lush's Bight, but pre-deformation igneous activity. It is not known to be cut by any other intrusive rocks.

Unit 6 Mafic intrusive rocks

Most of the intrusive rocks in the Stirling map-area are mafic in composition. They have been sub-divided into three types of sub-units, based on the presence or absence of phenocrysts and grain size: Feldspar porphyry (sub-unit 6a), medium-grained gabbro and diorite (sub-unit 6b), and

Plate XI



Drill core samples of intrusive rocks.

a: Feldspar porphyry - unit 6a. Coarse white mineral is highly altered (epidotized) feldspar.

b: Medium-grained, mafic, intrusive rock-unit 6b.

c: Fine-grained, mafic, intrusive rock-unit 6c.

fine-grained to aphanitic diorite and diabase (sub-unit 6c) (Plate XI).

Distribution and thickness

Feldspar porphyry occurs in both the "A" and "B" zones. It is generally the thickest of the mafic intrusives. In drill hole SP-31-69, it was intersected for about 190 feet. Correlation with a surface outcrop suggests that it is very steeply dipping and conformable with the host volcanic rocks. Thus, its true thickness is about 120 feet, however, this is interpreted to be a local thickening of the intrusion and its normal thickness is 60 feet or less. Dykes of sub-units 6b and 6c occur abundantly in the drill core and over most of the area mapped. In the whole map-area intrusive rocks comprise 10-20 per cent of the total rock volume. In some outcrops, dykes account for up to 40 per cent. The author has re-visited some of these outcrops to check if these outcrops were sheeted dykes. Field evidence indicates that this possible interpretation is not warranted. Although a great many dykes are parallel and sub-parallel with a northerly trend, they were not seen to intrude or be in contact with each other.

Dykes of sub-units 6b and 6c range in thickness form 5 to 20 feet.

Lithology

Feldspar porphyry in hand specimen is dark green, fine-grained, with 15-20 per cent large, altered, pink feldspar phenocrysts up to 7 mm. in diameter (Plate XI-a). The phenocrysts appear to be stretched and the grain boundaries are strongly altered. The groundmass has a strong fabric. Microscopically, deformation has obliterated nearly all the primary minerals and textures. Epidote, sericite, chlorite and sphene are the main alteration minerals abundantly present throughout. They are coarser in grain size where they are replacing the phenocrysts than in the groundmass. Very fine-grained, syn-tectonic quartz has grown in pressure shadows behind and within the remnant phenocrysts. Few hornblende grains are recognizable that have not been severely altered.

Sub-unit 6b, medium-grained gabbro and diorite, is generally faintly to distinctly porphyritic, however, the phenocrysts are much smaller than in 6a. Some medium-grained, non-porphyritic dykes have been included in this sub-unit. The colour of this sub-unit is typically dark greenish to greenish-grey (Plate XI). Plagioclase, chlorite, hornblende, pyroxene, epidote, calcite, quartz, sphene and leucoxene are the main minerals present in thin seciton, in highly varying proportions. Pyroxene phenocrysts are sometimes preserved but more commonly they have been replaced by hornblende. Hornblende has been partly altered to chlorite. Plagioclase ranges from 25 to 60 per cent. Epidote alteration is highly variable from sample to sample, ranging between 5 and 20 per cent. Original ophitic and sub-ophitic textures are sometimes recognizable where the metamorphic alteration is not too strong.

Sub-unit 6c is mainly composed of fine-grained to aphanitic diabase that is generally non-porphyritic, massive and greenish-grey in colour. The grain size is 0.1-0.2 mm. (Plate XI). Mineralogically, sub-units 6b and 6c are similar. Original textures are generally not well preserved while a chloritic foliation may be quite well preserved.

Contact relations

Mafic intrusive rocks cut all of the volcanic units (1-4). The main foliation (S_1) in the volcanic rocks similarly cuts the intrusives. Numerous instances of dragfolded dykes indicate that they have suffered the same deformational history as the volcanics. Chilled margins are commonly seen in outcrop and in the drill core and they range from a few inches to more than 2 feet in thickness.

Origin

The compositional similarity and the pre-main deformation age of most of these dykes indicate that they are probably feeder dykes to the volcanic pile.

Unit 7 Lamprophyre

Distribution and thickness

Possible lamprophyre dykes occur in drill holes SP-5-68 and SP-7-68 ('A' zone). In each hole there are several short 1-5 foot intersections.

Lithology

In hand specimen these rocks are a dull chocolate brown colour. They are hard, massive, sometimes porphyritic, fine grained and magnetic. One thin section shows the following modal analysis:

hornblende phenocrysts (primary?)	15%
plagioclase	55%
hornblende in groundmass	15%
magnetite	5%
chlorite, calcite and epidote	5-10%

Hornblende phenocrysts range in size from 0.3 to 1.0 mm. Their cores are generally partly replaced by chlorite and some calcite. Very fine hornblende grains also occur in the groundmass. They have an acicular shape and are about 0.2 mm. long. Some albite twinning is present. The plagioclase contains abundant fine inclusions. The magnetite grains are typically less than 0.1 mm. in size and uniformly disseminated throughout. Some fine-grained, cloudy epidote is also scattered in the groundmass. There is a preferred mineral orientation of the acicular hornblende and some of the plagioclase laths. This appears to be a primary lineation rather than a metamorphic fabric. The mineralogy and texture indicate this is probably a spessartite lamprophyre.

Age

The unusually fresh texture of these rocks suggests that they are the most recent intrusive event in the map-area, but their actual age is unknown. Elsewhere in Notre Dame Bay, Poole (1967, p.42) reports three K-Ar dates ranging from 115 to 144 million years on undeformed lamprophyres that cut Ordovician and Silurian rocks. H. Peters (pers. comm.) reports a K-Ar date of 385 million years on a biotite lamprophyre from just east of the Stirling area.

Petrochemistry

Major element analyses of ten representative drill core samples are presented in Table III-2. No trace element analyses were made. The results of only ten samples necessarily limits any interpretation or the drawing of any firm conclusions on the petrochemical origins of the Lush's Bight Group. The results do allow, however, simple comparisons with each other and with analyses of rocks elsewhere in the Lush's Bight Group.

Three analyses from siliceous members of unit 1 show a range between 64.1 and 69.7 per cent SiO_2 suggesting perhaps a rhyolitic composition, however, other oxides such as Fe_2O_3, MgO, Na_2O and K_2O do not give values typical

TABLE III - 2 CHEMICAL ROCK ANALYSES

Sample		SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	MnO	MgO	CaO	Na_2O	K_2O	Loss on** Ignition	Total
SP-7-69-457'	Epidote-rich basalt sub-unit 4a ("A" zone)	44.3	2.26	15.5	15.0	0.22	6.6	11.8	1.5	0.04	2.78	100.00
SP-15-68-206'	Chloritic basalt sub-unit 2a ("B" zone)	56.9	0.65	12.6	19.4	0.13	7.2	0.3	0.04	0.04	5.3	102.5
SP-23-69-185'	Carbonate-rich chlorite schist, sub-unit 2b ("B" zone)	53.3	0.73	14.0	10.7	0.17	6.2	4.4	4.0	0.04	6.0	99.54
SP-23-69-285'	Tuffaceous schist sub-unit 1a ("B" zone)	55.8	0.30	15.4	10.2	0.30	7.8	1.4	2.8	0.15	5.9	100.05
SP-1-69-173'	Chlorite schist sub-unit 2a ("A" zone)	55.9	0.15	12.5	20.0	0.18	5.4	0.3	0.04	0.12	4.8	99.39
SP-14-68-106'	Siliceous tuffaceous schist from unit 1	69.7	0.15	9.4	9.8	0.13	3.7	1.8	0.05	0.12	5.7	100.55
SP-14-68-158'	Siliceous tuffaceous schist, unit 1	65.2	nil	12.1	9.8	0.11	3.0	1.8	1.4	0.82	5.5	99.73
SP-26-69-820'	Siliceous tuffaceous schist, unit 1, ("B" zone)	64.1	0.86	12.5	11.1	0.16	3.4	1.1	2.5	0.15	3.6	99.47
SP-10-68-306'	Gabbro dyke, med.-gr. unit 6b ("A" zone)	51.8	0.65	15.7	10.8	0.19	6.0	8.8	2.0	0.67	3.3	99.91
SP-11-68-415'	Feldspar porphyry unit 6a ("A" zone)	48.3	0.81	18.1	7.8	0.14	6.0	11.2	2.6	0.15	3.6	98.70
Average Whaleback Volcanics (Papezik and Fleming, 1967)		50.83	0.75	15.54	3.11 6.94	0.17	7.30	9.33	2.70	0.12	3.21	100.00
Average St. Patrick Volcanics (Papezik and Fleming, 1967)		53.13	1.13	15.07	2.94 8.92	0.17	5.27	5.60	4.15	0.06	3.55	100.00
Chemical Rock Analyses Strongly altered basalt (MacLean, 1947) Morris Cove, Little Bay Head, Green Bay		46.92	1.72	16.32	2.85 8.26	0.18	6.62	12.40	2.32	0.23	2.96	100.78

These silica results are within the range of ± 0-3%. Those above 50% are on the high side. Those below 50% may be slightly low, ie. a silica of 69.7% may be as low as 67.6%, a silica of 44.3% may be as high as 45.6%. Those in the middle range shown have an error of ± 1% or less.

*Total Fe as Fe_2O_3 where only one value is listed

- where two values are listed Fe_2O_3 is first and FeO second.

** Total of P_2O_5 + CO_2 + H_2O

Analyst: G. Andrews

of rhyolites. The fact that this unit does not chemically resemble any major igneous rock group suggests that this unit has been severely chemically altered.

Sub-unit 4a appears to be similar to the "Average Whalesback Volcanics" (Papezik and Fleming, 1967). This sub-unit is probably a low-potash tholeiitic basalt, however, its S_1O_2 content is quite low at 44.3 per cent.

Unit 2, especially sub-unit 2b, shows strong similarities to the "Average St. Patrick Volcanics" (Papezik and Fleming, 1967). The St. Patrick Volcanics are spillitic in composition. In the Stirling area sub-unit 2b shows both chloritic and carbonate alteration.

The intrusive rock sub-units 6a and 6b are compositionally similar to units 2 and 4 which supports the conclusion made by most other workers in the Springdale area (Smitheringale, 1972; Marten, 1971; Sayeed, 1970; Peters, 1967) that they are comagmatic with the volcanics and feeder dykes to the volcanic pile.

The analyses of units 4 and 6 support the conclusion by Smitheringale (1972) that the Lush's Bight Group is predominantly a low-potash tholeiite. He favoured the origin of the Group to be the "upper (dominantly volcanic) part of layer 2 of oceanic crust" in support of Bird's and Dewey's (1970) conclusion. The Stirling area, therefore, is part of this volcanic environment. The occurrence of isolated pillows and the widespread abundance of dykes indicates the Stirling area is stratigraphically above the 'sheeted dykes' in the ophiolite stratigraphy.

CHAPTER IV

STRUCTURAL GEOLOGY

General Statement

The Stirling map-area has some of the most intense metamorphic alteration and structural deformation of any of the Lush's Bight areas. The primary features of individual volcanic flows or pyroclastic units cannot be recognized in outcrop due to this alteration and deformation. For this reason, true bedding cannot be measured. The pillow structures are invariably altered and replaced by epidote and quartz and therefore tops cannot be determined by pillows, as can be done in some other areas of Lush's Bight volcanics.

As primary attitudes of the volcanic flows and pyroclastics cannot be recognized in outcrop, it is necessarv to assume for purposes of structural interpretation, that contacts between the lithological units as drawn on a few drill cross-sections (with two or more holes) are roughly parallel to the primary stratigraphic contacts. The outcrop pattern of the volcanic units trends approximately 060° and the dips on the drill cross-sections range from 55° to 75° northwest.

With the exception of unit 7, all units have one good fabric - S_1. This fabric is penetrative, with the exception of the pillow structures of sub-unit 4b and the coarse volcanic fragments of unit 3. The S_1 fabric strikes 060^o to 070^o and dips between 50^o and 85^o northwest, with most between 60^o and 75^o. By comparing the orientation of the lithological contacts with the angle between S_1 and the core axis, as shown on the drill cross-sections (Figure 2), with two or more holes, it is seen that in most instances S_1 is either slightly steeper than or nearly parallel to the lithological contacts. From this, it is assumed that the volcanic units are upright with tops facing northwest. The area north of Stirling Pond is underlain by one limb of a major F_1 fold.

Locally, kink bands, small scale crenulation folding, and strain-slip cleavage, all affecting S_1, give evidence for a second deformation - D_2.

In a few thin sections of sericite schists from unit 1, a faint pre-S_1 sericite fabric was seen to be cut by the main sericite schistosity (Plate V-B). The angle between the early fabric and S_1 was seen in some sections to be about 35^o. As this pre-S_1 fabric was not seen in the chlorite-rich units, nor in outcrop, it is possible that this fabric was only locally developed or a penetrative early fabric has been almost completely obliterated by D_1.

Two sets of faults trending 030^o and 060^o have been recognized which correspond to strong topographic linears (Figure 1).

Units 1 to 6 have been regionally metamorphosed to the greenschist facies, with epidote, chlorite, albite, carbonate, quartz and sericite the common metamorphic minerals present.

D_1 deformation

The S_1 fabric consists of a moderately well developed cleavage in units 2a, 4 and 6, and a schistosity in units 1, 2b, and the matrix of the volcanic breccia, unit 3. In some outcrops of units 1b and 3, the schistosity consists of intersecting foliations that appear as a microaugen texture with chlorite and/or sericite wrapping around apparently siliceous grains or clasts.

Microscopically, the cleavage consists of closely spaced planes with chlorite growing with a preferred orientation. The schistosity is composed of either chlorite bands or sericite-carbonate bands separated by bands of mainly quartz and/or albite.

Major F_1 folds are believed to have been formed by D_1 on a scale that is as large as or larger than the map-area. All the area lying between Stirling and Buckshee Ponds is believed to be a volcanic sequence forming part of one limb of a very large fold. South of Stirling Pond

A Dragfolded dyke with "S" shape, 'A' zone near hole SP-3-68

B Dragfolded dyke with "Z" shape, at 8700E, 8600N.

A Boudinaged epidosite bodies in outcrop.

B Kink band in outcrop at 14,100E, 9600N.

the area underlain by unit 4b may represent another limb of the major fold with a fold axis striking through Stirling and both of the Twin Ponds. Alternatively, this area of 4b may represent part of the same volcanic sequence as north of Stirling Pond but exposed by faulting.

Minor F_1 folds occur as drag-folding in dykes (Plate XII). North of Stirling Pond, several drag-folds all have the same "S" shape and are steeply plunging. The "S" shape would indicate that the closure of the related major F_1 fold is to the west-southwest of the map-area. Only one drag-fold in a dyke was seen south of Stirling Pond and it has a "Z" shape opposite to the others. This would be expected if the area south of Stirling Pond is the other limb of a major F_1 fold and the closure is indicated to be in the same direction.

Boudinage is developed in a few places and is best seen in cliff faces (Plate XIII A). Epidosite bodies have been stretched into boudins parallel to the dip of S_1 indicating stretching in a steep direction during D_1 deformation.

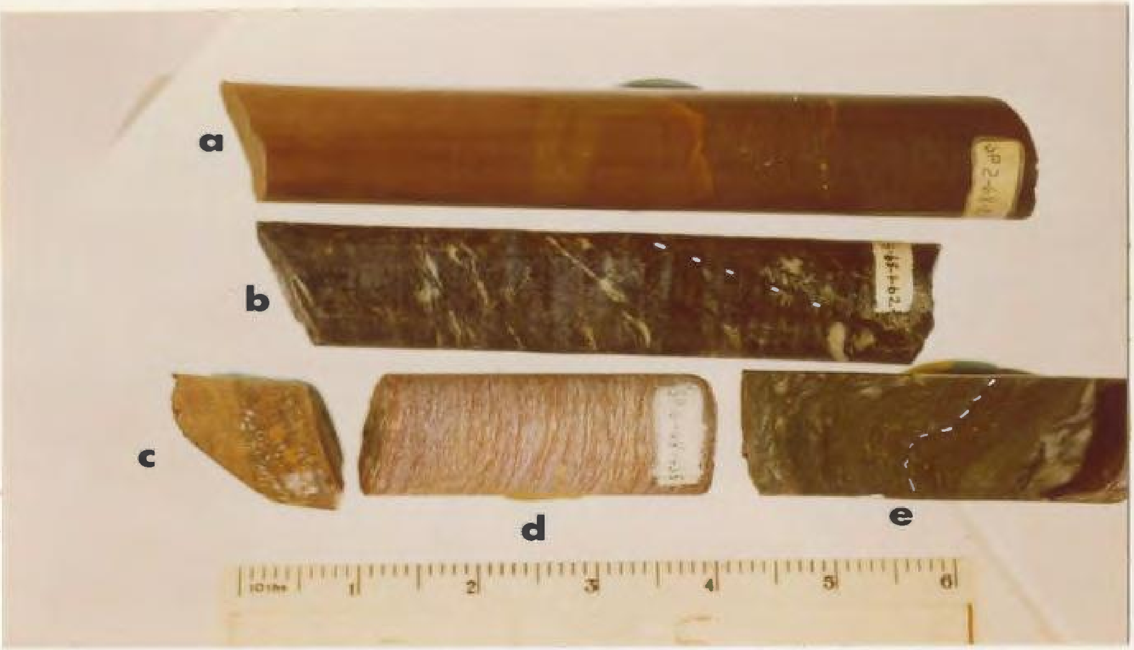
D_2 deformation

Kink bands, small-scale crenulation folding and strain-slip cleavage occur locally in only a few places. Kink bands were seen both in outcrop (Plate XIIIB) and in the drill core, while crenulation folding and strain-slip cleavage were seen only in the drill core (Plate XIV). In each case these structures have deformed S_1 and thus they are F_2 folds. Most occurrences of these structures are closely related spatially to faults or assumed fault zones.

Faults

Numerous intersections of fault breccia and gouge in the drill core are a direct indication of the abundance of faults in the map-area. Almost invariably the fault breccia or gouge intersections are accompanied by "bleached" alteration zones ranging in width from a few inches to (rarely) about 100 feet (core length - Plate XIV). Some of these "bleached" zones occur without a related fault intersection, however, from experience it is probably a safe assumption that a fault is nearby.

In the "B" zone (Figure 1) where the drill holes are closely spaced, correlation from hole to hole of many of the fault intersections is possible. The two main directions of faults are 060°, 45°NW and 030°, 55°W. Faults Fa, Fb and Fc belong to the 060° trend and Fd and Fe belong to the 030° trend. To the southeast of Fc are more faults that are possibly part of the 060° trend, but they have not been intersected in enough holes to be confirmed.



Drill core samples showing structural features.

a: 'Bleached' alteration zone related to faulting. Here both a dyke and chloritic basalt are altered

b: Strain-slip cleavage at about 30° to the core axis.

c: 'Bleached' fault breccia

d: 'Bleached' schist

e: Minor F_2 fold; S_1 sericite schistosity with highly siliceous layers in between

Note: white dots used to emphasize the structural features.

These two sets of faults underlie the two main topographical linears mentioned in Chapter 1. The apparent displacement along any given fault plane is probably small, however, collectively, the combined displacements of several parallel faults may be considerable. There is no direct evidence from either drill core or outcrop as to the relative ages or the displacement of the two trends. The writer interprets that the 030° trend is later than and offsets the earlier 060° trend. Here it is assumed that the fault zone under Stirling and Twin Ponds once continued directly on strike with the fault zone which was intersected in holes SP-43 and SP-44 underlying Sullivan Pond. Sullivan Pond, therefore, appears to be offset by the 030° trend. If this assumption is correct, the apparent offset at the surface along the 030° trend is in the order of 1500 feet of dextral movement.

Numerous other fault intersections elsewhere on the property may be part of these two main trends. Late cross-faults are probably present and fault Ff in the "B" zone is possibly one.

Discussion

The scant evidence from thin section of a pre-D_1 deformation allows comparison with the pre-regional deformation in the area south of King's Point where the 'schist zones' have two fabrics, S_1 and S_2 (DeGrace, 1971). He was able to clearly show minor F_1 folds cut by S_2, the regional foliation. The D_1 deformation of the Stirling map-area is equivalent to D_2 in DeGrace's area. The 'intersecting' foliations or microaugen texture mentioned previously are believed to be a single fabric that developed around small fragments in the pyroclastic units rather than the product of two deformations. At the present level of evidence one can only speculate about a pre-D_1 deformation in the Stirling map-area.

The D_1 deformation in the Stirling map-area is the main regional deformation common to the whole Central Mobile Belt. Williams (1969) considered this regional deformation to have been produced by the Acadian Orogeny during the Devonian period. Marten (1971) also favoured the same conclusion, stating a "post-Silurian, probably Devonian age for the strong deformation in the Lush's Bight Group". Sayeed (1970) concluded the D_1 deformation in the Colchester area resulted form the Ordovician Taconic orogeny.

The varied distribution of epidote, particularly in unit 4, replacing pillows, as veinlets, veins and irregular clots, and as cloudy grains in thin section, probably indicates an early stage of metamorphism or deuteric alteration. This was followed by the main stage of greenschist facies metamorphism of chlorite and sericite alteration. The main stage of metamorphism was coincident with the main deformation - D_1. The 'bleached' zones associated with the faults are a later stage of hydrothermal alteration.

The major F_1 folds were produced by NNW-SSE shortening with a steeply dipping stretching direction. This strain may also have produced the 060° fault trend during the late stages of folding as the lithology, S_1 fabric and the fault trend all have approximately the same strike.

CHAPTER V
ECONOMIC GEOLOGY

General statement

Copper and very minor zinc mineralization has been discovered in two separate zones designated "A" and "B". Zone "A" is located under the old shaft north of Stirling Pond. Zone "B" is located north of Lower Twin Pond (Figures 1 and 2). Both of these zones have been extensively tested by diamond-drilling to approximately 900 vertical feet below the surface.

Pyrite, chalcopyrite, with minor pyrrhotite, sphalerite and marcasite are the sulphide minerals identified in order of decreasing abundance. Chlorite, quartz and calcite are the main gangue minerals.

Mineralized zones

"A" zone

The "A" zone mineralization is typical of many copper deposits and prospects in the Lush's Bight Group. The mineralization occurs as massive or semi-massive bodies, disseminations, stringers and veins in sub-unit 2a.

Large angular fragments of massive sulphides consisting of mainly pyrite with interstitial chalcopyrite are present on the dump at the shaft. Good chalcopyrite mineralization was observed in some of the pits on strike with the shaft (Plate XV). The mineralized zone strikes 060° and dips between 60° and 70° northwest which is essentially parallel with the lithology and the main S_1 fabric. The strike length is about 400 feet. Hole SP-68-1 intersected high-grade chalcopyrite mineralization, 5.5% Cu over 14.5 feet, under the shaft. The best potentially mineable ore intersection is in hole SP-6-68, 1.7% Cu over 45 feet (core length). Section 10,000E (Figure 2) shows good vertical continuity of the mineralization to about 700 feet vertical depth. To the east, the mineralization appears to be pinching out, with only very weak mineralization intersected on section 10,000E. To the west, several scattered, weakly mineralized intersections on section 9700E suggest pinching out or, alternatively, the main mineralization has been displaced by faulting.

The ecomonic potential of this zone is limited by the combined problem of lack of continuity from hole to hole and narrow lenses up to 5 feet wide which probably have no economic potential, Further drilling on this zone is not warranted without first doing a detailed geophysical survey such as induced pollarization (I.P.).

"B" zone

In this zone mineralization occurs in several lenses within both units 1 and 2. The sulphides occur as disseminated grains and blebs and very commonly as a stockwork of narrow, massive and semi-massive sulphide stringers that are both concordant and in places oblique to the main fabric. Near the shaft at the west end of Lower Twin Pond massive pyrite and minor chalcopyrite were seen on the dump. Small, 6 inch pods of pyrite concordant with the main S_1 fabric were seen in an outcrop near the shaft.

The mineralized zone strikes 060^o to 070^o and dips 60^o to 70^o northwest which is again essentially parallel with the lithology and the main S_1 fabric. The strike length is approximately 1400 feet and the vertical depth is greater than 900 feet. Several lenses of mineralization comprise the given length and depth dimensions rather than one one continuous body. The width is highly variable throughout.

Section 13,900E (Figure 2) shows the best mineralization in the "B" zone. The intersections are as follows: SP-27-69: 1.3% Cu over 19 feet; SP-23-69: 0.57% Cu over 40 feet; SP-26-69: 0.8% Cu over 100 feet; and SP-39-69: 0.5% Cu over 97 feet. The last three intersections are probably wide enough for low cost underground mining methods, however, the grade is a little low and therefore will only be economic during periods of high copper prices.

It should be noted that the best mineralization occurs within sub-unit 1b, siliceous tuffaceous schists. This is not the typical host rock for copper mineralization in the Lush's Bight Group. The economic potential of the "B" zone is much greater than for the "A" zone. Again, further drilling on this zone is not warranted without first doing a detailed geophysical survey such as induced polarization (I.P.).

Other areas

Outside of the "A" and "B" zones, several other widely separated holes were drilled. With the exception of SP-36-69, no significant mineralization was intersected. In this hole, low-grade copper mineralization was intersected over 25 feet, which may indicate the "B" zone is open for at least 800 feet west of holes SP-15-68 and SP-16-68.

Mineralogy

Pyrite

Pyrite is the most abundant and widespread sulphide mineral in the map-area. It is abundant in units 1 and 2, and is disseminated in minor amounts in units 3,4,5,6b and 6c. Pyrite occurs as massive bodies (probably pod-like), veins, stringers, and disseminated grains and blebs (Plate XVI-c,e,g and Plate XVII-d). It is medium- to coarse-grained and granoblastic to euhedral. Commonly, the pyrite has broken and crushed corners indicating that it has behaved brittly during deformation. The pyrite is strongly fractured and matching walls are commonly seen. Highly anomalous interference colours are also seen.

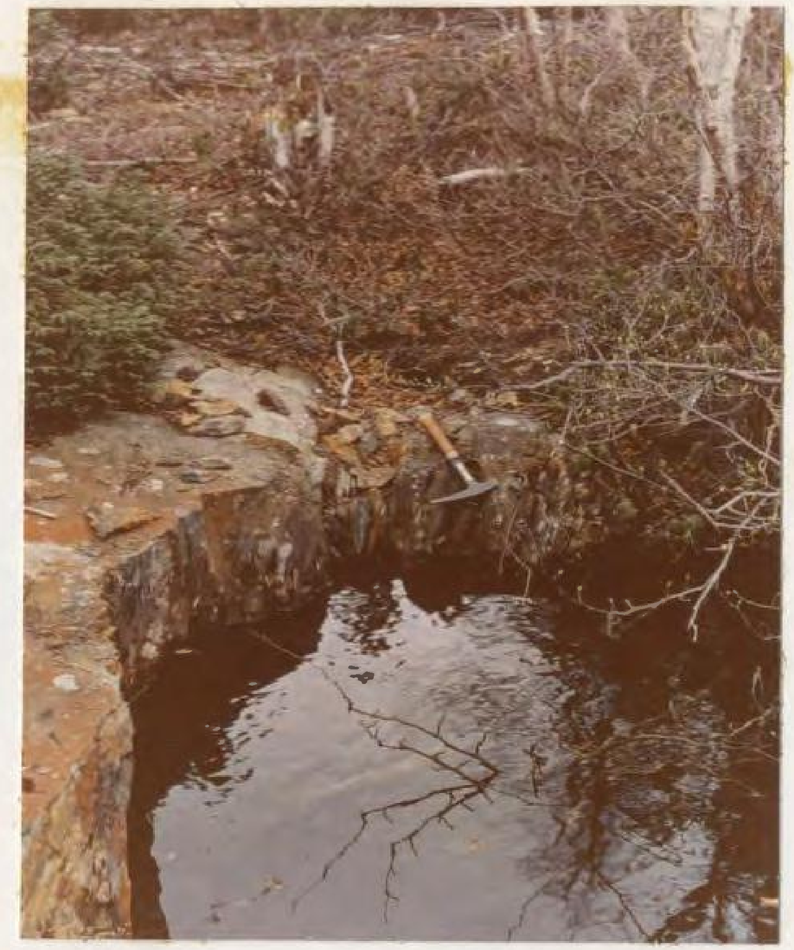
Chalcopyrite

Chalcopyrite, the second most abundant sulphide, usually occurs in close association with pyrite. This chalcopyrite-pyrite association is mainly restricted to units 1 and 2. The high-grade intersections (Plate XV-B) consist of massive or semi-massive chalcopyrite with lesser amounts of pyrite, usually as inclusions (Plate XVI-a,d,f, and Plate XVIII-B). In the low-grade intersections and the massive pyrite bodies, chalcopyrite is mainly present as fracture fillings within and around the pyrite grains. Typically, the chalcopyrite is fine grained and anhedral. Twinned chalcopyrite was observed in one polished section.

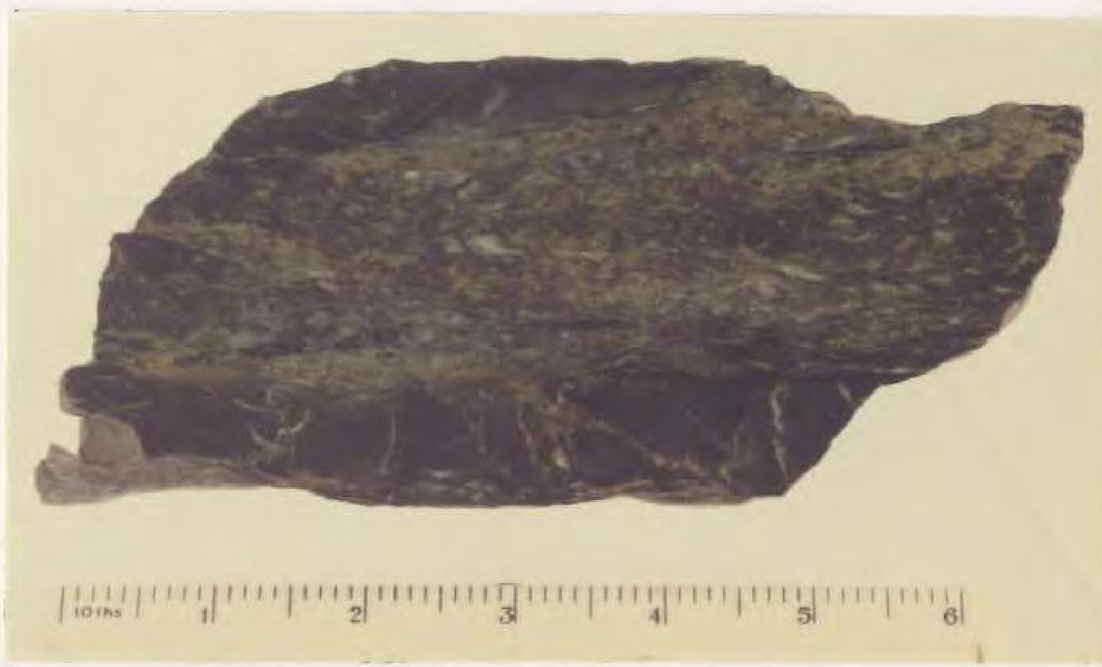
Pyrrhotite

Pyrrhotite occurs locally in minor amounts in the 'B' zone. In one outcrop of sub-unit 4a, about 500 feet north of Upper Twin Pond, pyrrhotite was seen as fine disseminated grains. It has also been recognized in the

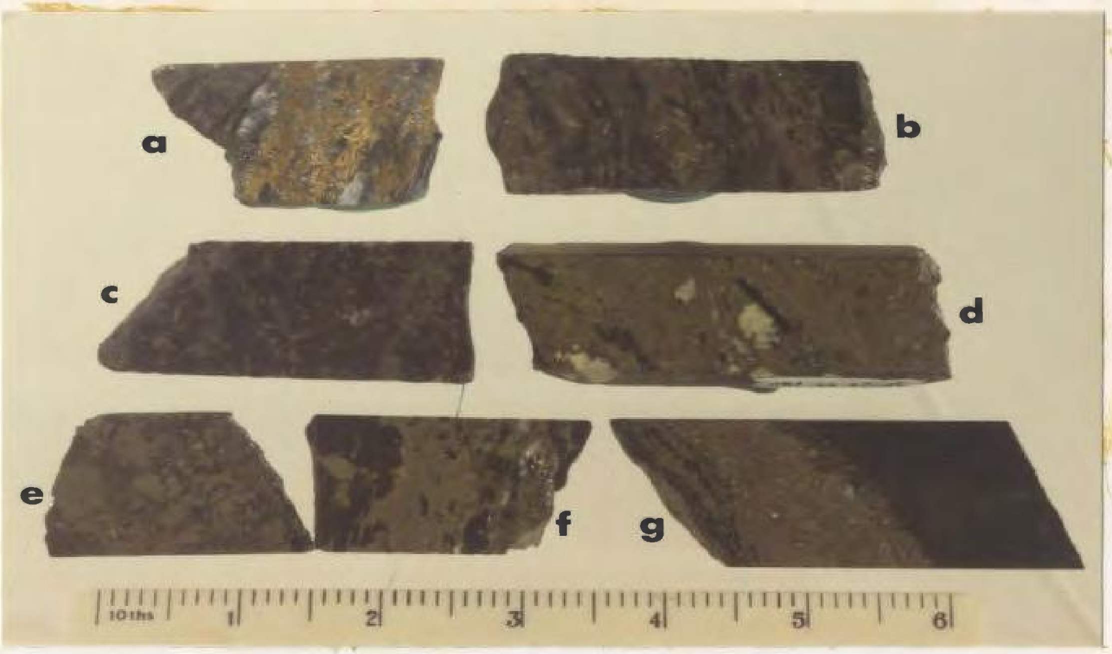
Plate XV



A Test pit on the 'A' zone, on baseline near shaft. On the left note the distinct reddish iron staining.



B Rich chalcopyrite in dark green chlorite schist from above pit at position of the hammer.



Drill core samples of sulphides:

a: narrow, massive chalcopyrite with abundant inclusions in chlorite schist.

b: semi-massive pyrite and chalcopyrite in chlorite schist.

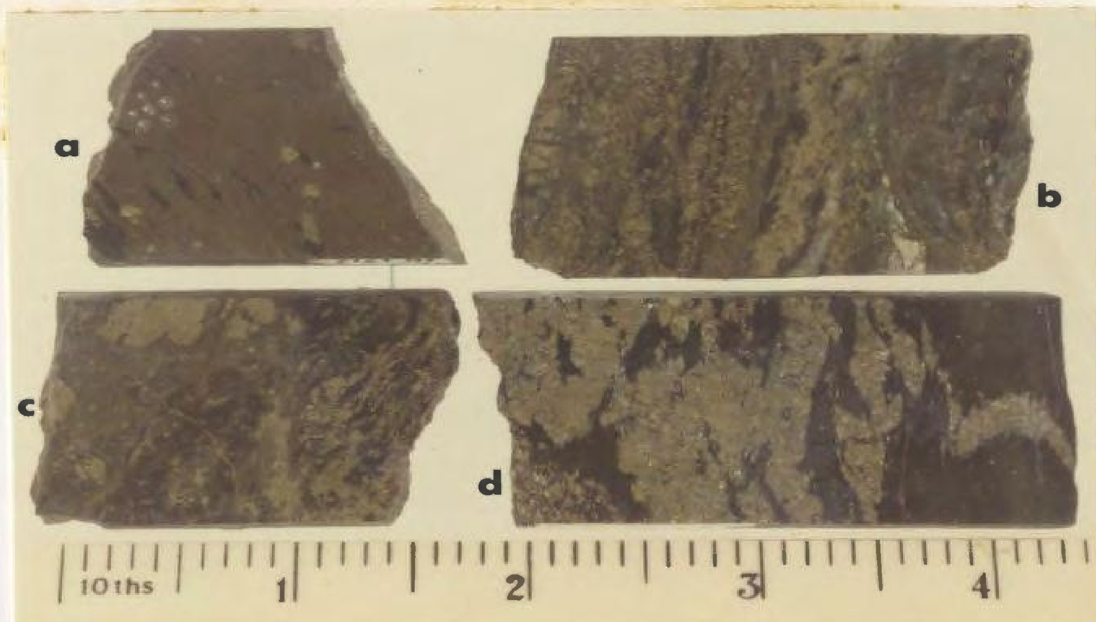
c: disseminated pyrite interstitial to jasper grains.

d: massive chalcopyrite with pyrite and inclusions of chlorite and quartz.

e: coarse pyrite grains with fine-grained interstitial patches of pyrrhotite (brown).

f: massive chalcopyrite, minor pyrite in chlorite schist.

g: pyrite stringer, massive in middle with disseminated grains at margins concordant with S_1 fabric.



Drill core samples of sulphides:

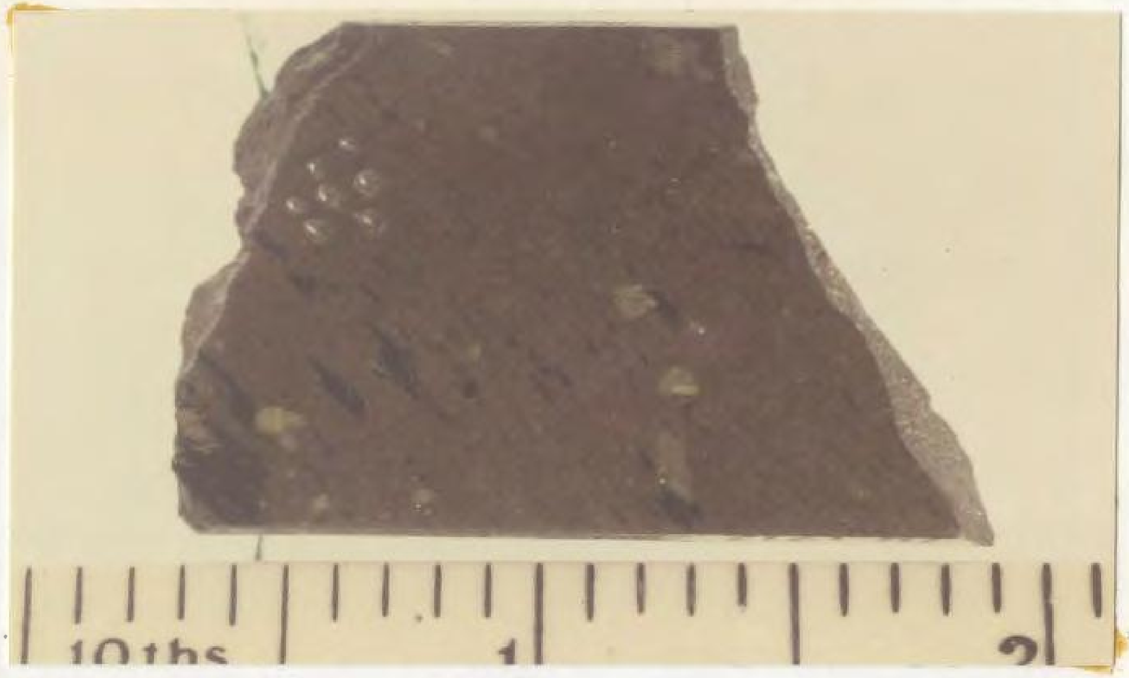
a: massive pyrrhotite with chlorite schist and pyrite inclusions.

b: banded semi-massive sulphides.

c: marcasite (dark brown) with anhedral pyrite inclusions (light)

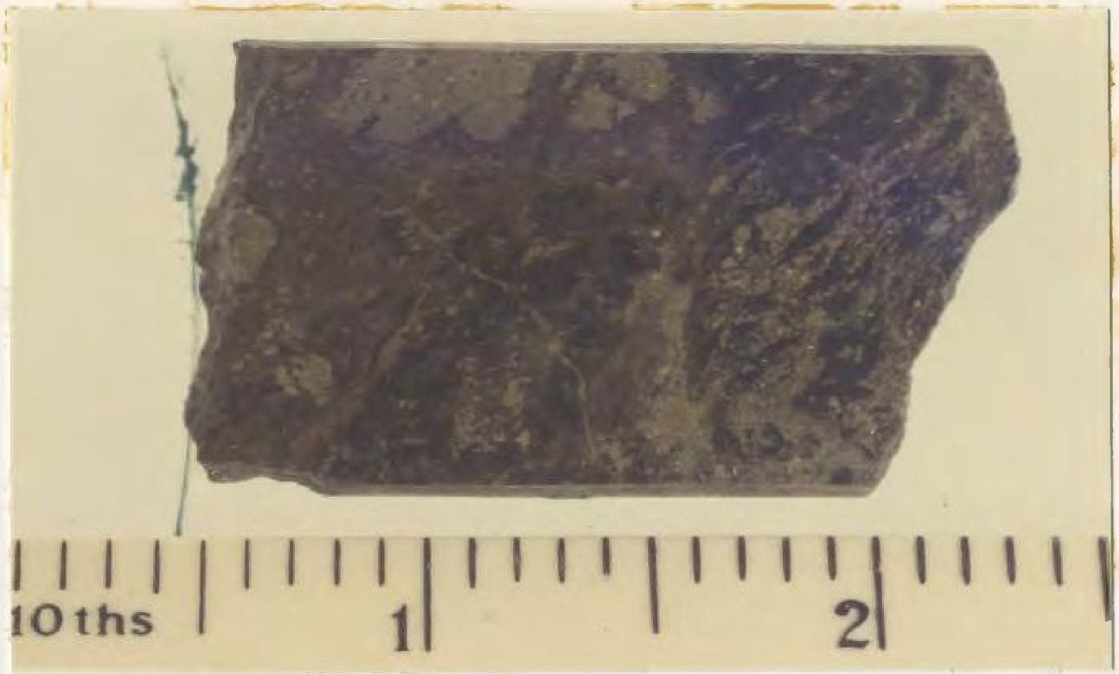
d: deformed pyrite - note at end small cross-cutting veinlet openly folded by main S_1 fabric.

Plate XVIII

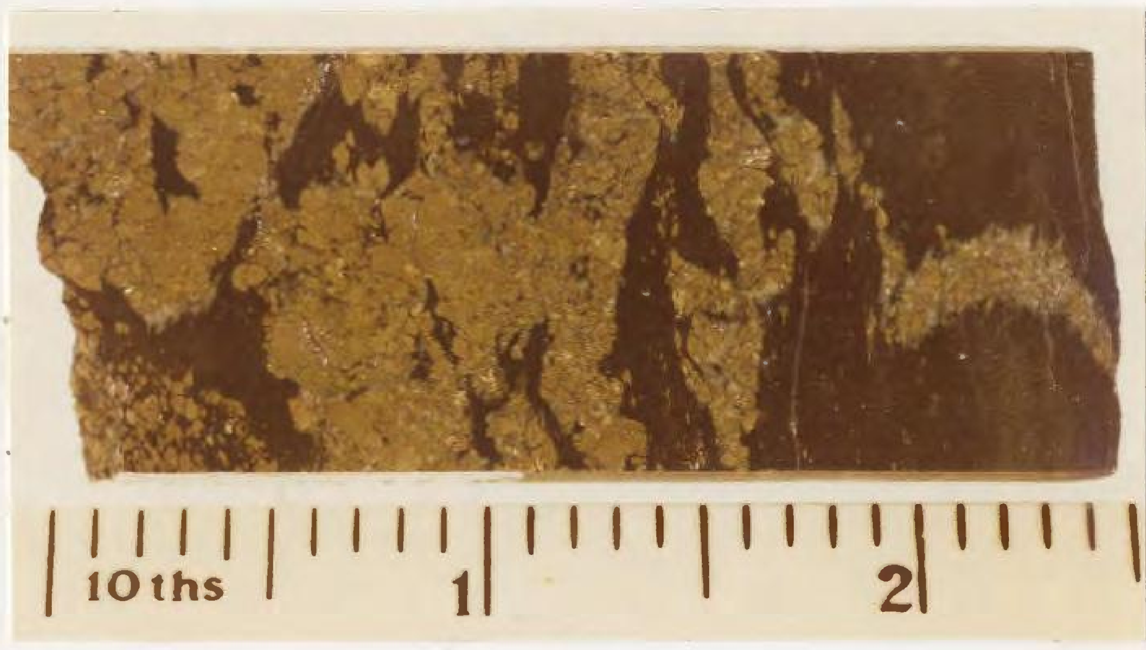


A Massive pyrrhotite, higher magnification of Plate XVII a. Note the dark chlorite schist inclusions have the main S_1 fabric.

B Banded sulphides, higher magnification of Plate XVII b. Ragged band of chalcopyrite in the middle and coarse granoblastic pyrite on the left side.



A Marcasite ? (dark brown) close-up of Plate XVII c. Also pyrite and minor chalcopyrite in chlorite schist.



B Deformed pyrite, close-up of Plate XVII d. Coarse-grained, fractured pyrite with abundant quartz in pressure shadows. Note on right, folded veinlet. In lower left corner, finer grains of crudely foliated pyrite.

following holes: SP-21-68, SP-23-69, SP-31-69, SP-37-69. In these holes it occurs as massive or semi-massive veins only a few inches thick, and as interstitial grains around coarse pyrite grains (Plate XVI-e and Plate XVII-a). Within these massive veins are a few rounded and fractured pyrite grains that are probably the unreplaced remnants of larger grains. Chlorite, quartz and carbonate inclusions are abundant and show a preferred orientation that is probably part of the S_1 fabric (Plate XVIII - A).

Sphalerite

Sphalerite is a very minor accessory sulphide mineral that appears to be restricted to the "A" zone. In one polished section (SP-1-68-180) sphalerite was seen as fine, euhedral grains within massive chalcopyrite and also bordering and filling fractures in pyrite. Texturally, the occurrence of sphalerite is much the same as chalcopyrite and pyrrhotite with respect to pyrite.

Marcasite

Marcasite was identified in one polished thin section. Its microscopic texture is banded and pyrite inclusions are abundant (Plates XVII -c and XIX-A).

Deformation of the sulphides

The main deformation D_1 has produced several small-scale structures in the sulphides indicating their remobilization. Most commonly the euhedral pyrite grains have crushed or broken corners and have many fractures indicating their brittle behaviour during deformation. Chalcopyrite and other sulphides commonly fill fractures in and around pyrite. Plate XIX-B shows a pyrite veinlet that has been openly folded by the main S_1 fabric. Plate XVIII-A shows massive pyrrhotite with chloritic inclusions all with the same preferred orientation. In places the disseminated pyrite grains show a preferred orientation that is part of the main S_1 fabric. Rarely, pods of massive pyrite about 6 inches long are bounded by an augen-like schistosity.

In the "A" zone, the sulphides closely conform to the main structural and stratigraphic trends. In the "B" zone some narrow, massive sulphide stringers in places show cross-cutting relationships to the structure and stratigraphy, however, this is to be expected in a sulphide zone that is predominantly a stockwork of stringers, veins and disseminations.

The D_2 deformation is only locally present as kink bands and small-scale folds. In the drill core, an F_2 fold is rarely seen in a sulphide intersection. Elsewhere in the Lush's Bight terrane (i.e. the Colchester property) the writer has seen sulphides concentrated or remobilized in the noses of F_2 folds.

Origin of the sulphides

The regional setting of the sulphide deposits in the Springdale area, i.e. always occurring in the Lush's Bight Group, has led most workers since Williams (1963) to genetically relate the sulphides to the Lush's Bight volcanism. In the Stirling map-area definitive primary sulphide textures, such as colloform pyrite were not seen. The banded sulphides shown in Plate XVIII-B may be of primary origin.

There is evidence for local remobilization of the sulphides as a consequence of deformation and accompany-ing recrystallization, as discussed above.

There is no evidence noted within the map-area such as 'foreign' intrusive bodies to question the volcano-genic origin for the sulphides.

Comparison with other sulphide deposits

The cupiferous sulphide deposits in the Troodos complex in Cyprus are used as type examples of ophiolite sulphide mineralization (Hutchinson and Searle, 1971 and Searle, 1972). Upadhyay and Strong (1973) cite the Betts Cove copper deposits (approximately 25 miles north of the Stirling map-area as an example of ophiolite sulphide mineralization.

Some workers such as Strong and Searle contend that these ophiolitic sulphide deposits occur at a stratigraphic level low in the volcanic pile, at or above the distinctive sheeted diabase-pillow lava contact.

Similarly the York Harbour copper-zinc deposits in Western Newfoundland are stratabound lenses accompanying underlying disseminated and stringer sulphides that occur near or at the contact between lower altered pillow lavas with upper less altered and magnetite bearing pillow lavas. Both these pillow lava units are part of the Blow Me Down layered ophiolite. The pillow lavas are underlain by gabbro and peridotite (Hutchinson and Duke 1974).

The Stirling deposit lies above the sheeted diabase, however, its exact level is not known as the sheeted diabases are not seen in the vicinity. The abundance of dykes in the area suggests that the deposits may be close (in a stratigraphic sense) to the contact.

The Stirling and many other sub-economic deposits in the Springdale area have the same simple sulphide mineralogy of pyrite and chalcopyrite with minor sphalerite and pyrrhotite. They also occur in tholeiitic volcanic rocks which are interpreted as oceanic crust (Smitheringale, 1972). Therefore, these deposits are fundamentally similar to the deposits near the contact of the sheeted diabases and pillow lavas.

The occurrence of the pyroclastic rocks of unit 3 signifies that local centres of explosive volcanic activity were present, as well as relatively quiescent fissure eruptions. Volcanogenic sulphides may have been produced in either environment. The writer prefers the interpretation that the sulphides were deposited from ore fluids in lithologically receptive host rocks such as unit 1 (tuffs) and, to a lesser extent, unit 2. The variation from disseminated to massive sulphide mineralization may be attributed, at least in part, to local variations in the permeability of the host rocks.

In their model of a Cyprus-type sulphide deposit, Hutchinson and Searle (1971) show an upper sedimentary, iron-rich zone, underlain by the massive sulphide zone, followed by a disseminated sulphide stockwork. The Stirling deposits, especially the "B" zone are comparable to the disseminated sulphide stockwork. It is not known if the other zones were ever present or, if present, have been dislodged or separated from the stockwork part of the deposit.

CHAPTER VI

CONCLUSIONS

The Stirling map-area has been mapped in detail for both bedrock and subsurface geology. From this mapping and subsequent laboratory studies the writer has drawn the following conclusions:

1. The map-area is underlain by a sequence of volcanic units of the Lower Ordovician Lush's Bight Group. In this area the Group has been divided into four distinct, mappable volcanic units: unit 1, tuffaceous schists; unit 2, chloritic metabasalts; unit 3, volcanic breccia; and unit 4, epidote basalt and isolated pillow basalt. Cutting the volcanic units are mafic, intrusive rocks (unit 6) which are considered feeder dykes and sills to the volcanic pile. Unit 5, rhyolite, and unit 7, lamprophyre, are very minor units that are seen only in isolated drill core intersections.

   The whole-rock analyses of units 4 and 6 have compositions that fit the tholeiitic suite. Therefore, the conclusions of Bird and Dewey (1970) and Smitheringale (1972) that the Lush's Bight Group is a low-potash tholeiite derived from layer 2 of ancient oceanic crust is supported by this very limited amount of petrochemical data.

Analyses of altered samples of unit 1, particularly from sub-unit 1b, indicate a highly siliceous composition, not typical of any general rock type.

2. The volcanic units and the related feeder intrusives have been deformed by the main regional deformation (D_1) that has affected the whole of the Lush's Bight Group. This deformation has produced one good penetrative fabric that is either a cleavage or a schistosity depending on the rock type. It is interpreted from cleavage and lithological contact relationships, that this steeply northwest-dipping volcanic sequence is upright and faces north. The whole map-area is probably part of one limb of a major F_1 fold.

There is rare evidence from a few thin sections of schists that an early fabric may have been locally developed by a pre-D_1 deformation. A few kink bands and crenulations of the S_1 fabric attest to a locally developed D_2 deformation. Two main sets of faults trending 030° and 060° have been recognized in the drill core and correspond to strong topographical linears.

3. Two zones of pyrite and chalcopyrite mineralization with minor pyrrhotite and sphalerite have been designated "A" and "B". The sulphides occur as massive or nearly massive lenses, pods and as a stockwork of stringers. Blebs of sulphides are disseminated throughout the zones.

In the "A" zone, the sulphides occur mainly within unit 2a; in the "B" zone the sulphides are found both in unit 1 and to a lesser extent in unit 2. Where the sulphides occur in the chloritic unit 2, they are very similar to many other copper deposits in the Lush's Bight Group such as Whalesback, Little Bay, and Colchester. The occurrence of mineralization in highly siliceous, tuffaceous schists (unit 1) is not nearly as common elsewhere.

The general outline of the mineralized zones is roughly conformable with the stratigraphy and structure, however, internally within the zones, high-grade sulphide stringers locally exhibit cross-cutting relationships.

The sulphides are likely related to volcanic activity. Primary textures have been obliterated by recrystallization and remobilization during the main D_1 deformation.

The present distribution of sulphides closely resembles the lower disseminated stock-work zone in the ophiolitic 'Cyprus type' copper deposit, and the stratigraphic setting or level of the Stirling copper deposits may be similar to the disseminated parts of the Cyprus, Betts Cove and York Harbour deposits.

4. Within the Stirling map-area, the best mineralized section is 13,900E, in the "B" zone. The "B" zone, and in particular sub-unit 1b, is the most favourable area for additional sulphides.

It is recommended that before any drilling, a geophysical survey be carried out over the known zones, and if a favourable response is obtained, then the survey should be extended to cover units 1 and 2. Induced polarization (I.P.) surveying may be the most useful type for this area due to its capability of detecting low-grade sulphide mineralization at depths down to 900 feet.

5. The detailed exploration carried out by Brinex on this property during the period 1967-1970 coincided with the operation of their

Whalesback mine. The Stirling property was an attractive exploration target during this period because of the close proximity to the Whalesback mill and the relatively high price of copper. The closing of the Whalesback mine and the drop in the price of copper, along with erratic copper values from the drilling program, undoubtably led to the decision by Brinex to drop their option on the property.

In the future, periods of relatively high copper prices and/or technological advancement may warrant a re-appraisal of the potential of this property.

BIBLIOGRAPHY

Baird, D.M. (1948): Copper Mineralization in the Betts Cove-Stocking Harbour District, Notre Dame Bay, Newfoundland; Bull. Can. Inst. Mining Met., Vol. 41, p. 211-213.

-- (1956): Base Metal Deposits of the Buchans-Notre Dame Bay Area, Newfoundland; Proc. Geol. Assoc. Canada; Vol. 8, p. 167-168.

Bird, J.M. and Dewey, J.F. (1970): Lithosphere Plate-Continental Margin Tectonics and the Evolution of the Appalachian Orogen; Geol. Soc. Amer. Bull., Vol. 81, No. 4, p. 1031-1060.

DeGrace, J.R. (1971): Structural and Stratigraphic Setting of Sulphide Deposits in Ordovician Volcanics South of King's Point, Newfoundland; Unpubl. MSc. Thesis, Memorial University of Newfoundland, 62p.

Douglas, G.V., Williams, D. Rove, O.N. (1940): Copper Deposits of Newfoundland; Nfld. Dept. of Nat. Resources, Bull. No. 20, 176p.

Espenshade, G.H. (1937): Geology and Mineral Deposits of the Pilleys Island Area; Nfld, Dept. of Nat. Resources, Bull. No: 6, 56p.

Fleming, J.M. (1971): Petrology of the Volcanic Rocks of the Whalesback Area, Springdale Peninsula, Newfoundland; Unpubl. MSc. Thesis, Memorial University of Newfoundland, 107p.

Fogwill, W.D. (1970): Mineral Deposits and Prospecting Environments of Newfoundland; Nfld. Dept. Mines, Agr., and Res., Min. Res. Div., Information Circular No. 14, 45p.

Gale, G.H. (1970): The Primary Dispersion of Cu, Zn, Ni, Co, Mn, and Na Adjacent to Sulphide Deposits, Springdale Peninsula, Newfoundland; Unpubl. MSc. Thesis, Memorial University of Newfoundland, 143p.

Heyl, G.R. (1936): Geology and Mineral Deposits of the Bay of Exploits Area, Newfoundland; Nfld. Dept. Nat. Res., Geol. Sec., Bull. 3, 66p.

Hutchinson, R.W. and Duke, N.A. (1974): Geological Relationships Between Massive Sulphide Bodies and Ophiolitic Volcanic Rocks near York Harbour, Newfoundland. Can. Jour. Earth Sci., Vol II, No. 1

Hutchinson, R.W. and Searle, D.L. (1971): Stratabound Pyrite Deposits in Cyprus and Relations to Other Sulphide Ores; Soc. Mining Geol. Japan, Spec. Issue 3, p. 198-205.

James, J.E.S. (1967): Geology of the Buckshee Brook Area, Springdale, Halls Bay, Newfoundland; Unpubl. BSc. Thesis, Memorial University of Newfoundland, 43p.

-- (1967a): Geology of the Buckshee Brook Area; Unpubl. Brinex Report.

Kanehira, K. and Bachinski, D. (1968): Mineralogy and Textural Relationships of Ores from the Whalesback Mine, Northeastern Newfoundland; Can. Jour. Earth Sci., Vol. 5, No. 6, p. 1387-1395.

Kennedy, M.J. and DeGrace, J.R. (1972): Structural Sequence and its Relationship to Sulphide Mineralization in the Ordovician Lush's Bight Group of Western Notre Dame Bay, Newfoundland; Can. Inst. Min. and Met. Bull., Vol. 65, No. 728, Dec. 1972, p. 42-50.

MacLean, H.J. (1947): Geology and Mineral Deposits of the Little Bay Area; Newfoundland Geol. Surv., Bull. No. 22, 45p.

Marten, B.E. (1971): The Geology of the Western Arm Group, Green Bay, Newfoundland; Unpubl. MSc. Thesis, Memorial University of Newfoundland, 72p.

Morris, D. (1965): Geological Report on the Sullivan Pond Area, Sheets D7 and D8; Unpubl. Brinex Report.

Murray, A. and Howley, J.P. (1881): Geol. Surv. of Nfld. from 1864-1880; London, p. 502.

-- (1918): Reports of Geol. Surv. of Nfld. from 1881 to 1909; St. John's, p. 236.

Neale, E.R.W., Nash, W.A. and Innes, G.M. (1960): King's Point, Newfoundland; Geol. Surv. Canada Map. 35-1960.

-- and Nash, W.A. (1963): Sandy Lake (East Half), Newfoundland; Geol. Surv. Can. Paper 62-68, 39p.

-- (in prep.): King's Point Map-area, Newfoundland; Geol. Surv. Can. Mem.

Papezik, V.S. and Fleming J.M. (1967): Basic Volcanic Rocks of the Whalesback Area, Newfoundland; Geol. Assoc. Can., Spec. Paper No. 4, p. 181-192.

Peters, H.R. (1967): Mineral Deposits of the Halls Bay Area, Newfoundland; Geol. Assoc. Can., Special Paper No. 4, p. 171-179.

Poole, W.H. (1967): Tectonic Evolution of the Appalachian Region of Canada; Geol. Assoc. Can., Special Paper No. 4, p. 9-51.

Sander, G.W. (1969): Report on the Combined Helicopter-Borne EM and Magnetometer Survey on Behalf of British Newfoundland Exploration Limited in the vicinity of Springdale, Newfoundland; Unpubl. Brinex Report.

Sayeed, U.A. (1970): Tectonic Setting of the Colchester Plutons, Southwest Arm Green Bay; Unpubl. MSc. Thesis, Memorial University of Newfoundland, 76p.

Searle, D.L. (1972): Mode of occurrence of the cupiferous pyrite deposits of Cyprus; Inst. Mining Metallurgy Trans., Vol. 81, p.B189-B197.

Smitheringale, W.G. (1967): Geological Map and Notes, Sullivan Pond Area; Unpubl. Brinex Report, 3 p.

-- (1972): Low-Potash Lush's Bight Tholeiites: Ancient Oceanic Crust in Newfoundland?; Can. Jour. Earth Sci., Vol. 9, No. 5, p. 574-588.

Snelgrove, A.K. (1931): Geology and Ore Deposits of the Betts Cove-Tilt Cove Area, Notre Dame Bay, Newfoundland; Can. Inst. Mining Met., Bull. 228, p.477-519.

-- and Baird, D.M. (1953): Mines and Mineral Occurrences of Newfoundland; Nfld. Dept. of Mines and Res., Information Circular No. 4, 149p.

Spry, A. (1969): Metamorphic Textures; Pergammon Press 350p.

Upadhyay, H.D. (1970): Geology of the Gullbridge Copper Deposit, Central Newfoundland; Unpubl. MSc. Thesis, Memorial University of Newfoundland, 134p.

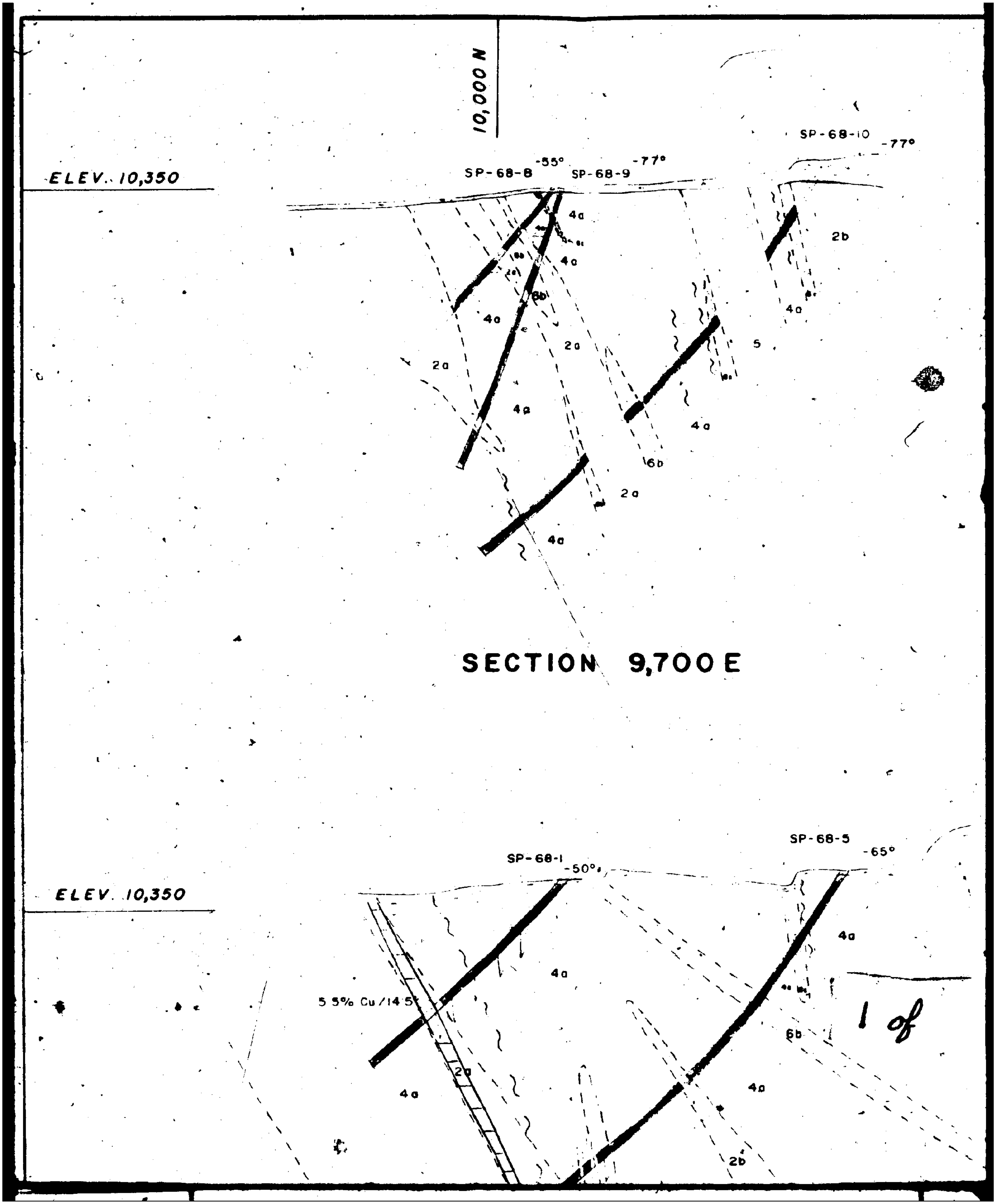
-- and Strong, D.F. (1973): Geological Setting of the Betts Cove Copper Deposits, Newfoundland; An Example of Ophiolite Sulphide Mineralization; Economic Geology, Vol. 68, p. 161-167.

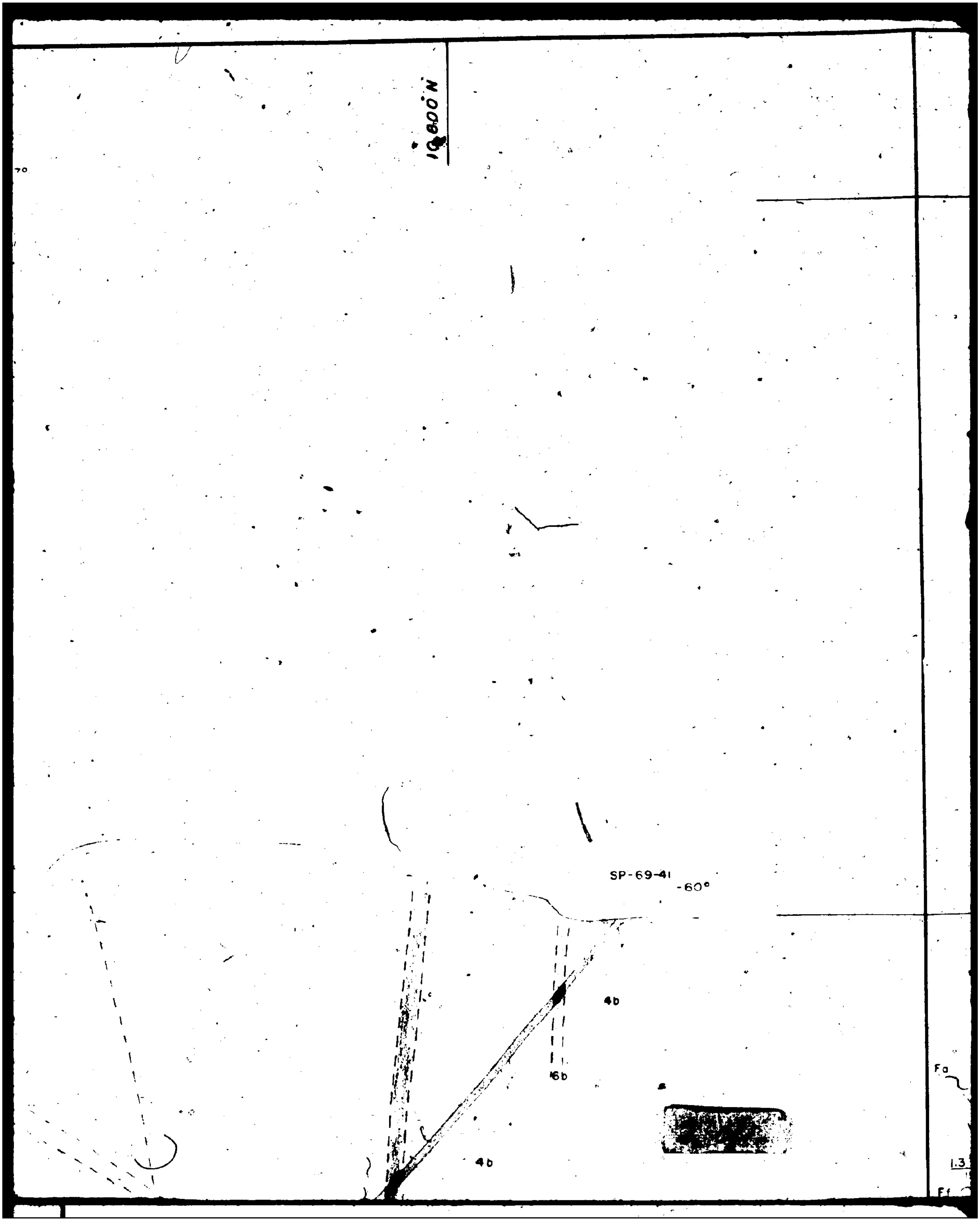
Wadsworth, M.E. (1884): Notes on the Rocks and Ore Deposits in the Vicinity of Notre Dame Bay, Newfoundland; Amer. Jour. Sci. 3rd. Ser. Vol. 28, p. 94-104.

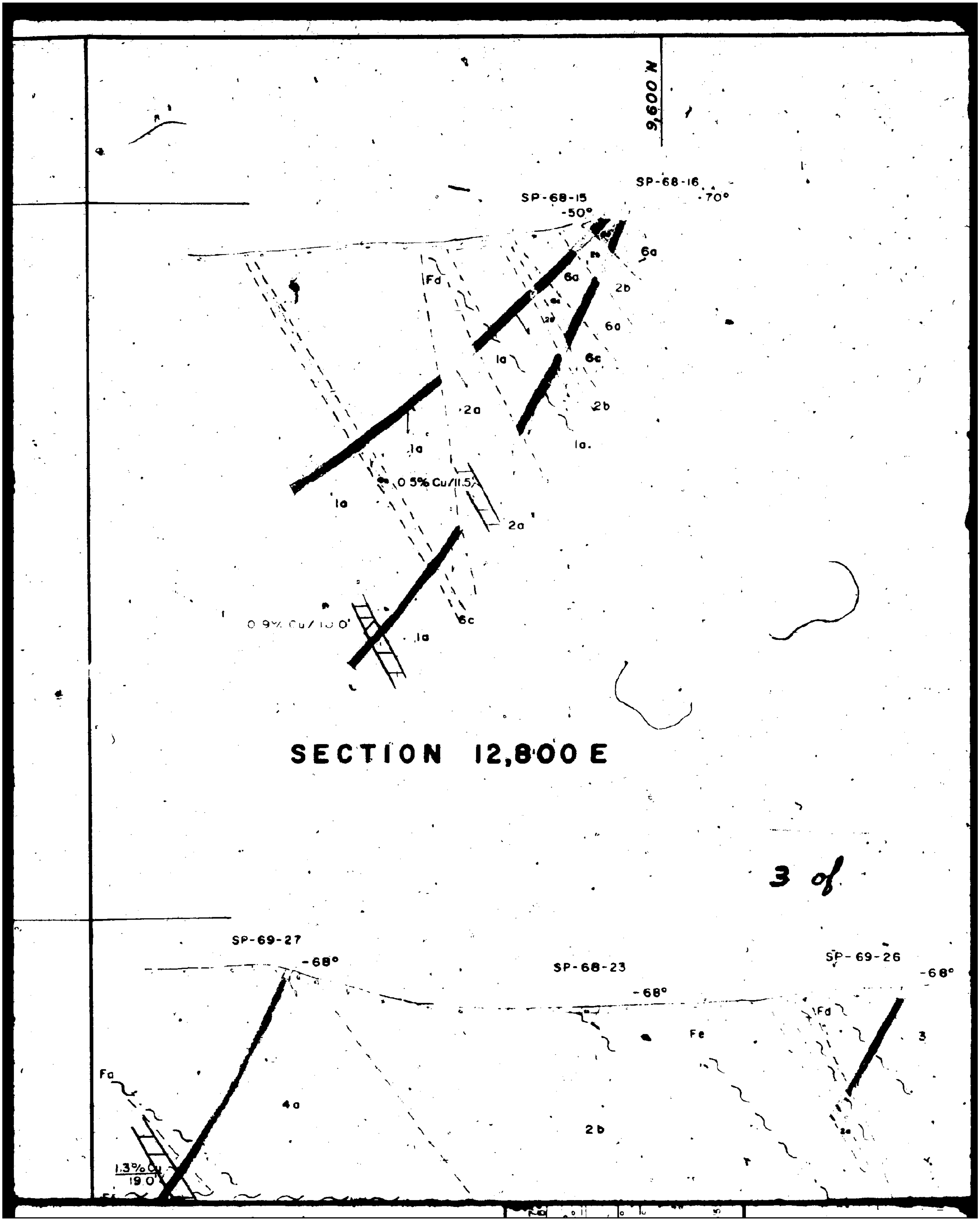
Williams, H. (1962): Botwood (West Half) Map-area, Newfoundland, Geol. Surv. Can. Paper 62-9, 16p.

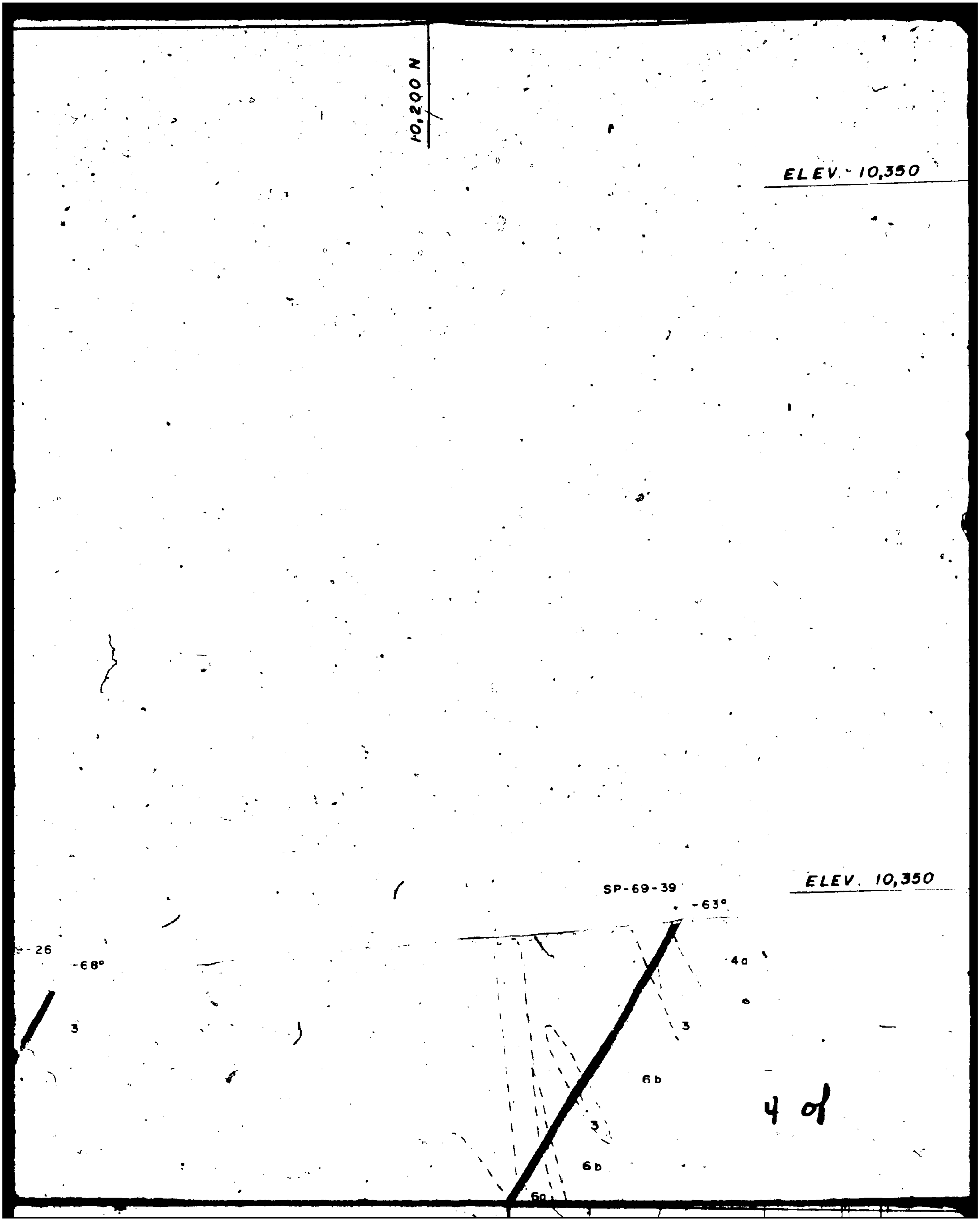
-- (1963): Relationship Between Base Metal Mineralization and Volcanic Rocks in Northeastern Newfoundland; Can. Min. Jour., Vol. 84, No. 8, p. 39-42.

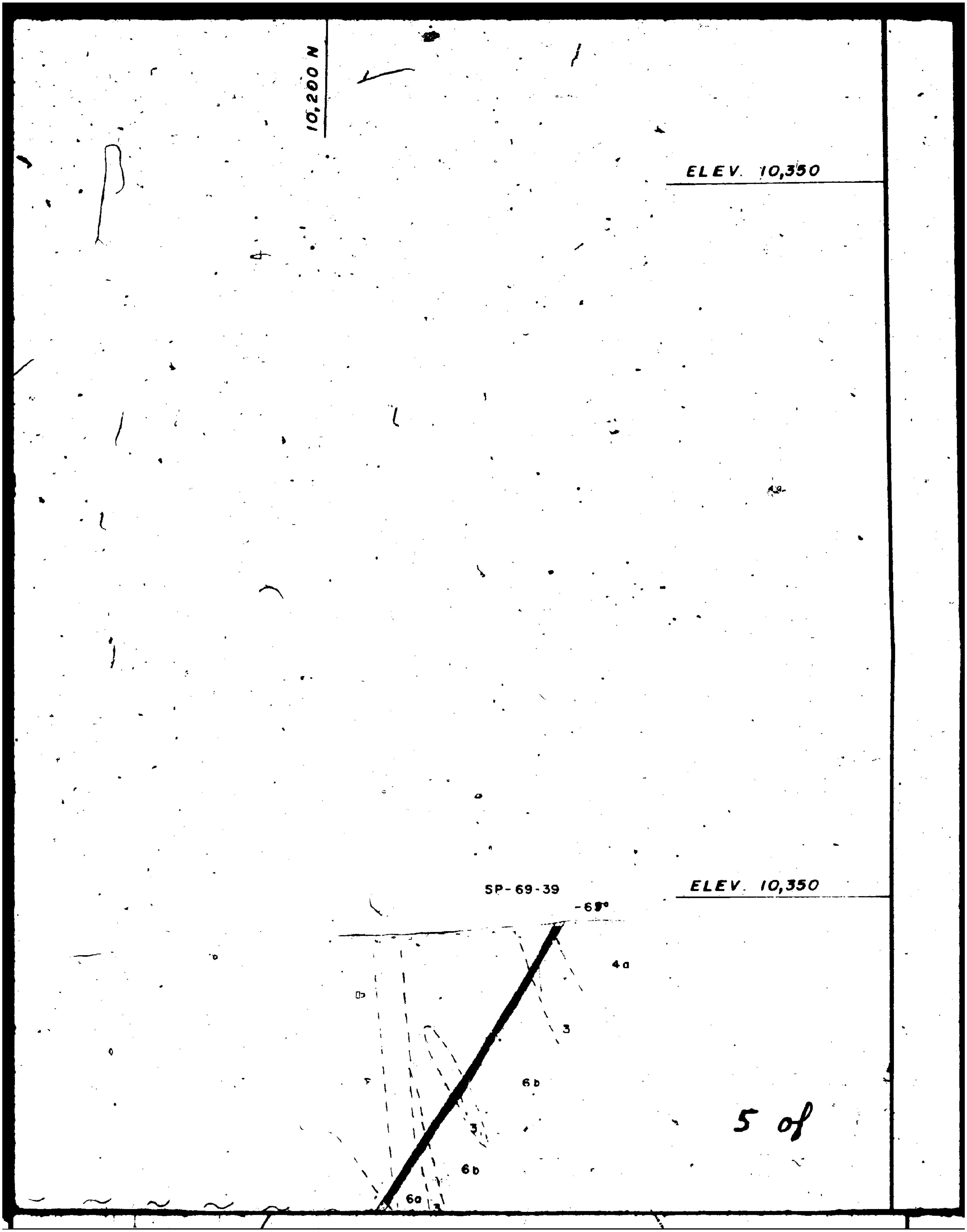
-- (1969): Pre-Carboniferous Development of Newfoundland Appalachians; North Atlantic Geology and Continental Drift, Mem. 12, Amer. Assoc. of Pet. Geol., p. 32-58.

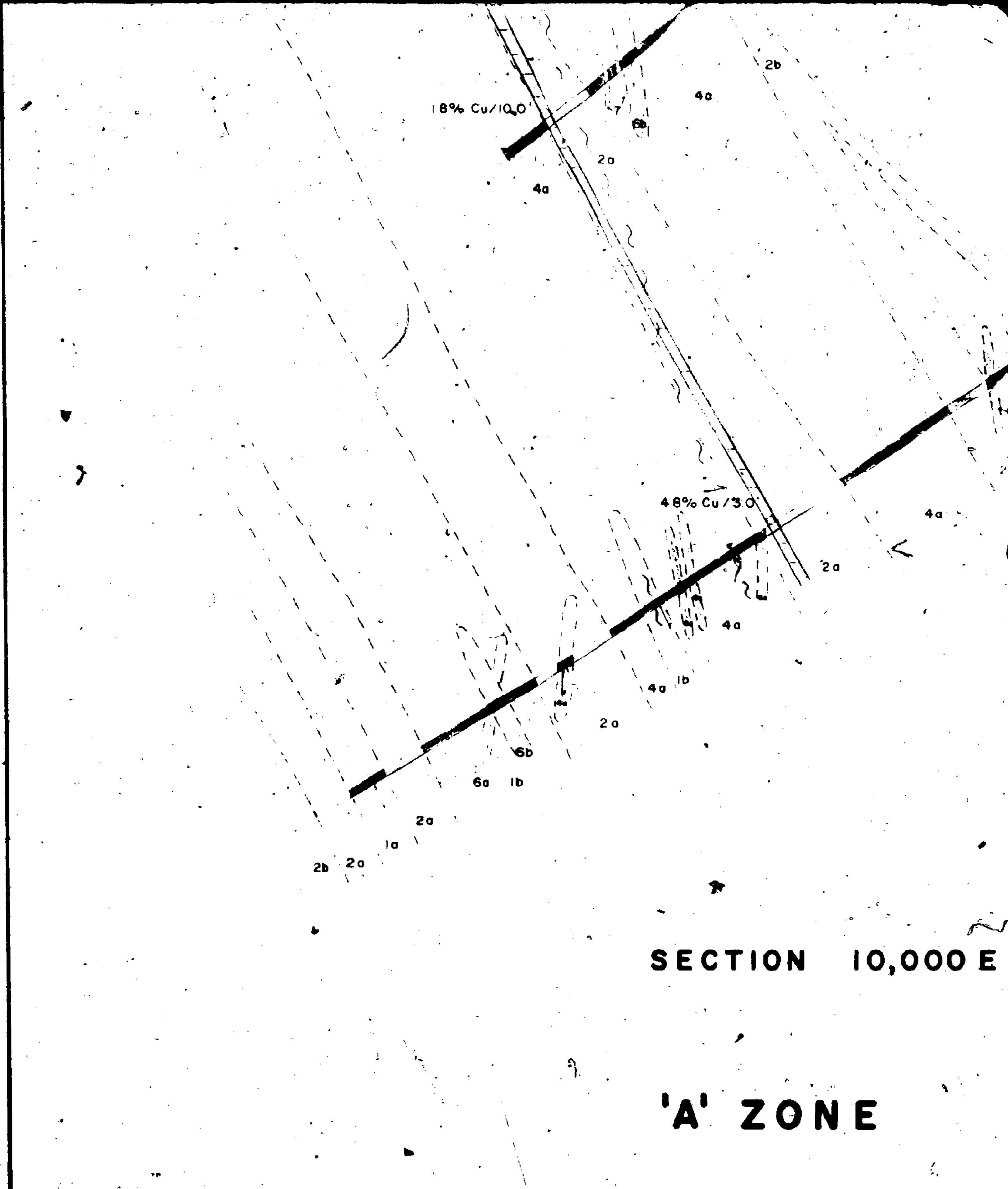

10,000 N
ELEV. 10,350
SP-68-8
-55°
SP-68-9
-77°
SP-68-10
-77°
4a
2b
2a
6b
5
SECTION 9,700 E
ELEV. 10,350
SP-68-1
-50°
SP-68-5
-65°
5.5% Cu/14.5'
2b
1 of


10,800 N
SP-69-41
-60°
4b
6b
4b
Fa
1.3
Ff


9,600 N
SP-68-16
-70°
SP-68-15
-50°
6a
6a
2b
6a
Fd
6c
2b
1a
2a
1a
1a.
0.5% Cu/11.5'
1a
2a
6c
0.9% Cu/10.0'
1a
SECTION 12,800 E
3 of
SP-69-27
-68°
SP-68-23
-68°
SP-69-26
-68°
Fd
Fe
3
Fa
4a
2b
1.3% Cu
19.0'


10,200 N
ELEV. 10,350
ELEV. 10,350
SP-69-39
-63°
-26
-68°
4a
3
3
6b
3
6b
6a
4 of

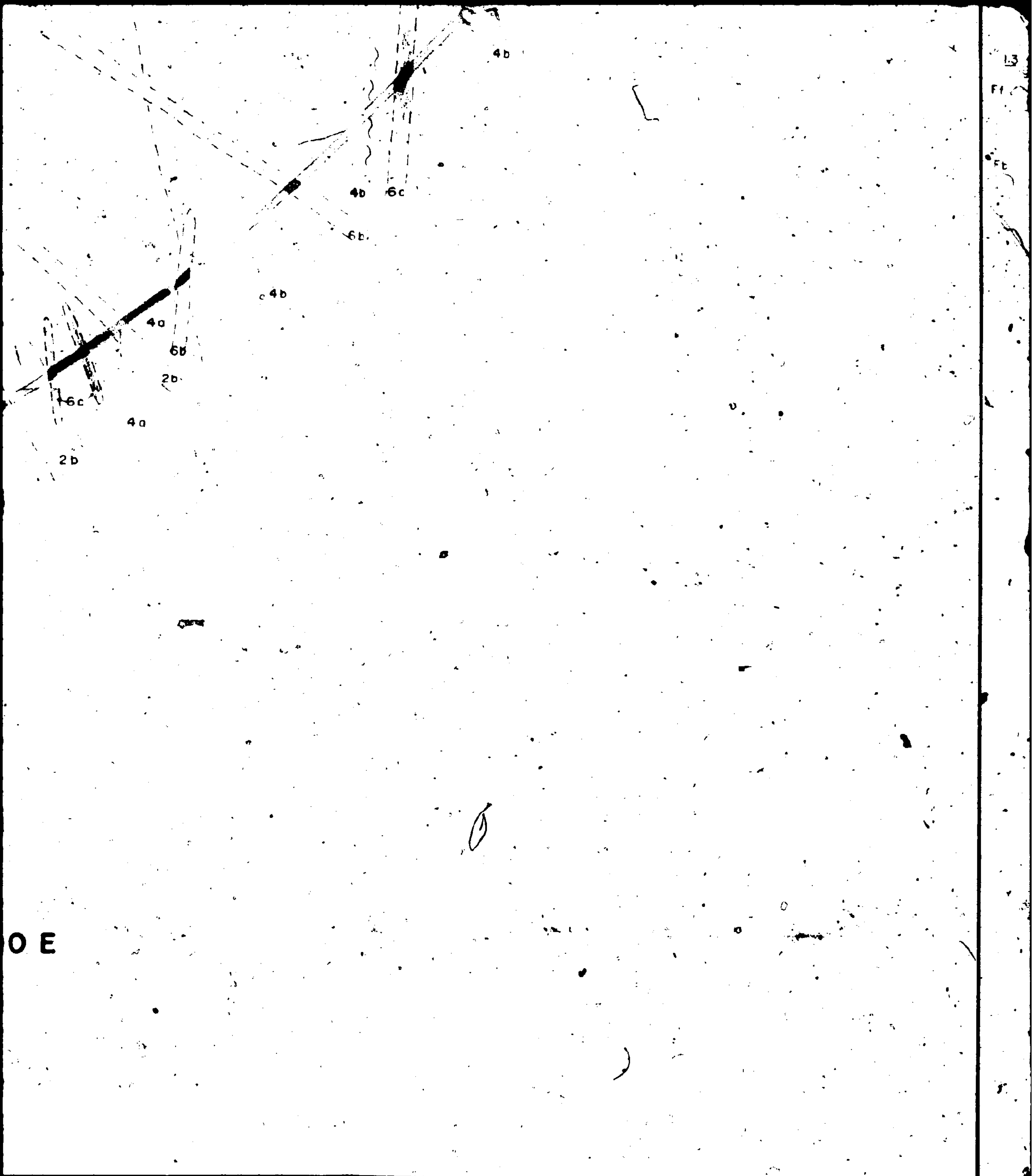

10,200 N
ELEV. 10,350
SP-69-39
ELEV. 10,350
4a
3
6b
3
6b
6a
5 of



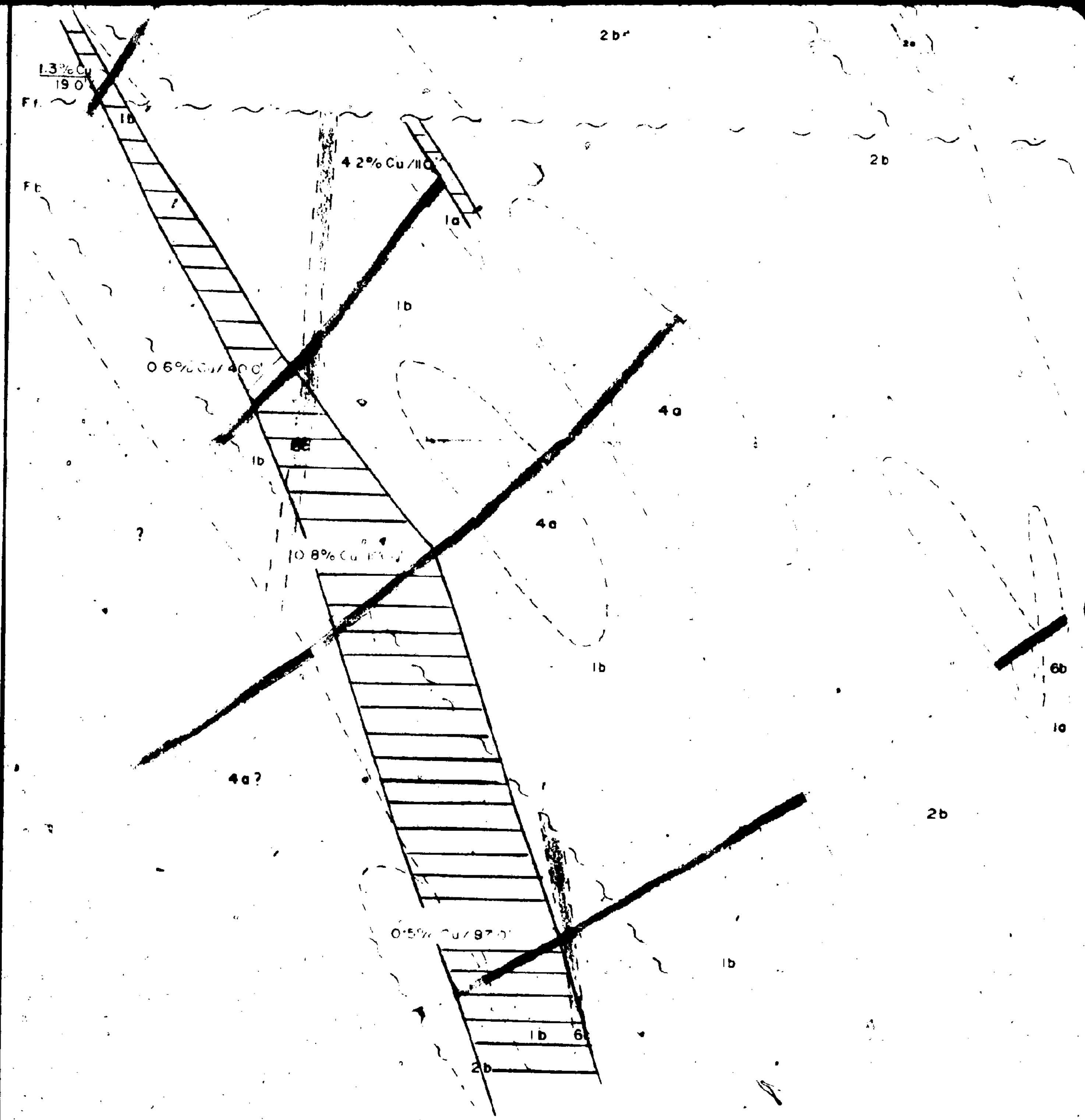
SECTION 10,000 E

'A' ZONE

6 of



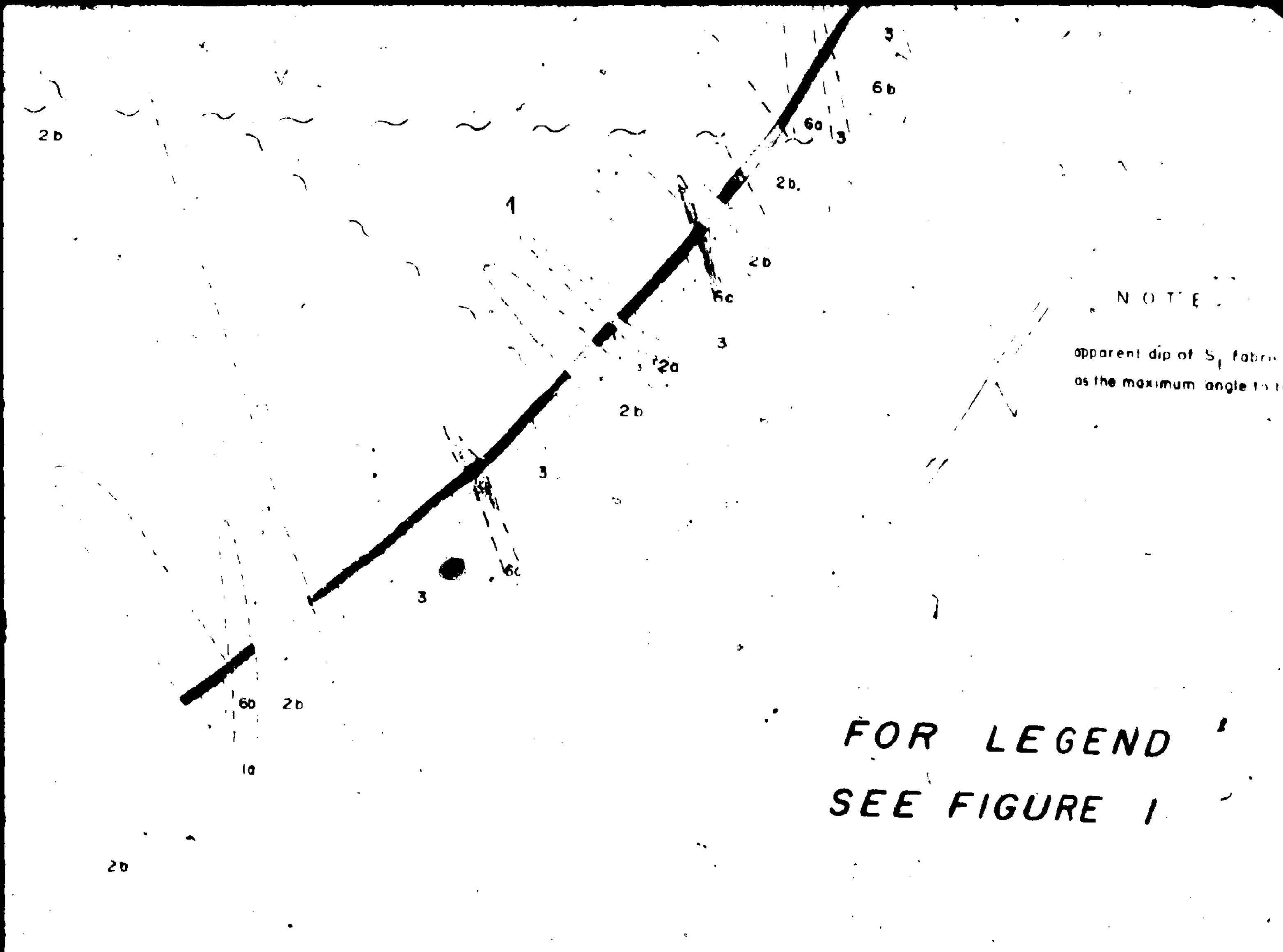
7 of



SECTION 13,900 E

'B' ZONE

8 of



FOR LEGEND
SEE FIGURE 1

BRITISH NEWFOUNDLAND EXPLORATION COMPANY L

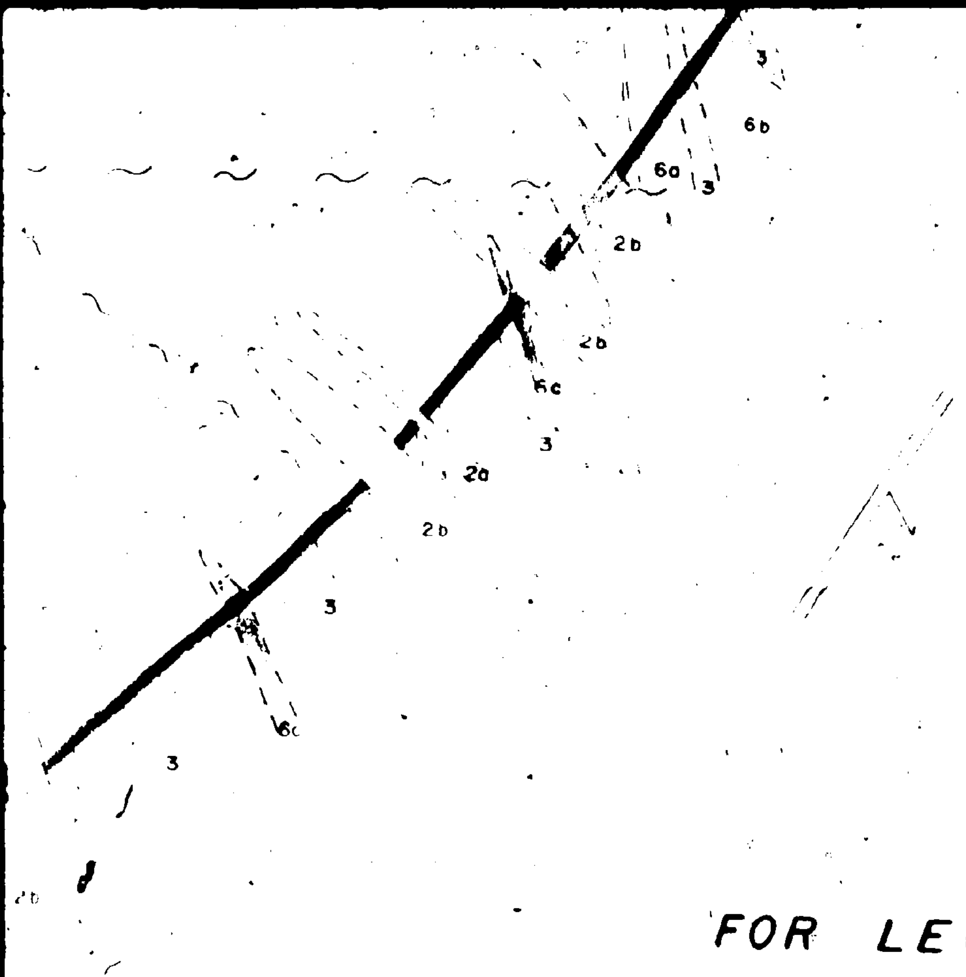
STIRLING PROPERTY

DRILL CROSS-SECTION

SPRINGDALE NOTRE DAME BAY NEWFOUNDLA

SCALE 100 50 0 100 200 300 FT. 1" = 100'	DRAWN BY
BRINEX MAP NO N.T.S. 12 ~~H/9~~ E	GEOLOGY BY
McARTHUR MSc. THESIS FIGURE 2 MARCH 1972	CHECKED BY

9 of



NOTE

apparent dip of S_1 fabric measured as the maximum angle to the core axis

FOR LEGEND SEE FIGURE 1

BRITISH NEWFOUNDLAND EXPLORATION COMPANY LTD.

STIRLING PROPERTY

DRILL CROSS-SECTIONS

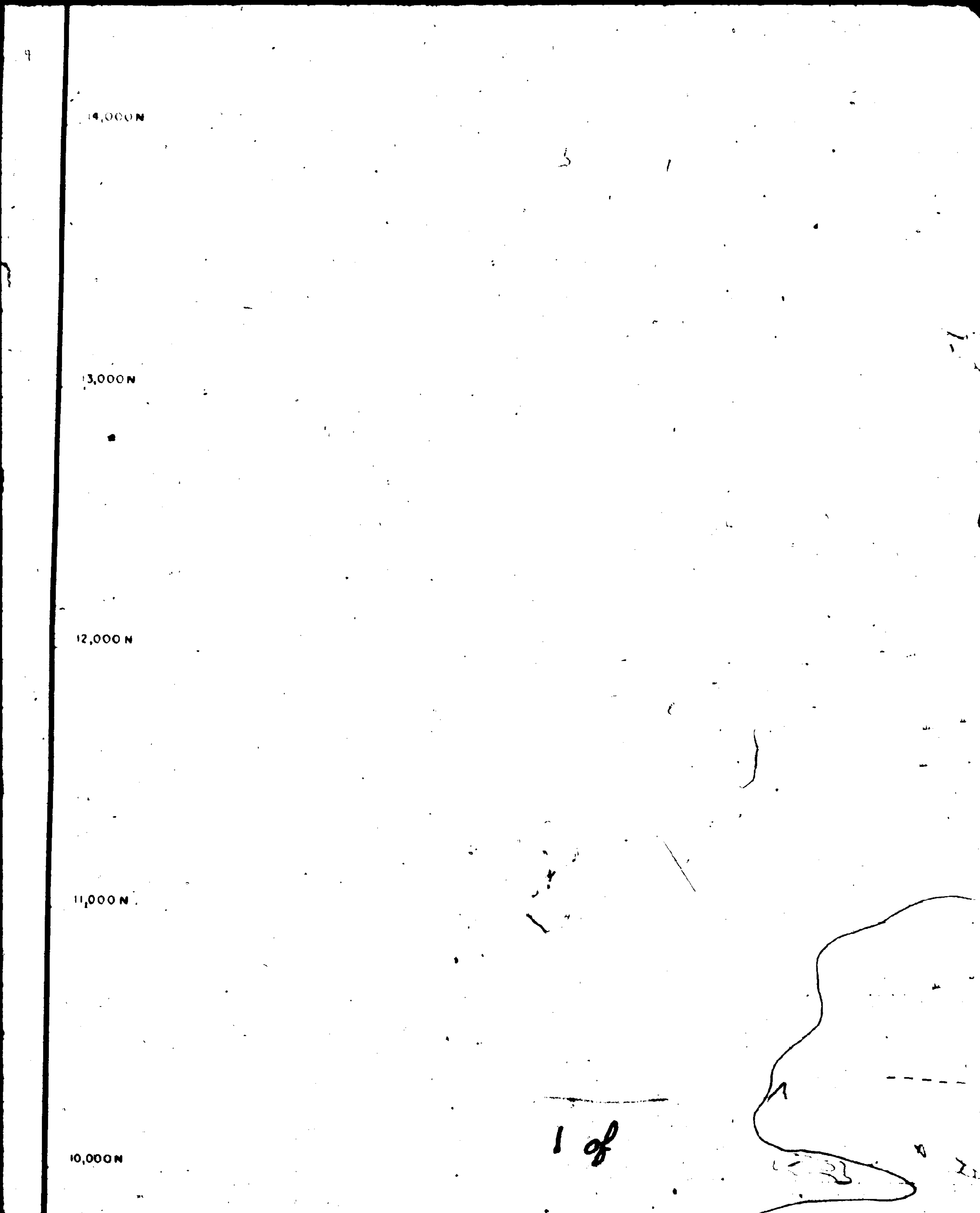
SPRINGDALE NOTRE DAME BAY NEWFOUNDLAND

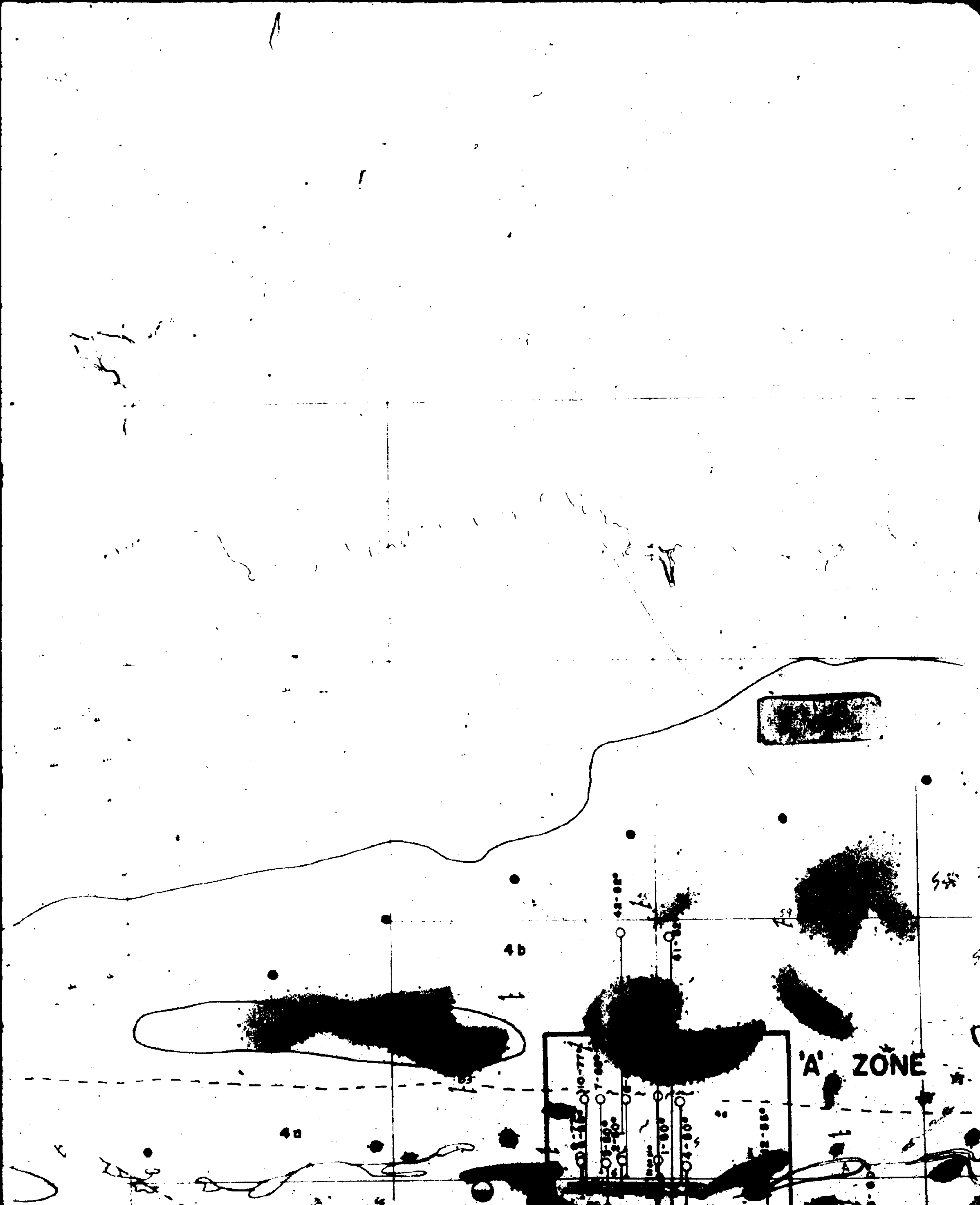
SCALE

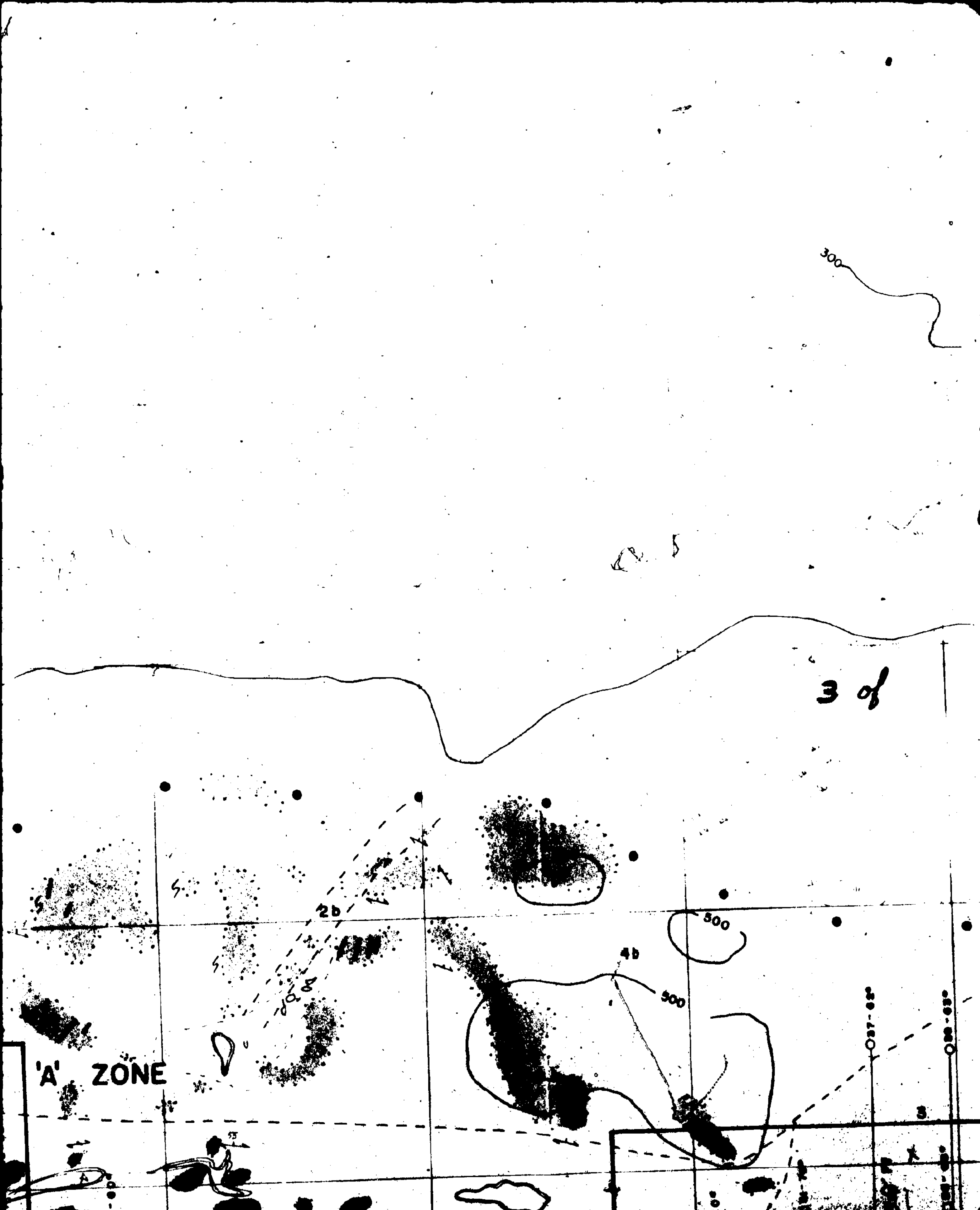
100 50 0 100 200 300 FT.

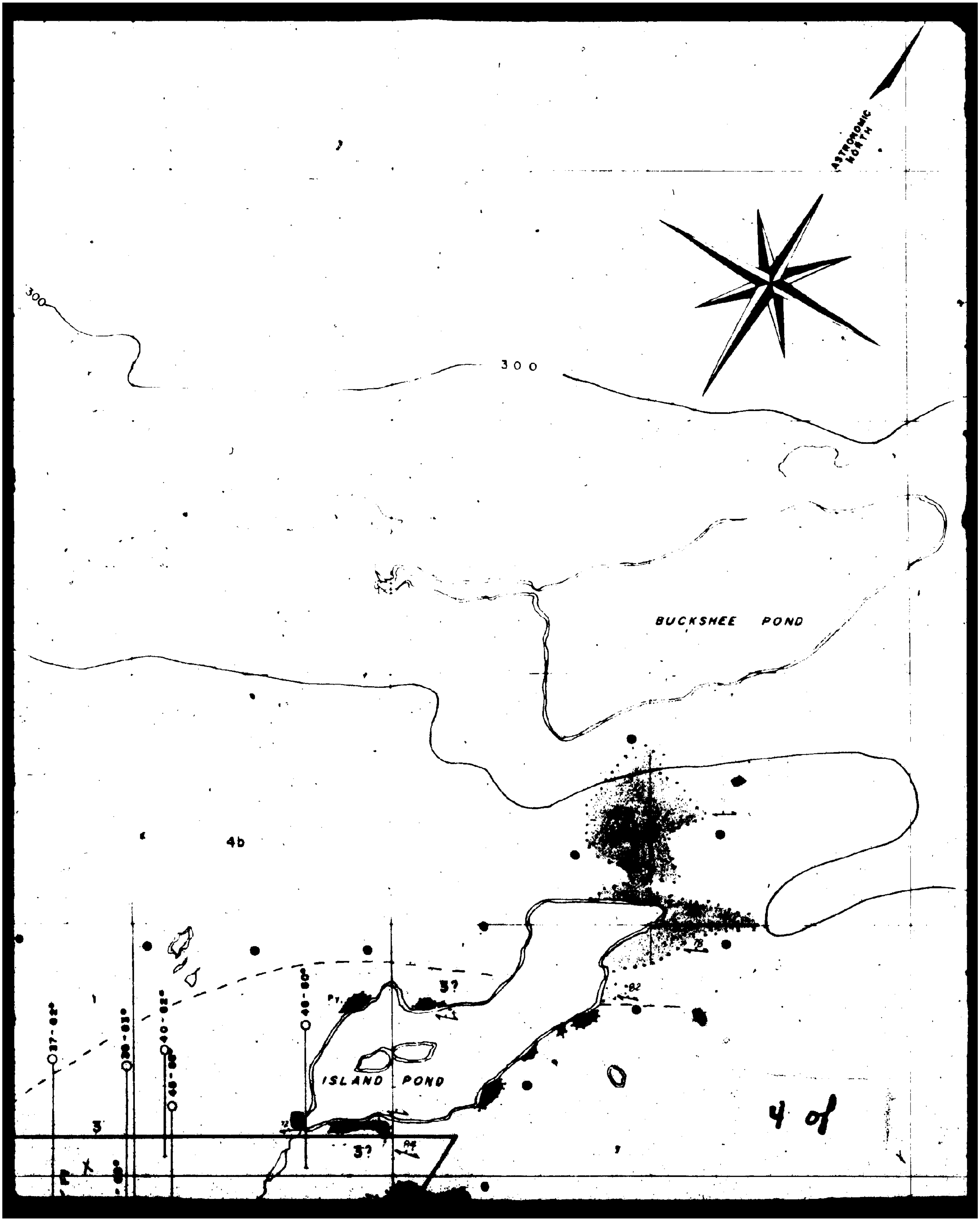
1" = 100'

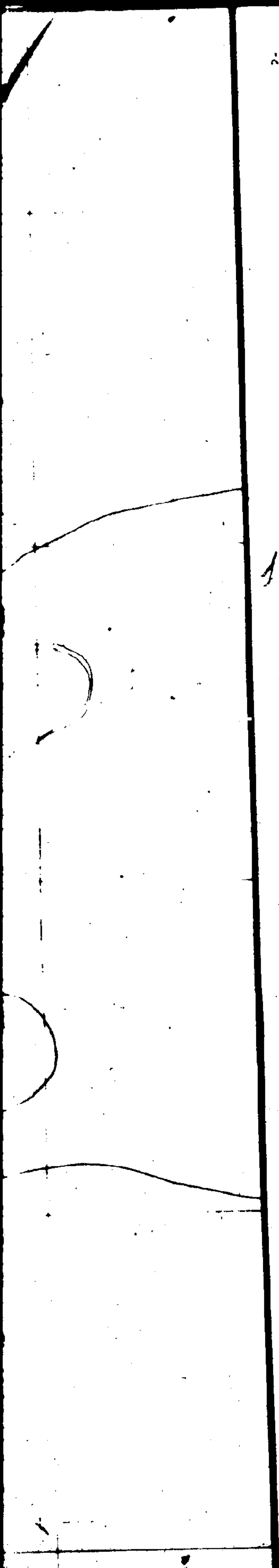
BRINEX MAP NO N.T.S. 12 H/9 E	DRAWN BY: H.B. & J.G.M.
McARTHUR MSc. THESIS FIGURE 2 MARCH 1972	GEOLOGY BY J.G.M.
	CHECKED BY:


14,000 N
13,000 N
12,000 N
11,000 N
10,000 N
1 of


4b
4a
'A' ZONE


300
3 of
2b
500
4b
500
'A' ZONE


ASTRONOMIC NORTH
300
300
BUCKSHEE POND
4b
ISLAND POND
3?
3?
3
1
4 of



LEGEND

JURASSIC OR EARLY CRETACEOUS (?)

[illegible]

ORDOVICIAN AND YOUNGER

MAFIC INTRUSIVE ROCKS

6a 6b 6c [illegible]

5 [illegible]

EARLY ORDOVICIAN

LUSHS BIGHT GROUP

4b [illegible]

4a [illegible]

3 [illegible]

2a 2b [illegible]

1 [illegible] schists; 1b Siliceous [illegible] schists

MINERALIZED ZONE [illegible]

SYMBOLS

Outcrop

Geological contact

Limit of geological mapping

First fabric, cleavage and schistosity S_1

[illegible]

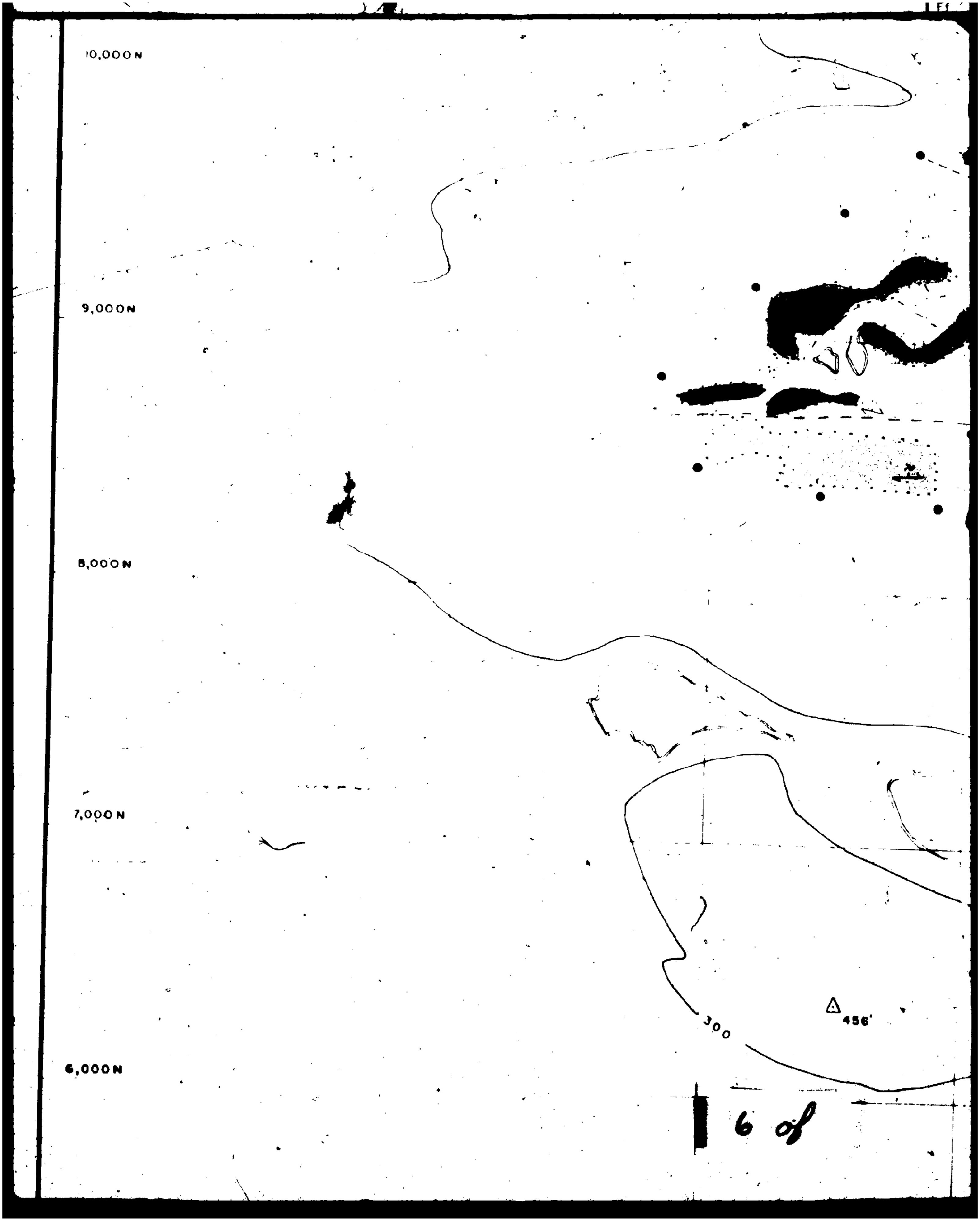
Drag-fold

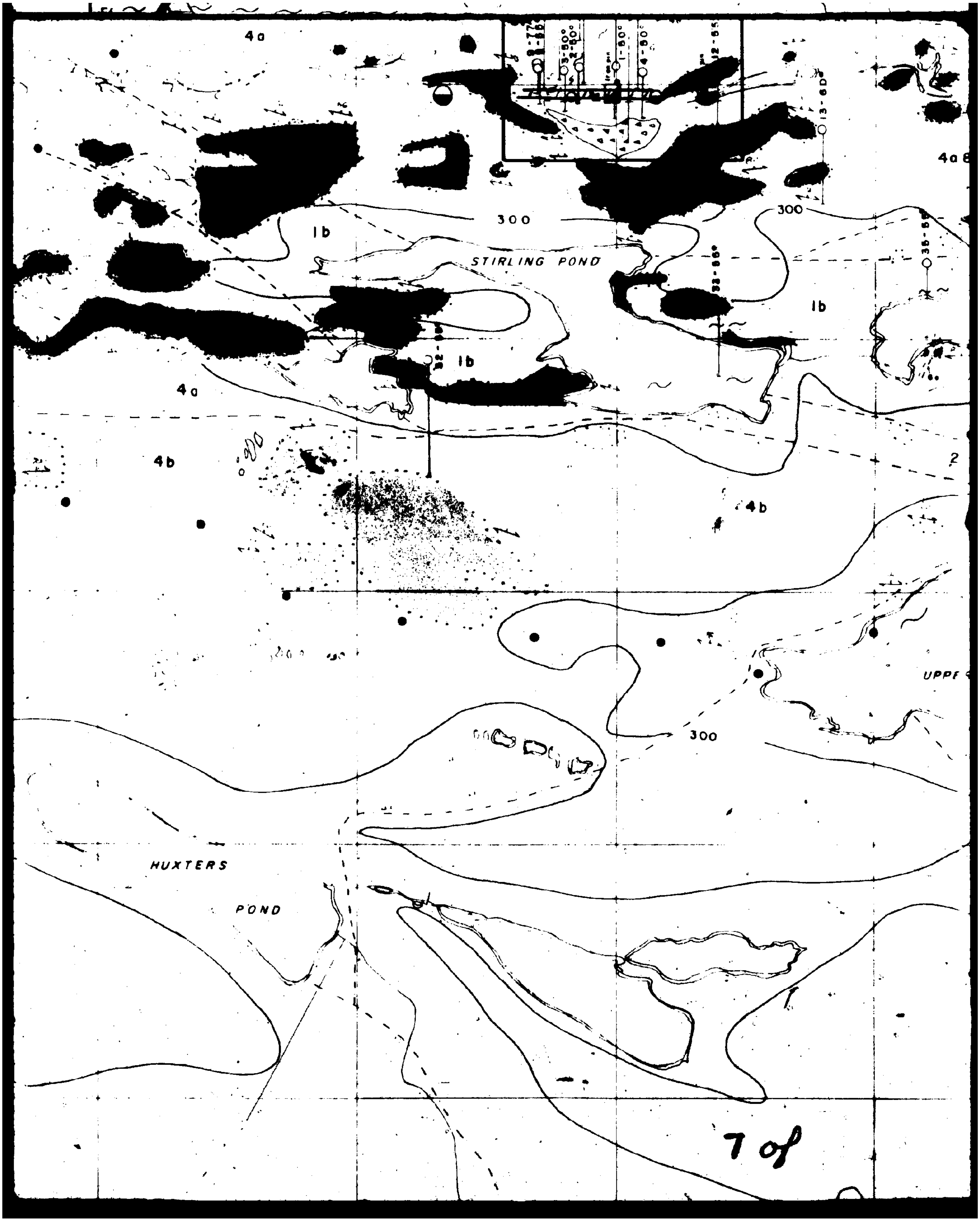
Fault

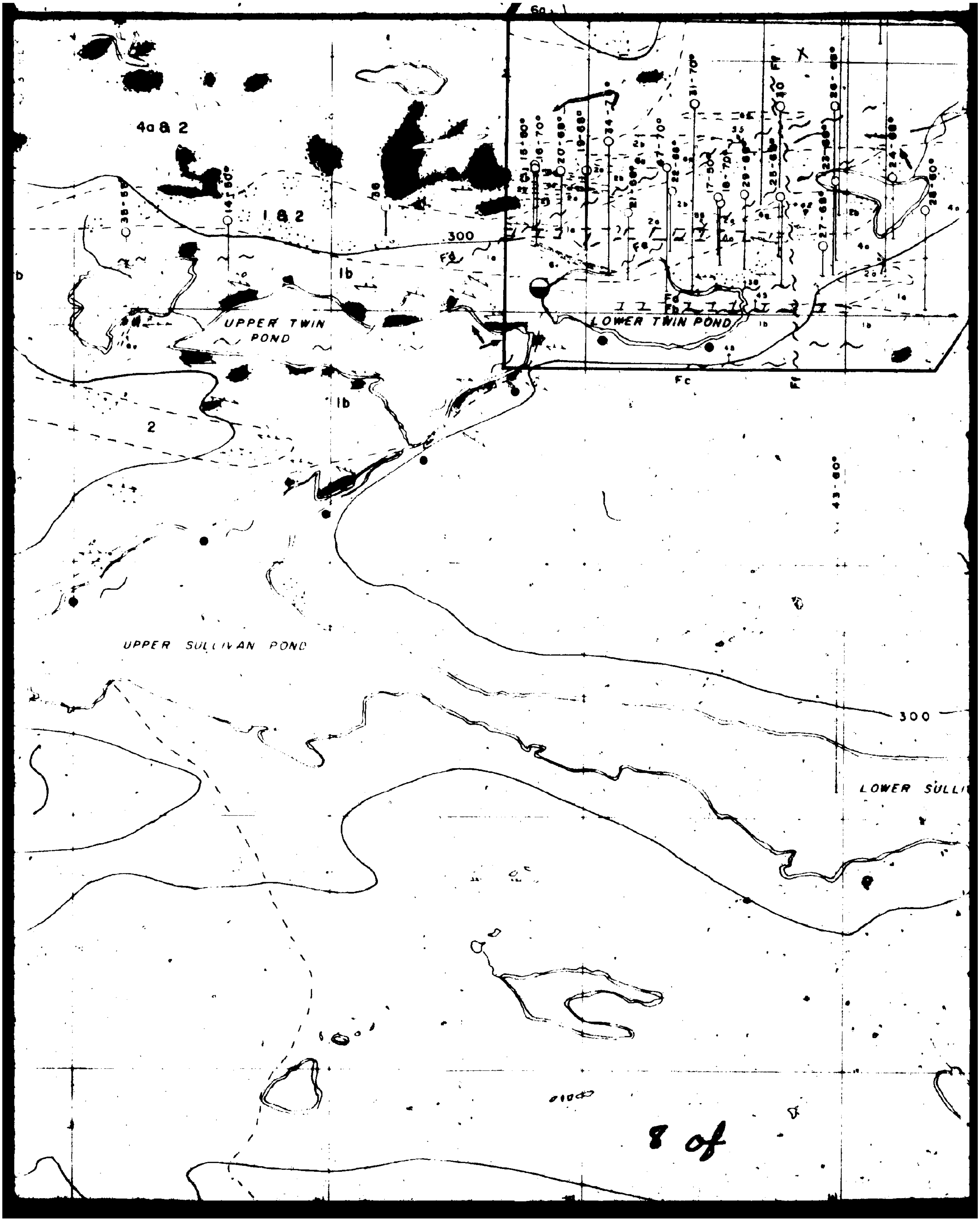
Dyke

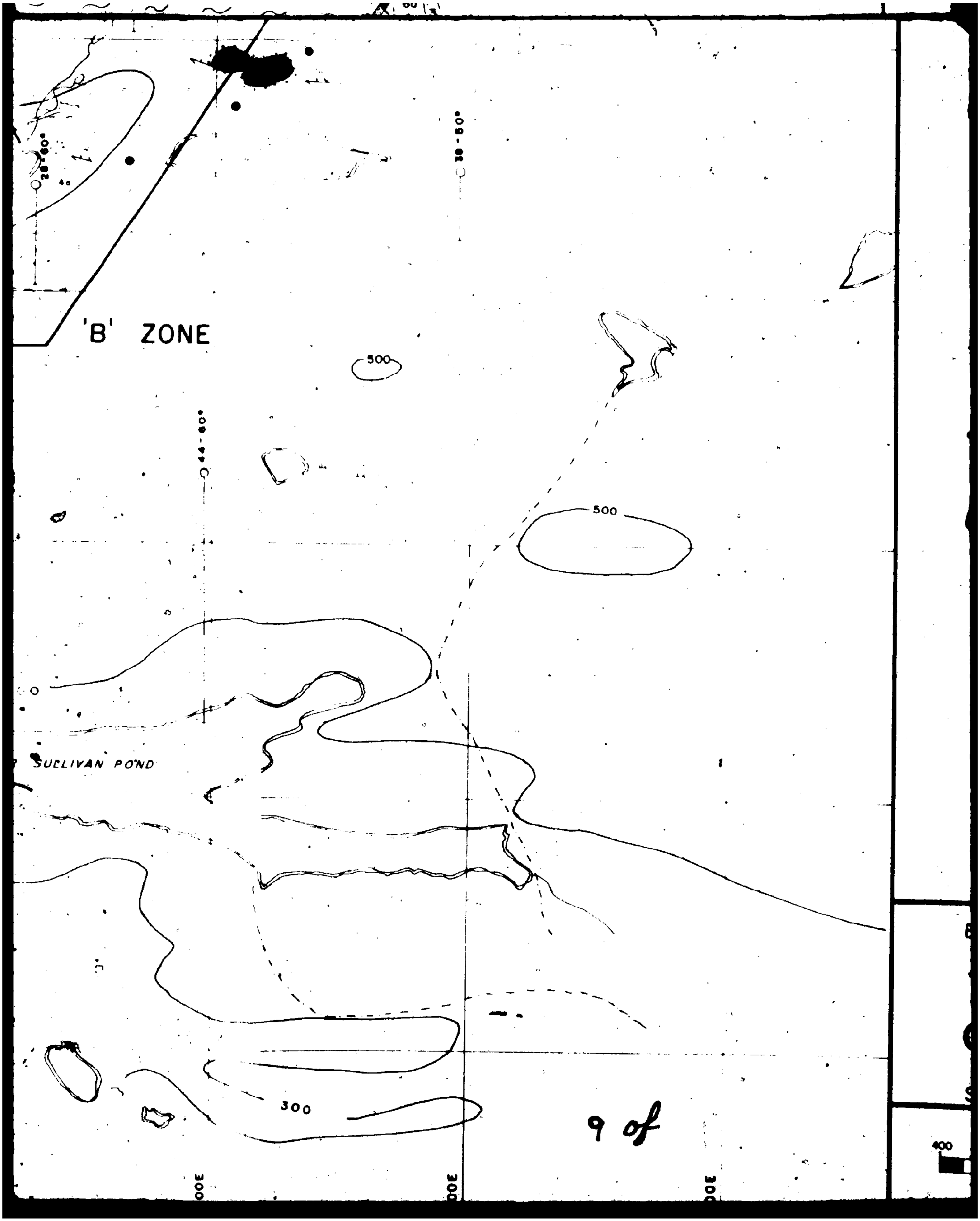
Mine dump

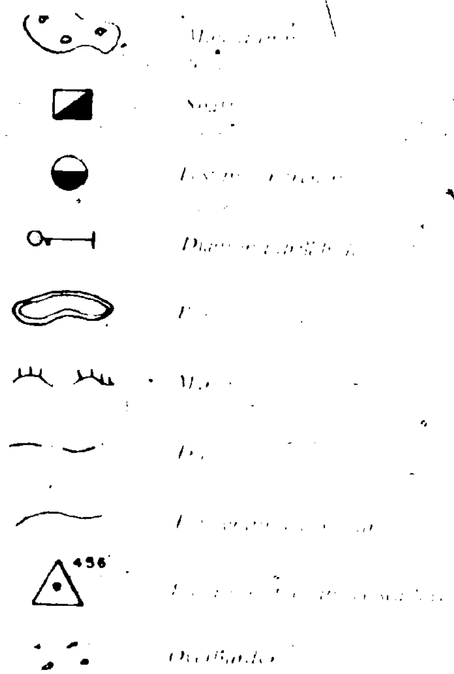
5 of

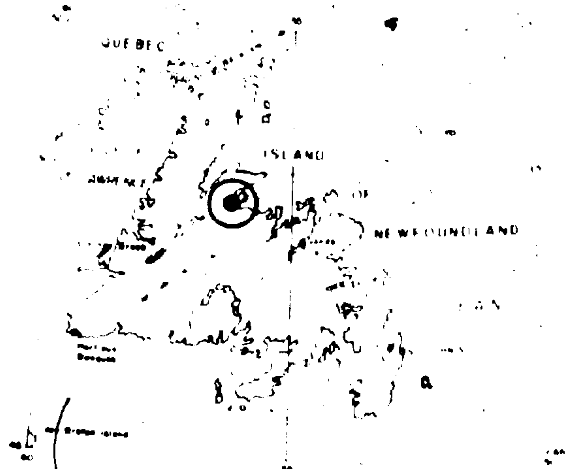

10,000 N
9,000 N
8,000 N
7,000 N
6,000 N
300
456'
6 of


4a
300
1b
STIRLING POND
1b
1b
4a
4b
4b
2
UPPE
300
HUXTERS
POND
7 of


4a & 2
1 & 2
300
1b
UPPER TWIN
POND
LOWER TWIN POND
2
UPPER SULLIVAN POND
300
LOWER SULLI
8 of


'B' ZONE
500
38-50°
28-60°
44-60°
500
SULLIVAN POND
300
9 of
00E
00E
00E
400





INDEX MAP

BRITISH NEWFOUNDLAND EXPLORATION COMPANY LTD.

STIRLING PROPERTY

10 of

GEOLOGY – DRILL PLAN

SPRINGDALE NOTRE DAME BAY NEWFOUNDLAND

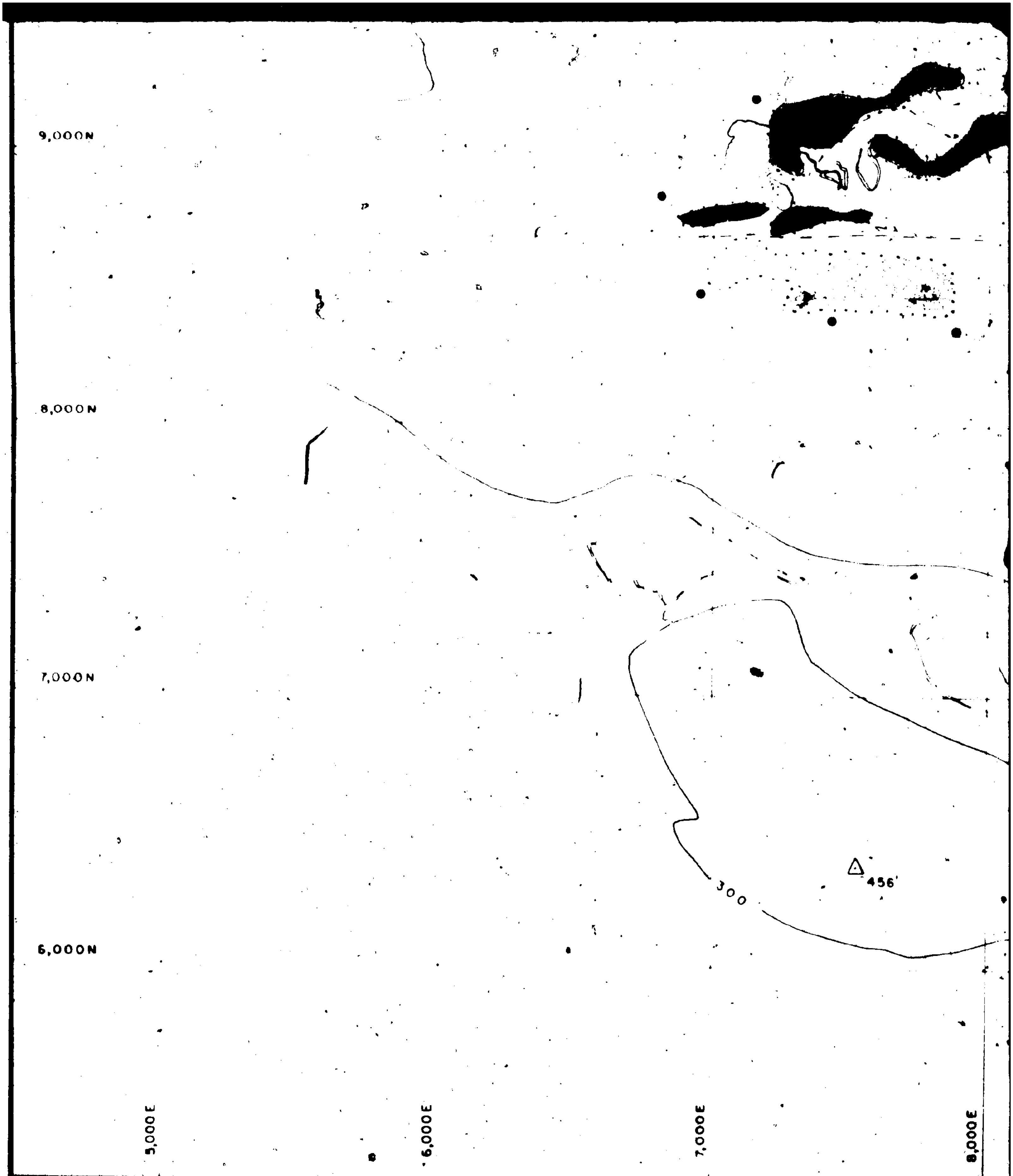
SCALE

400 200 0 400 800 1200 FT.

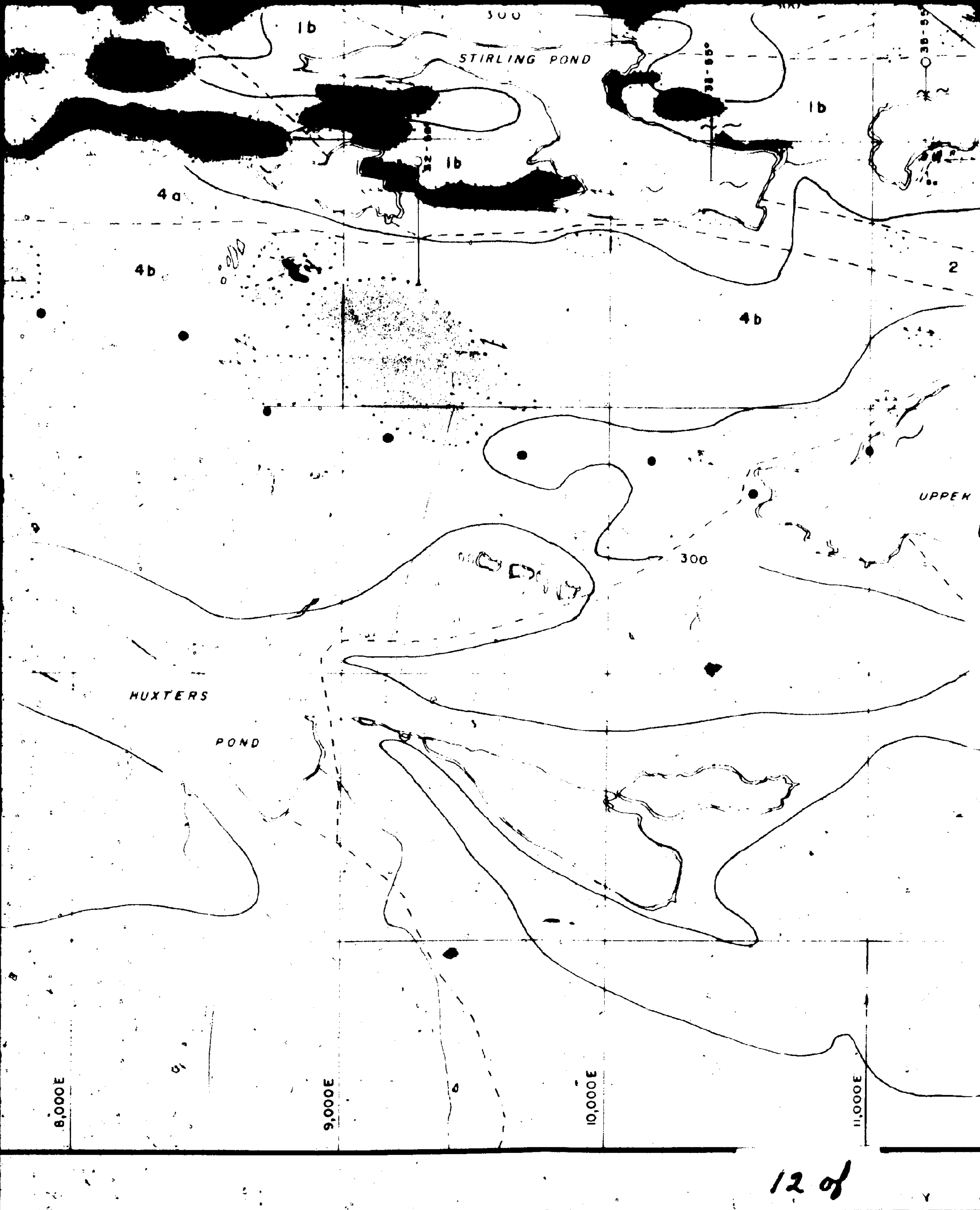
1" = 400'

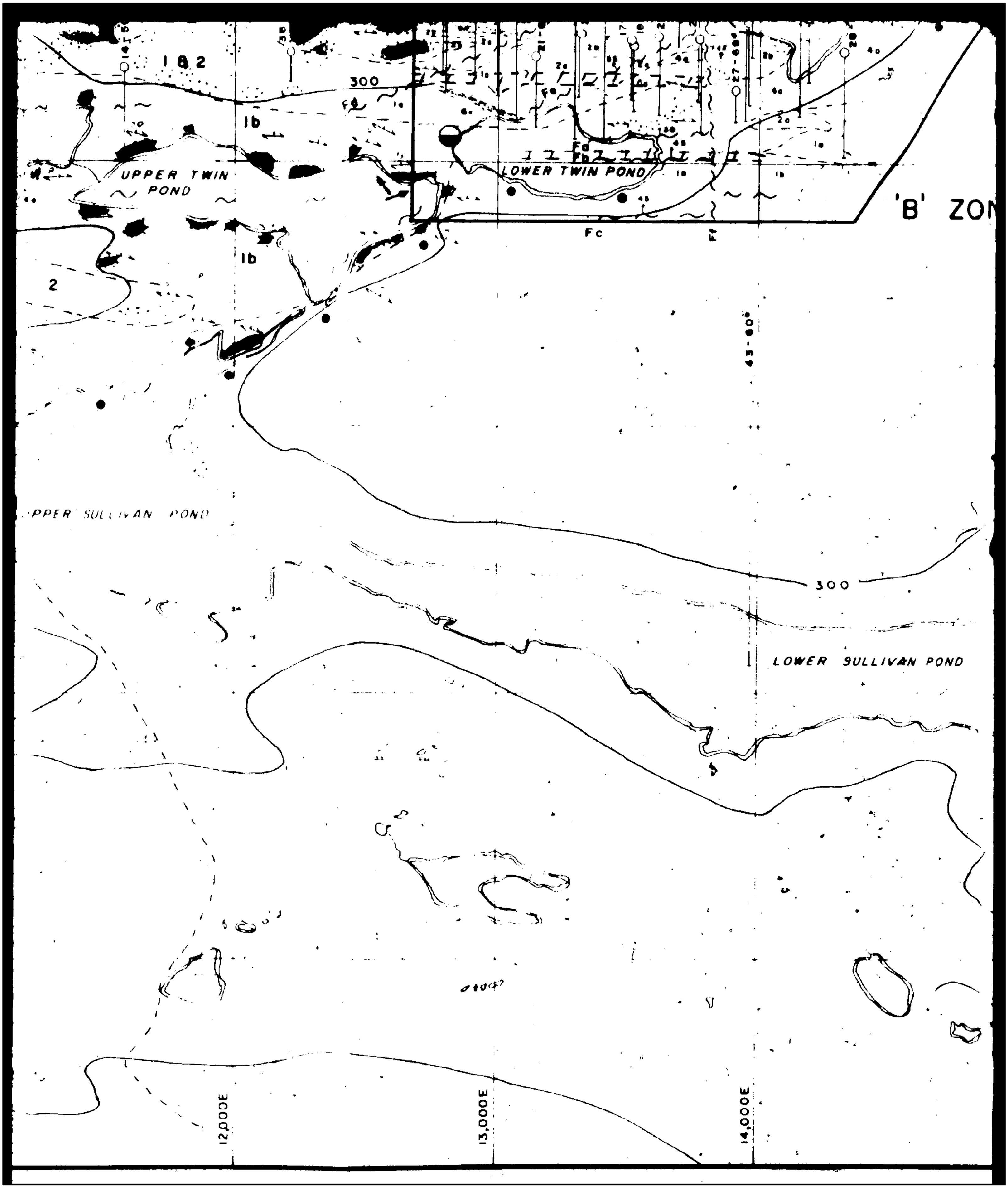
DRAWN BY: H.B. & J.G.M.

GEOLOGY BY: J.G.M.

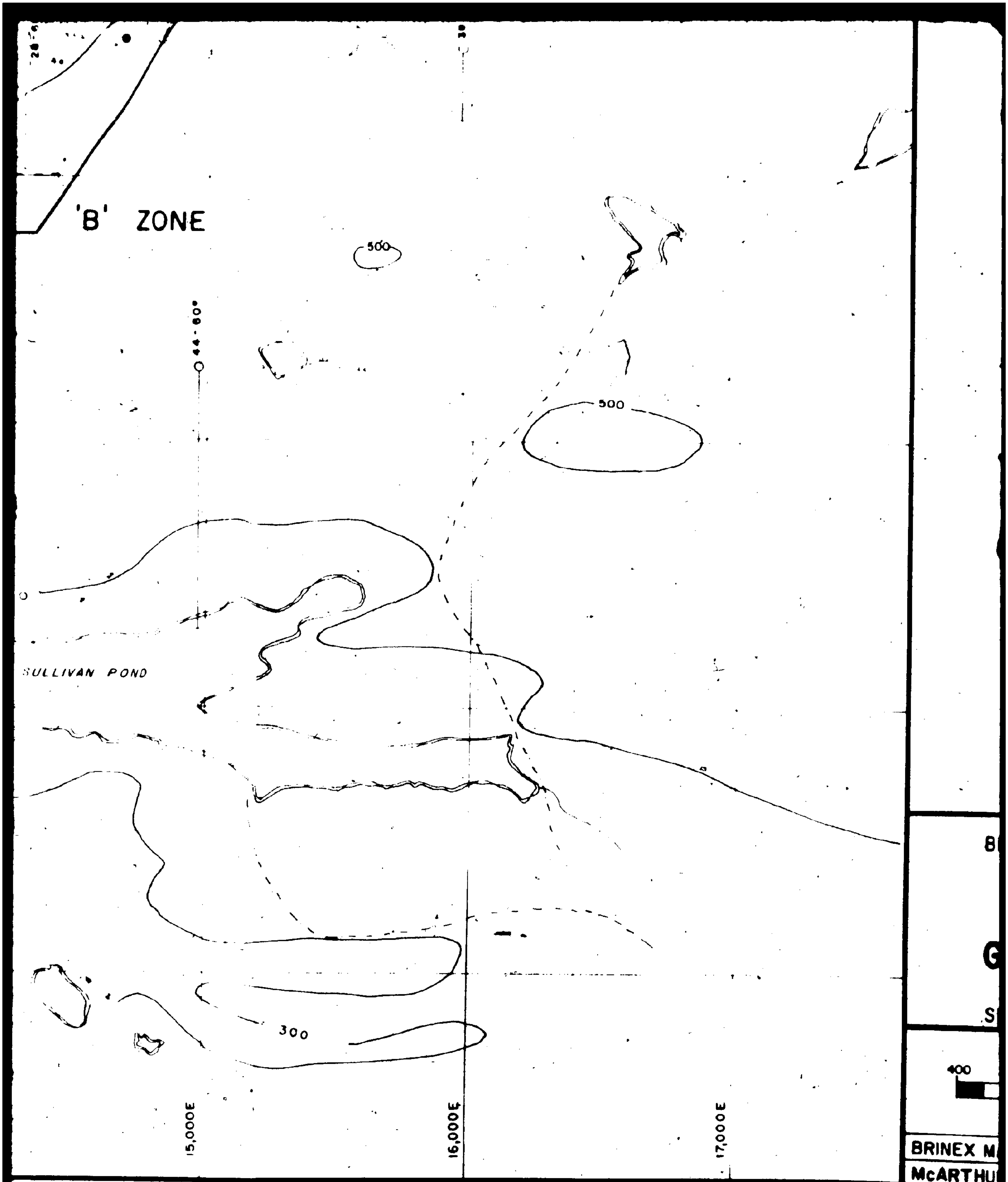


11 of


300
1b
STIRLING POND
1b
1b
4a
4b
4b
2
UPPER
300
HUXTERS
POND
8,000E
9,000E
10,000E
11,000E
12 of

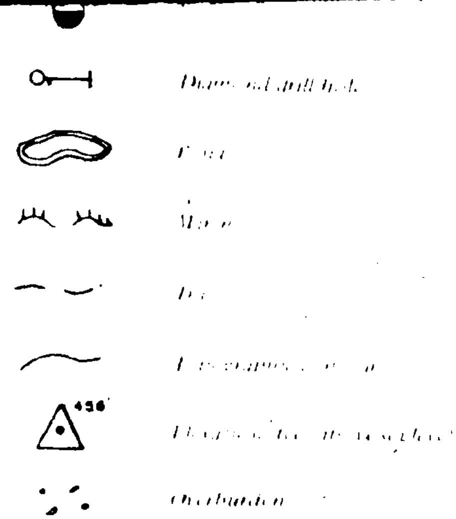


1 & 2
300
1b
UPPER TWIN POND
LOWER TWIN POND
'B' ZON
Fc
2
UPPER SULLIVAN POND
300
LOWER SULLIVAN POND
12,000E
13,000E
14,000E



'B' ZONE
500
44-60°
500
SULLIVAN POND
300
15,000E
16,000E
17,000E
400
BRINEX M
McARTHU

14 of



INDEX MAP

15 of 15

BRITISH NEWFOUNDLAND EXPLORATION COMPANY LTD.

STIRLING PROPERTY

GEOLOGY – DRILL PLAN

SPRINGDALE NOTRE DAME BAY NEWFOUNDLAND

SCALE 400 200 0 400 800 1200 FT. 1" = 400'	DRAWN BY: H.B.& J.G.M.
BRINEX MAP NO. N.T.S. 12 H/9 E	GEOLOGY BY: J.G.M.
McARTHUR MSc. THESIS FIGURE 1 MARCH 1972	CHECKED BY