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Columbia University, Ph.D., 1967
Geology

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THE STRUCTURAL DEVELOPMENT OF LABRADOR TROUGH FORMATIONS IN THE GRENVILLE PROVINCE, WABUSH LAKE AREA, LABRADOR

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ABSTRACT

The Wabush Lake area of southwestern Labrador embraces parts of the Superior province, the Labrador trough, and the Grenville province. Certain structural relations regarding these are evident from a regional structural examination of part of this area. Labrador trough formations are readily distinguishable in the Grenville province and provide an unusual opportunity to examine the effects of regional metamorphism and deformation upon older formations. The metamorphic rank of trough formations varies from greenschist along the Grenville front to amphibolite rank within the Grenville province, the metamorphism retrogressively affected basement gneiss and gabbro intrusions.

A deposit of iron formation in the amphibolite rank area lies in a large, northwestward overturned, subisoclinal syncline whose northeast trending axes are subhorizontal. The mineralogic schistosity in the bedding-foliation laminae forms a widespread lineation that plunges southeast, parallel with the axes of small folds and nearly parallel with one of the intersection axes described by foliation attitude variations. These linear fabric elements are subnormal to the axes of other small folds and the syncline. The age relationships between the two sets of folds are not locally apparent because the kinematic

significance of the mimetic lineations is unknown. The southeast plunging folds, lineations, and related northwest trending axial surfaces are however, superposed in space upon, and preferentially developed in, the northwest limb of the syncline.

A large scale, regional fold system extends northeasterly through the area. The distribution of trough formations in this system outlines a linear to arcuate structural pattern that is systematically arranged with respect to a more uniformly, northwest trending regional fold system which has significantly reoriented the northeast trending system in several parts of the area. One, northwest trending, axial-hinge zone cuts completely across the northeast trending fold system from well within the Grenville province to abut against the Superior province gneiss immediately northwest of the Grenville front. One fold discovered in a regional examination conclusively demonstrates that the northeast trending folds are older than the smaller northwest trending, superposed folds.

The northeast trending fold system is structurally correlated with the Hudsonian fold system in the central Labrador trough. Gabbro intrusions occupy both northeast and northwest trending structural lineaments, and are known to have been metamorphosed and deformed by the superposed orogenic events. There is reason to suspect that these are Elsonian intrusions, if so, this period is perhaps about the time of the early to middle stages of the orogeny that affected this part of the Grenville province.

The Grenville front is a zone about 4 miles wide that follows the northwest edge of the Labrador trough for about 30 miles in the Wabush-Sawbill Lake area. The trough formations and the northeast trending fold system are continuous along the front zone, and the northwest trending, superposed fold system is basically continuous across the front zone. Superposed deformational effects change southeastward from cataclastic features in the Superior province gneiss, accompanied by folds in the trough formations in the front zone, to passive folds of variable amplitude in the amphibolite rank area.

The trough formations, and the two fold systems in the Grenville front zone, are not cut by any recognizable, regional, post metamorphic-deformational event fault system. The relationships between the Superior province, the Labrador trough, and the Grenville province imply, as a working hypothesis, that migratory processes of superposed metamorphism and deformation operated, "in situ", upon older rocks and structures as a result of the variable imposition, in space and time, of heat from outside sources related to the long term, regional crustal diastrophism that is responsible for the development of the Grenville province.

INTRODUCTION

The meaning of the term "Grenville" has long been a subject of debate. It has meant a sedimentary series, regional metamorphism, granitization, deformation, orogeny, an area, or time to different geologists. The geology of the Grenville province is complex and regionally variable as a result of a long history of multiple sedimentary, intrusive, metamorphic and deformational events. These events affected and produced rocks of various origins in different parts of the province during several periods of time extending from the Archean to the middle Proterozoic. Potassium-argon ages record only the terminal period of the last major event, an orogeny characterized by widespread regional metamorphism and deformation. Grenville is used as a provincial term in this paper.

Rocks of the Superior and Churchill provinces have been traced across the northern border of the Grenville province in several areas. One of these areas is unique because the rocks represent three of the fundamental geologic units of the Canadian shield. This is the Wabush Lake area in southwestern Labrador, figure 1, where Archean Superior province basement gneiss is overlain by Proterozoic formations of the Labrador trough and the rocks of both groups are metamorphosed and deformed in the Grenville province. The Labrador trough formations are readily distinguishable over a large area in the Grenville province and provide a most unusual opportunity to examine the effects of regional metamorphism and deformation upon these formations. The structural geology of part of this area is the subject of this paper.

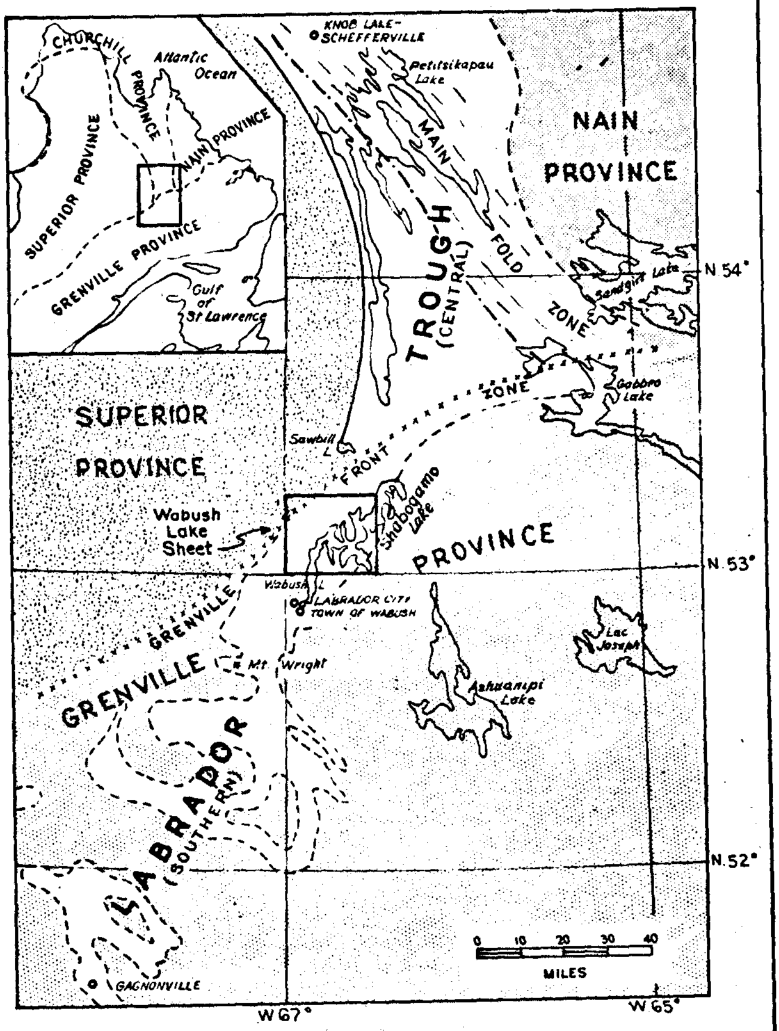
The Problem

The sedimentary formations in the Wabush Lake area are deformed into complex, large scale folds whose limbs strike in several directions, and smaller scaled folds whose axes are oriented at variable angles to the axes of the large scale folds. The problem of the relationships between these structures was specifically examined in 1959 while the writer was engaged in studies of the Julienne Lake deposit of metamorphosed iron formation.

This examination indicated that the small folds are partly dependent upon the large folds for their orientation. The writer felt that the regional structures in the metamorphic tectonites might be similarly related. Subsequent work has involved the collection and examination of information for a structural analysis of an area sufficiently large to examine the relationships and to include a part of the boundary between the Superior and Grenville provinces.

FIGURE 1

INDEX MAP



Geologic Information

The presence of ferruginous and associated unmetamorphosed rocks in the central Labrador trough has been known since 1893. Geologic information concerning the Wabush Lake area, in the metamorphosed southern Labrador trough, dates from 1914 when the area was prospected for gold. Several expeditions were in the area before World War Two, geologic information collected during one of these periods was presented by Gill, Bannerman, and Tolman, (1937).

Systematic geologic investigations sponsored by exploration groups for iron ore resources began in 1948 in the Mt. Wright area and date from 1949 in the Wabush Lake area. There were at least six field parties in the district in 1953; geologic mapping, drilling, and related mining development work has been done each year since. Several students have written thesis about various aspects of the geology in different parts of the area. Including company reports, there is a broad literature concerning the region of economic interest embraced by the southern extension of the Labrador trough.

The Geological Survey of Canada and the Quebec Department of Natural Resources have sponsored field parties in different parts of the region. The area specifically included in this study is part of the large area mapped by

Fahrig, (1960), that extends into the central Labrador trough. Duffell and Roach, (1959), mapped a large part of the region around and southwest of Mt. Wright. Jackson, (1962), examined an area between Mt. Wright and Wabush Lake. Clarke, (1964), included a structural review in his examination of the Mt. Wright-Lac Gras area, 30 to 50 miles southwest of Wabush Lake.

The geology of the region is variable on a broad scale and the significance of local relationships may easily be misinterpreted. Some of the interpretations made by the writer in 1954 and 1955 from local investigations were found to be in error during regional mapping programs conducted in 1956, 1957 and 1958. The observations made during these programs by the writer's field parties appear in two papers concerning the Wabush Lake area, Knowles and Gastil, (1959), and Gastil and Knowles, (1960). These papers were presented to stimulate interest in the geologic problems of the area. The field work upon which they were based was handicapped by the logistical problems that confront everyone working in the region. The area of general interest is so immense and inaccessable, and exploration rights are so divided, that no single person or group has yet had an opportunity to become geologically familiar with more than small parts of the region. Divergent opinions arose under these circumstances, but as information accumulated a reasonable uniformity of thought has developed about general geologic relationships, particularly with respect to stratigraphy and metamorphism.

This does not apply to the structural aspects however. Virtually all of the geologists have recognized structural complexity, their reports usually mention two fold systems. Some attempted to interpret the structures, others were content merely to point out the structural complexity.

Purpose - Scope

This paper presents the available evidence regarding the structural geology of the area. The structural relationships between large and small scaled fold sets with different trends are examined and interpreted in terms of orogenic events. It is hoped that the work will, in some measure, contribute towards a better understanding of geologic problems in the Grenville province.

The work is a regional investigation limited to the map area investigated, although the writer is confident that the results are applicable to adjoining areas. It is based upon mesoscopic and macroscopic evidence gathered from outcrops and drill core. It is intended to serve as a framework for future detailed structural studies of local areas which should include microscopic scale investigations.

Procedure

The Julienne Lake deposit is examined in detail. Mesoscopic scale fabric elements and observed small folds are described and illustrated. The geometric relationships between the fabric elements are graphically examined in equal area projection. Mesoscopic and macroscopic physical evidence in the deposit is correlated with the geometry to relate the surficial pattern described by the distribution of submembers of the iron formation to the macroscopic folds. The deposit is found to be an overturned syncline containing smaller folds whose axes are oriented subnormal to the axes of the syncline.

The regional examination utilizes information collected by numerous geologists and a limited amount of information collected specifically for this study. The examination is largely based upon the patterns described by the distribution of formations and the geometry described by attitude variations in 15 large domains. Local mesoscopic features are included to illustrate structural features. The regional relationships are found to be similar to those found in the Julienne deposit.

Interpretations directly related to the evidence are presented in the first three sections, geotectonic considerations are discussed in section four.

Geography - Physiography

The location of the Wabush Lake-Mt. Wright area is shown in figure 1. The towns of Wabush and Labrador City service the two iron ore mining operations currently operating in the area. A local network of roads allows access to some parts of the area. A much larger area is accessible by boat from the Wabush-Julienne-Shabogamo lake system.

The area specifically included in this paper is the area included within the Wabush Lake sheet, number 23G2 of the National Topographic System. The sheet includes an area of about 350 square miles situated in the northeastern part of the Wabush Lake area.

The area is part of the Labrador plateau. The relatively even skyline is formed by numerous rounded hills that rise 300-800 feet above the elevation of lowland areas. The physiography is dominated by a geologically controlled range of hills that extends northeastward through the area. The range contains a large proportion of quartzose rocks that have been more resistant to erosion and glacial action. The highest part of the range is situated just west of

Wabush Lake, where barren quartzite ridges reach elevations exceeding 2800 feet and are known as the Wapussakatoo Mountains.

Numerous glacial striae indicate southeastward glacial advance. Common glacial features include: roches moutonnées, striae, erratic boulders, moraines, sandy outwash deposits, eskers, kame and kettle forms, crag and tail forms, and elevated wave cut terraces. Henderson, (1959), has reported on the glacial geology of the area.

Much of the area is covered by a blanket of bouldery till that does not cover bedrock equally, some lowland areas are completely covered, others have only a thin cover. Some upland areas are heavily blanketed, others are barren rock. Extensive deposits of fine silt in some lowland areas below terrace level indicate deposition of fine clastic material in glacial lakes.

The sub-arctic climate supports an open spaced woodland forest of black spruce with a caribou moss ground cover in drained areas. Wet areas support Labrador tea (a variety of laurel) and alders. Subordinate trees include balsam, tamarack, aspen, and locally, white birch groves. The tree line is situated at about elevation 2500 feet, lichen and moss are found at higher elevations.

Geologic Setting

The sedimentary sequence present in the area has a distinctive lithology and provides the reference to which the total geologic picture is related. The iron formation is a unique and readily identifiable sedimentary rock that was originally nearly flat lying. The formations are correlated with the Labrador trough sequence of Proterozoic sediments. This provides a time-stratigraphic reference useful in interpreting the effects of younger geologic events.

The trough formations have their origin and subsequent history in a long zone that exhibits geologic features characteristic of geosynclinal evolution. The term, trough, is derived from the lowland physiographic expression of the formations in the central Labrador trough. The term, Labrador geosyncline, has been used synonymously with Labrador trough. Frarey and Duffell, (1964), have revised the stratigraphic nomenclature for the central part of the Labrador trough. The term "trough rocks" is commonly used when referring to the formations contained in the Labrador geosyncline. The writer will use the terms trough formations and trough structures when referring to the sedimentary and structural aspects of the Labrador geosyncline.

The Labrador Trough

Labrador trough formations are present in a zone extending about 700 miles from the western side of Ungava Bay southeasterly, southerly, and southwesterly to the Matonipi Lake area. Gross, (1960), has described the general features of the iron formation present in the trough and his map well illustrates the immensity of this structure. The presence of iron formation in somewhat similar sequences further west at each end has lead to correlations with other areas, as the Cape Smith, Belcher and Mistassini areas, but the lack of continuity restricts the term Labrador trough to the unit lying east of the Superior province, or where the trough formations are recognizable within the Grenville province.

The geology of the Labrador trough is summarized in "The Labrador Geosyncline" by Gastil, et al (1960). The geology of the northern portion is therein described by Bergeron, the central portion by Blais, and the southern portion by Knowles; the historical synthesis is by Gastil.

The trough formations rest unconformably upon Superior province granitic gneisses exposed to the west. The three main trough groups appear to total in the order of 20,000 feet, Harrison, (1952). The formations consist of stable shelf-miogeosynclinal sedimentary rocks in the western portion which interfinger with eugeosynclinal volcanic rocks further east.

The metamorphic rank of the western part is low and the assemblage contains grit, sandstone, arkose, shale, slate, chert, dolomite and iron formation. Metamorphism intensifies eastward, it is accompanied by a greater proportion of volcanic rocks and basic intrusions, and the identity of western trough formations is gradually lost proceeding eastward.

The structural geology in the central Labrador trough is characterized by folds and associated thrust faults that trend northwest in the main fold zone. This zone trends parallel with the distribution of the trough formations northwest of Schefferville, but trough formations also lie west of the main fold zone south of Schefferville. The typical structure in the main fold zone near Schefferville is "the overturned anticline, with a large part of the overturned limb truncated along a thrust fault", (Harrison 1952, p. 15). Synclines commonly have sharper hinges than anticlines and are often V shaped, plunges are typically low to moderate and reversals of plunge are common.

Formations - Wabush Lake Area

Ashuanipi Complex. The basement complex exposed in the northwest part of the map area is a part of the

Superior province assemblage of hybrid gneisses. Duffell and Roach, (1959); Fahrig, (1960); and Stevenson; (1964), have mapped these rocks for the Geological Survey of Canada. The complex consists of massive and foliated gneiss of granitic to granodioritic composition, and pyroxene bearing granodiorite gneiss. They contain mineral assemblages stable in the granulite facies of regional metamorphism and have been attributed to the charnockite suite. They are characterized by the presence of greasy feldspar and blue colored quartz eyes.

Jackson, (1962), reports no hypersthene in these rocks where he observed them, but Clarke, (1964), recognized hypersthene granulites of intermediate to basic composition in the Mt. Wright area. He felt that some of the coarse grained, leucocratic gneisses represented intrusive rocks.

These workers agree that these rocks have suffered retrograde metamorphism in the Grenville province and that the degree of alteration increases southeastward. Hypersthene is partly to completely converted to anthophyllite; uralite, biotite and quartz in the retrograde greenschist zone; and to garnet, biotite and quartz in the amphibolite rank areas.

Southwest of latitude 53N, the northern edge of the Grenville province is marked by the transition zone between

Superior province granulite and Grenville province amphibolite rank metamorphism. The line of X marks on figure 1 represents the approximate location of this zone as mapped by Duffell and Roach, (1959). To the northeast, a zone about 4 miles wide of greenschist metamorphism in trough formations lies between the Superior province and the amphibolite rank area. Northeast of Sawbill Lake, the Grenville Front is marked by the change from slate to schist and gneiss of argillaceous trough formations. Fahrig, (1960), has mapped the biotite isograd in trough formations and is shown on the regional geologic map.

Katsao Formation. The Katsao is the oldest Labrador trough formation recognized in this district. It is a coarse grained, garnetiferous, mica, quartz-plagioclase, lit-par-lit paragneiss. Biotite usually predominates over muscovite. Hornblende may be an important local constituent, and quartz rich horizons also occur. The quartz exhibits undulatory extinction, garnets are sometimes fractured, and boundinage forms exist.

The formation probably originated as a peletic assemblage of sandstone, siltstone, and shale; it may be correlated with the Attikamagen formation in the central Labrador trough, table 1. Its thickness is unknown.

Duley Formation. The Duley formation is a coarse grained, banded siliceous meta-dolomite. Samples collected near Lake Leila Wynne indicate a composition of about 11% silica, 27% calcium oxide, 19% magnesium oxide, and 42% carbon dioxide. The marble contains numerous parallel quartz stringers a few inches thick. Some of these are continuous for distances known to exceed 50 feet and appear to represent bedding, others are more lens like and extend a few inches or a few feet. The writer has not observed cross-cutting relationships between these quartz stringers. Tremolite is occasionally present along the quartz-carbonate interface. The marble is locally represented by white, lime-silicate rocks containing tremolite, quartz, diopside, and calcite in variable proportions, Dobell, (1957). Muscovite is sometimes present in brown weathering bands.

The Duley formation may be correlated with the Denault dolomite in the central trough. The thickness of the formation is unknown but it is regionally variable to over several hundred feet. Deformational lamella have not been observed in thin sections.

Wapussakatoo Formation. The Wapussakatoo formation is the massive, white, quartzite responsible for the prominent ridges in the Wapussakatoo Mountains. It was subdivided by Mumtazuddin, (1958), into a thin muscovite bearing lower

ROUGH

CENT ABRADOR TROUGH
Cl a - Grenville province

basic gabbro, anorthositic

Diabasic gabbro, anorthc
Lake area.

Sims formation, (local),

Montagnis group
Retty formation.
Wakuach formatio

Kaniapiskau Supergroup

Doublet group
Willbob formatio
Thompson Lake fo
intercalated
Murdoch formatio
minor sedimen

Knob Lake group c arenites, argillites
Menihek formatio ist. Local granitic gneiss.
greywacke, ba
Purdy formation, on formation. Quartz-iron
Sokoman formatio nd carbonate facies.
silicate and vite-biotite schist.
Ruth formation. assive quartzite, local grit.
Wishart formatio
greywacke and
Fleming formatio e dolomitic marble.
Denault formatio ferous biotite gneiss,
Attikamagen form
argillites, i
Seward formation
quartzite, gr

Ashuanipi Complex (Supe r province)
Paragneiss, granitiz d and pyroxene gneiss
ovince.

member; a thick, (200 feet plus), massive middle member; and a thin upper member in which iron oxides may locally occur. The quartz crystals are typically glassy, ¼ to 2mm in diameter, generally inequigranular and exhibit undulose extinction. The question of whether the quartzite might represent a metamorphosed chert lead Gross, (1955), to examine specimens from the Mt. Wright area for heavy minerals. He found rounded zircons and concluded that the formation is a completely recrystallized, exceptionally clean sandstone. Clastic grain forms have not been observed in thin section to the writer's knowledge. There is at least one locality however, where a quartzite outcrops in which small pebbles and grains can locally be observed in the partially recrystallized quartzite-grit. This outcrop, on the northwest shore of Julienne Lake, is believed to be part of the Wapussakatoo formation.

The Wapussakatoo formation is not everywhere resistant to erosion. There are places where it was less resistant than adjacent formations, and it is extremely friable and underlies a valley at one place south of Wabush Lake. The Wapussakatoo quartzite may be correlated with the Wishart quartzite in the central trough.

Huquette Formation. This is a thin, (0-50 feet), formation that lies between the quartzite and the iron formation in several places in the area. It has a variable mineralogy; assemblages include biotite-hornblende amphibolite with quartz and plagioclase, garnet-biotite-hornblende schist, quartz-muscovite schist, and quartz-feldspar-muscovite-biotite schist. It is highly altered to a sericitic mud in some places. This formation may be correlated with the Ruth formation in the central trough.

Wabush Formation. The Wabush iron formation is the most widely distributed formation. It has been found resting upon basement gneiss, upon the Katsao, the Duley, the Wapussakatoo and on the Huguette. The rocks and deposits of this formation have naturally received more attention than other formations because of its economic significance.

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It contains three basic mineralogic assemblages; 1) quartz-iron oxides, 2) quartz-iron-silicates, and 3) quartz-iron carbonates. The iron oxides are specular hematite, hematite (martite), magnetite, and minor limonite-goethite. The iron silicates include a great variety of minerals. The cummingtonite-grunerite series predominates, other associated silicates include garnet, ferrohypersthene, hornblende, actinolite and clinopyroxene among the more common ones, plus such alteration products as chlorite, stilpnomelane, talc, and limonite-goethite. The iron carbonate is usually considered to be ankerite, though siderite, sideroplesite, pislomesite and parankerite are reported in the literature. There are also small amounts of chlorite, stilpnomelane, calcite and graphite.

These mineralogic varieties are present in layers in the iron formation of such thickness and extent that they form distinct mineralogic members. Some members are mixtures of some of the varieties. The relationships between the members vary systematically, geographically and stratigraphically, in such a manner that most workers in the area have accepted the concept of pre-metamorphic compositional facies changes as the major cause of the internal stratigraphic-mineralogic construction of the iron formation. The iron formation can be classified as in Table 11.

These facies-members are usually distinctly laminated to thinly banded, but massive bands tens of feet thick are known, particularly in quartz-magnetite members. The members often grade into each other across sharp contacts and retain their identities along strike.

The quartz and iron oxides usually form a mosaic, in which the quartz tends to have a polygonal texture with straight line quartz-quartz boundaries and triple grain junctions. This is one of the features suggesting post deformational annealing recrystallization, Rast, (1964). Quartz seems to preceed iron oxides in the paragenitic sequence. Magnetite is typically finer grained than adjacent specular hematite. The silicates are usually 1-4 mm in length and often lie parallel with each other to form a lineation. Undulatory extinction is weak and seldom observed. Certain bands within the oxide members contain small carbonate lenses about one half inch long. These are locally leached and the vugs are coated with secondary iron or manganese hydroxides.

Table 11

Compositional Facies and Metamorphic Mineralogy
Wabush Iron Formation - Grenville province.

Chert-iron facies.	Major metamorphic mineral assemblages
Oxide	quartz-specular hematite-anthophyllite quartz-specular hematite quartz-specular hematite/magnetite quartz-magnetite
Iron Oxide-Silicate	quartz-magnetite-cummingtonite/grunerite
Silicate	quartz-cummingtonite/grunerite, quartz-actinolite
Silicate-Carbonate	quartz-cummingtonite/grunerite-ankerite
Carbonate	quartz-ankerite
Sulfide (rare)	pyrite and graphite with silicates

The stratigraphy within the iron formation is locally and regionally variable. Jackson, (1962), indicates a sequence for his area, from older to younger, composed of silicate, oxide, silicate/oxide, carbonate, and silicate facies totalling about 1000 feet. Gross, (1955), did not recognize a stratigraphic sequence at Mt. Wright, but felt that oxide facies might grade into silicate facies along strike. Clarke, (1964), reports that a layer of iron formation changes from oxide to silicate-carbonate facies along strike in the Bloom Lake syncline. The latter is the only locality the writer is aware of where a lateral facies transition has been directly observed.

Carbonate and silicate facies form the lower members, and oxide facies the upper members in the Wabush Lake area. These are known as the Lower and Upper Wabush formations respectively. The Upper Wabush locally grades upward into a quartz rich member that exhibits alteration products sometimes seen in carbonate iron formation. The total thickness of the iron formation around Wabush Lake exceeds 700 feet. The Wabush formation is correlated with the Sokoman formation in the central trough.

<u>Nault Formation</u>. Most Nault rocks in the Wabush-Shabogamo Lake area are distinctly phyllitic to weakly schistose and exhibit assemblages stable in the upper greenschist

metamorphic facies due to their location along the Grenville front zone. Northwest of the biotite isograd, Fahrig, (1960), and others who have worked there, describe the Nault as consisting of a mixed-assemblage of phyllitic, chloritic, locally carbonaceous, polymictic grits, argillites and sandstones. The Nault is correlated with the Menihek formation in the central trough. The Menihek formation is composed of a thick succession of argillites, sandstones, carbonaceous shale-slate, and greywacke with minor chert and dolomitic horizons.

Some areas in the general vicinity of the Wabush-Nault contact zone are underlain by granitic rocks. They are believed to be granitized equivalents of the Nault or Katsao formations, although they may be difficult to distinguish from granitic phases of the Ashuanipi complex.

Shabogamo Intrusions. The Shabogamo gabbros derive their name from a large area southeast of Shabogamo Lake where they form the core of nearly every hill. They vary in composition from dioritic to ultrabasic, but for the most part they consist of olivine bearing gabbro or their metamorphosed derivatives. They range from tabular bodies several miles long concordant within the regional structural pattern to small plugs a few tens of feet across and intrude all formations in the district. Outside of the type area, they are most abundant in the quartzose zone where the Wapussakatoo and Wabush formations predominate.

The larger bodies exhibit fairly fresh gabbro with a subophitic texture, but thin sections indicate that some degree of alteration is usually present. The borders of these bodies often consist of a garnetiferous amphibolite or stripped biotite schist that changes inward into a spotted, hornblende-feldspar rock that gradually gives way to normal appearing gabbro. There are tabular amphibolites in the iron formation in several places. Gross, (1955), showed, on the basis of chemical composition, that these are amphibolitized gabbro. Jackson, (1962), Duffell and Roach, (1959), and Clarke, (1964), have shown that the retrograde metamorphism of the gabbros is exhibited by the development of "coronas" of metamorphic amphibolite rank alteration minerals surrounding olivine.

Thin sills of amphibolitized gabbro are folded along with the formations they intrude, and it is generally accepted that most of the meta-gabbros are not later than the metamorphism and the deformation.

<u>Other Rocks</u>. Gill, Bannerman and Tolman, (1937), believed there were intrusive granites north and west of Wabush Lake, This thought persisted during the early years of regional investigations and the term "Sawbill Granites" was applied

to most leucocratic granitic bodies.

Subsequent regional investigations have indicated that these "granites" are probably granitized Nault or Katsao rocks, or are part of the basement complex. Jackson (1962), suggests the possible existence of a post basement pre-trough granite, but concludes that there are no large granitic bodies known to intrude trough formations. There are no post-trough granites or related plutonic rocks anywhere in the district to the writer's knowledge, though there are numerous gneiss domes southwest of Mt. Wright.

Pegmatitic bodies of various sizes and shapes are locally present in all formations in the district. They are most common in the Katsao where they may form bands of unknown extent concordant with the foliation. These bands locally swell to form lensoid bodies up to ten feet in thickness. They are coarse grained mixtures of quartz-muscovite/biotite, albite or oligioclase, sometimes with microcline.

Pegmatitic veins cut the iron formation in several localities. They usually are about 6 inches wide and often occur in sets that follow fractures. Small, subsidiary veinlets shoot off from these veins and follow other cracks or lie between bedding surfaces where they may be as thin as a fraction of an inch. These veins are sericitic mud in several places.

Quartz veins are present throughout the area, but are not particularly common. They are coarse grained and glassy. Sulfides are reported to be associated with them in a few localities but are of no economic significance.

Quartz veins containing specular hematite and/or magnetite occur within the oxide iron formation. They are not common, are only a few inches wide, and are discontinuous. No veins containing iron oxides are known to exist in other formations, though botryoidal goethite is found in the Wapussakatoo quartzite in some areas.

Most students of the district have concluded that the pegmatitic-quartzose lenses and veins represent migratory material sweated out of the formations during metamorphism. They probably are mostly late metamorphic stage features, but some deformed or offset veins are reported.

Metamorphism

The metamorphic evidence indicates that there has been only one period of intense regional metamorphism of Labrador trough rocks in the Wabush Lake area. The trough formations north of the Grenville province are essentially unmetamorphosed in the western part of the trough. Harrison, (1952), described some enlargement of detrital quartz grains, local metamorphic development of minnesotaite, partial recrystallization of chert and the formation of slates. Preservation of cross bedding, ripple marks and oolites is common. Gross, (1960), placed the metamorphism in the lower greenschist facies, increasing eastward. Neither Frarey, (1961), Fahrig, (1960), Wynne-Edwards, (1961), or Stubbins et al, (1961), considered metamorphism of central Labrador trough formations of sufficient importance to warrant discussion in their papers.

All workers who have studied the mineral assemblages of the trough formations in the Wabush-Mt. Wright district have found assemblages considered stable in the quartz-albite-muscovite-chlorite subfacies of the greenschist facies in the Grenville front zone and the almandine-amphibolite facies south of the front zone. The investigations range from Mt. Wright to the general vicinity of Wabush, Julienne and Shabogamo Lakes, and indicate that amphibolite rank metamorphism was approximately uniform along the length of the district. Some of the students concluded that metamorphism was more or less isochemical, excepting the alkali metasomatism that is probably responsible for the granitic gneisses believed to represent granitized trough rocks. The retrograde effects of the regional metamorphism appear in the rocks of the Ashuanipi Complex and the Shabogamo Intrusives.

Fahrig, (1960), did not elaborate upon the effects of metamorphism upon trough rocks in the area herein studied other than to indicate the approximate position of a biotite isograd, shown on the regional map, and indicate the mineralogic contrast on either side of the Grenville front zone. From the writer's experience north and west of Wabush-Julienne-Shabogamo Lakes, he is left with the impression that the metamorphic rank becomes nonuniform or patchy towards the biotite isograd. The occurrence of partially recrystallized quartzite has already been mentioned and fine grained, chloritic schists and phyllitic rocks occur in several places in this part of the area. At least one deposit of iron formation exists north of Julienne Lake in which the silica is present as distinctly granular quartz while the hematite is fine grained, not the usual coarse grained, specular variety. Small remnants of red-blue jaspillite also occur; they have been noted "floating" within normal quartz-specular hematite in the Julienne deposit.

These observations suggest that the northwest side of the area of fairly uniform amphibolite rank metamorphism is a zone several miles wide in which the metamorphic rank becomes gradually lower northwestward in an irregular fashion. The variation is probably due to a combination of chemical-lithologic variations within the formations, structural relationships, presence or effects of basement rocks, time, and perhaps a purely geographic variation in the intensity of the metamorphic processes. Sufficient petrographic work has not been done in this area to define the several isograds that could be recognized. The southeasterly increasing metamorphic rank is expressed by increased grain size, replacement of marble by calcium-silicate gneiss, appearance of kyanite and sillimanite, presence of granulites, and the development of pyroxene in the silicate iron formation.

Several students have investigated the metamorphism of the iron formation in considerable detail; Gross, (1955), Kranck, (1961), Klein, (1960), Mueller, (1960), Jackson, (1962), and Clarke, (1964). Their basic conclusions are that metamorphic processes operated in a virtually closed system in which the resultant mineralogy was largely specified by the chemical composition of the rocks present. Jackson, (1962), believed that much of the hematite in the oxide iron formation is metamorphically oxidized magnetite; however, he did not work in an area where the effects of post-metamorphic leaching and oxidation were important. Sufficient work has not been done to fully examine the problem of co-existing specular hematite, martite, and magnetite. Until useful criteria are found for distinguishing metamorphic hematite from later martite, the problem of oxygen availability during metamorphism must be left open.

Remarks

The regional mapping in the Wabush Lake area was done on a lithologic basis and interpretations of the stratigraphic sequence and the structural relationships are mutually dependent. The Wapussakatoo quartzite has been shown by drilling programs to underlie the iron formation. This relationship is the basis of regional stratigraphic-structural interpretations. The iron formation may locally lie upon any of the older formations, however. Facies changes, limited sedimentary distribution, or unconformities are believed to account for the regionally variable stratigraphic relationships.

The distribution of the formations is a reflection of the stratigraphic sequence and structural disturbances. Large, regional folds with subparallel limbs trending sinuously northeasterly are shown by the distribution of formations across the map area. Northwest trending lines of symmetry are expressed by the linear to arcuate pattern. The structural geology of the Julienne deposit of metamorphosed iron formation, situated in the center of the map area, will be presented in the following chapter. The structural features expressed in the deposit are typical and representative of the structural relationships observed throughout the Wabush Lake area.

THE JULIENNE STRUCTURE

General Information

Exploration

The Julienne deposit of metamorphosed iron formation crops out in a hill that rises up to 220 feet above lake level. The hill was an island in glacial lake Wabush, a prominent wave terrace is present at elevation 1820. About 300 outcrops exist above the terrace where the overburden is thin, the overburden thickens to over 100 feet in short distances beyond the terrace. The deposit was initially examined in 1956, nine diamond drill holes were drilled in 1957-58. Detailed geologic studies were begun in 1959 and continued in later years as more information became available.

The peninsula has been magnetically surveyed at 25 foot intervals on lines 125 feet or less apart in order to help correlate submembers of the iron formation between outcrops. Magnetic highs and lows trend along the length of the deposit for distances exceeding 1000 feet. The magnetic pattern correlates reasonably well with the general mineralogic-stratigraphic trends exhibited at individual outcrop areas and has been used as a guide for the interpretation shown on the geologic map.

Magnetic surveys also show that the iron formation extends at least 15,000 feet in a northeasterly direction from the northern part of Wabush Lake well into Julienne Lake. The north of the local grid system is oriented N27W with respect to true north. All directional references in the succeeding parts of this chapter refer to the local grid system.

Stratigraphy-Mineralogy

The white, massive, Wapussakatoo quartzite is exposed on both sides of the iron formation. It contains a small amount of disseminated muscovite which becomes more abundant towards the sericitic muscovite schist that is usually present between the quartzite and iron formation.

The basal member of the iron formation is a limonitic and goethitic quartz rock that is probably an altered silicate-carbonate member. The siliceous goethite is non-magnetic and the magnetic contact follows the zone between this unit and the overlying oxide members. The upper member of the lower iron formation is a quartz-specular hematite rock containing subordinate amounts of locally distributed granular hematite and orange-brown colored laminations containing the altered remains of a silicate mineral that is usually found in association with specular hematite.

Granular hematite refers to grains of hematite that are about equidimensional and do not reflect light in contrast with reflective specular hematite. The distinction is readily apparent in coarse grained iron formation; but is less clear in finer grained material. The granular hematite is believed to be post metamorphic martite. Other expressions of secondary leaching and oxidation include friability of specular hematite rich submembers; limonitic, goethitic and red hematitic stains and replacements associated with granular hematite bearing bands; vugs, leached silicate bands, and the existence of less than one percent magnetite in drill core. Leaching and oxidation have affected the deposit to depths greater than 700 feet. The leached silicate mineral has not been identified, but similar material found in unleached iron formation elsewhere was identified as anthophyllite by Klein, (1960).

The middle iron formation arbitrarily includes all members lying above the leached specular-silicate up to the appearance of several lean bands called ferruginous quartzite. The lower member is generally richer in specular hematite than other members in the middle unit. Specular hematite, granular hematite and thin semi-continuous bands of hard, very fine grained blue hematite or black manganiferous hematite make up the numerous bands which form the other members in the middle iron formation.

The upper iron formation contains several bands of lean quartzite usually associated with quartz-granular hematite bands. Specular hematite is found in the upper member. The stratigraphic top of the iron formation is not known to be present.

The layered character of the iron formation is exhibited along the stripped area and the terrace to the east. The family of form lines drawn along the length of the deposit have been placed as a best fit between the outcrop evidence and the magnetic pattern.

Structural Fabric

Large Scale Fabric Features

The regional stratigraphic sequence of iron formation over quartzite suggests that the deposit is a syncline trending easterly. The fold is about 1800 feet wide on the west side and 3000 feet wide on the east side. The beds dip to the south or southeast in a range from about 25 to 60 degrees, suggesting that the fold is overturned to the north. A pronounced magnetic low immediately south of the deposit indicates however, that the south limb does not underlie the quartzite.

The nearly straight, east trending, surface expression of the south limb rises through about 150 feet of vertical relief and indicates that the south limb stands about vertical. The north limb would have to dip northwest according to the topographic expression of the north contact on the northwest side of the hill. As this is contrary to all other evidence, the north limb cannot be a plane in this area.

The arcuate patterns exhibited by the stratigraphy suggests that plunging folds exist. The question is, do they plunge east, west, or in some other direction? The syncline, as a large unit, must have subhorizontal axes because if the axes are more inclined, the overlying Nault formation should appear along the extension and the iron formation should split into two bodies; but the iron formation remains about 3000 feet wide for nearly a mile to the east beyond the map area.

Small Scale Fabric

Bedding. The bedding in the iron formation is exhibited by mineralogic banding that varies from laminae a fraction of an inch to one or two inches thick. Quartz rich bands alternate with iron oxide rich bands which contain specular hematite, granular hematite or both. The bedding is usually not uniform across the strike and may change form in short distances. Some sections are massive and exhibit little evidence of bedding or other textural variations.

Foliation. The tabular specular hematite crystals lie with a schistose arrangement that parallels compositional banding.

This arrangement is common in the Wabush Lake area where it is rare to encounter an outcrop area where metamorphic recrystallization has produced an arrangement other than bedding foliation. The term, foliation, as used in this paper, means bedding foliation unless otherwise specified. It is used in the manner suggested by Harker, (1965), as "an interleaved fabric caused by planar disposition of fabric elements", where the fabric elements are the schistosity and mineralogic layering.

Lineation. A lineation is present in some of the rocks. The lineation, meaning a parallelism of linear fabric elements, is internal in the foliation laminae. No cases are known to the writer of a linear feature that is caused by mesoscopic structures transecting several bedding surfaces. The lineation is mineralogic and best appears in coarse grained rocks in which there is some degree of optical contrast between the mineral components.

Hand lens examination of lineated quartz-specular hematite rocks shows that the lineation is formed by two factors, 1) the long dimensions of quartz crystals are generally parallel with each other and are parallel with the flat side of tabular specular hematite crystals, and 2) the tendency of some specular hematite crystals to lie at variable angles with respect to the average foliation laminae. In other words, a line passing through the long dimension of a quartz crystal will also lie in the flat surface of a specular hematite crystal, but this surface need not necessarily lie parallel with the average bedding foliation laminae.

Typical lineated surfaces are seen under the hand lens to consist of elongated quartz crystals interspersed with specular hematite crystals. Some of the specular hematite crystals have their flat side parallel with the bedding foliation laminae and some are seen on edge, with the edge of the flat crystals parallel with the quartz crystal elongation.

Rotation of specimens about the lineation axis in directed light produces reflections from the flat side of the specular hematite crystals through about 20 degrees on either side of the foliation laminae. Rotation about axes in the foliation surface normal to the lineation yields reflections over a more limited range. Although the 20 degree range given above is an average figure, some specimens exhibit reflections over much larger rotations. Crenulation of the foliation laminae is usually visible in these instances.

These features of lineated quartz-specular hematite rocks are considered as evidence for the existence of an orderly, preferred spatial arrangement of individual crystals within the recrystallized rock that can be described in space by the attitude of the lineation. The lineation is often present throughout a particular outcrop. Some outcrops contain nonlineated bands among lineated bands, but there usually is a mineralogic difference between these bands. Lineations observed in plane foliation outcrops are all closely parallel to each other regardless of how well they are developed in individual foliation laminae.

A lineation is generally not present in massive rocks or rocks containing an appreciable portion of granular hematite. A lineation is locally exhibited in the Wapussakatoo quartzite due to the linear arrangement of muscovite flakes in muscovite bearing laminae.

The most striking lineation appears in the leached specular-silicate rocks. The lineation in these rocks is caused by the parallel arrangement of the altered silicate needles in the silicate rich laminations.

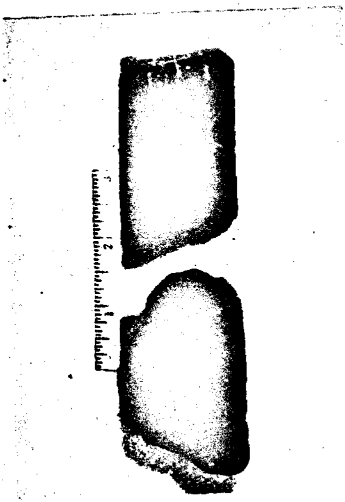
Crenulation. The foliation is not planar at some localities but is irregularly undulatory on a scale ranging from less than an inch to several inches. The foliation surfaces may be corrugated, bedding laminations may be discontinuous on a small scale, or two or more specular hematite schistosity arrangements may lie at various attitudes with a diamond shaped pattern. The crenulated laminae contain the same mineralogic lineation seen in planar foliation surfaces and the lineation and crenular forms are observed to be parallel. The crenulations and lineated planar foliation laminae appear in different parts of a few outcrops; both are parallel to each other.

Concordant and Discordant Folds

The geologic investigations begun in 1959 led to the discovery that there were small folds in the deposit whose axes were parallel with the lineation, and there also were folds present whose axes were oriented at a high angle to the lineation.

One of the folds discovered is shown in figure 2. The two pieces of core were six inches apart in a vertical drill hole. Both pieces exhibit a lineation on the foliation surfaces, but it doesn't show in the photograph very well because the scale of the lineation is but little larger than the grain size. The lineation is marked for presentation and the cores may be oriented with respect to each other such that the lineations are directionally parallel. The upper core exhibits a fold whose axial plane strikes approximately perpendicular to the plane of the photograph and dips gently to the left. The axes of the fold plunge left approximately parallel with the photograph.

Figure 2



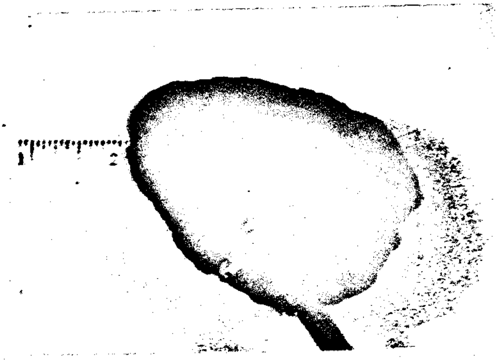
Small folds, axes discordant and concordant with respect to the lineation. Julienne Lake Deposit.

The lower specimen exhibits a fold whose axis is parallel with the lineation. Its axial plane strikes about parallel with the plane of the photograph and dips towards the camera. The two specimens cannot be oriented, in any combination of relative positions, so that the two fold axes are parallel and still satisfy the requirement that the cores remain vertical. These folds, therefore, exhibit contradictory geometric relationships between the folds. The fold axis of one fold is parallel or concordant with the lineation, the other fold axis is not parallel and is discordant with respect to the lineation.

A fold was eventually discovered in outcrop that provided a clue helpful in understanding the structure of the deposit. This was found in the southwest corner of the deposit near 8640N x 8230E where there is a band of leached specular-silicate rock about three feet wide. The generally planar foliation strikes east and dips about 45 degrees south. The lineation plunges about 40 degrees along S30E. Within this band, a W shaped fold less than a foot wide was discovered that exhibits about a 35 degree spread between the limbs. Excavation of the fold showed that the fold axes were approximately horizontal, striking east. Dissection of parts of the fold showed that the lineated silicates tended to continue around the hinges of the fold so as to maintain continuity of the lineation to the other limb, and that the southeast directional property of the lineation was maintained. This showed that the plunge of the lineation was locally variable and dependent upon the shape of the fold, but the lineations lay in planes that were approximately vertical. Part of this fold is shown in figure 3 where the top view of the reoriented specimen shows the lineation plunging southeast parallel with the pencil, and the end view shows the fold form exhibited by marked specular hematite laminae on the west face sawed approximately parallel with the lineation plane.

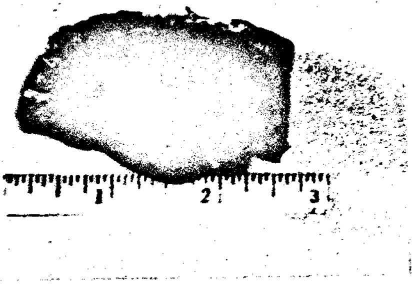
This is another discordant fold similar to that in

Figure 3



Top View

Altered silicate lineation parallel with the pencil, scale parallel with fold axes



West end view

Small fold outlined by white lines in specular hematite laminae, scale represents horizontal.

figure 2. In both cases, the lineation direction appears to be unrelated to the fold while its plunge is dependent upon the local attitude of the foliation as determined by the shape of the fold. Essentially, the only difference between the discordant fold of figure 2 and the larger fold represented by figure 3 is a difference in the scale of the fold in comparison with the scale of observation. If this can occur on a small scale, perhaps it also occurs on a scale applicable to the entire deposit.

Fabric Orientation

The problem offered indicates that folds both concordant and discordant with respect to the lineation exist in the deposit, that the axes of one fold set are parallel with the lineation while the axes of the other set are not parallel, and that the lineation appears to be superimposed upon the discordant fold forms. Whether or not these two fold sets are related to each other in space or time must be deduced from the fabric geometry and other evidence within the deposit. The deposit has been divided into four domains for examination of fabric geometry. Each is characterized by a somewhat unique pattern outlined by the stratigraphy.

Surficial Geometry

Northwest Domain. This part of the deposit exhibits a weakly arcuate pattern. Part of this pattern is a topographic expression of southerly dipping beds, but east of 8250E the members must be folded because the contacts change trend to a little south of east while rising through 75 feet. They then trend arcuately east and northeast into the central portion of the deposit. Northwesterly trending lineaments in the pattern near hole 5 represent axial traces. Foliation strikes generally follow the stratigraphic trends, as interpreted from the magnetics.

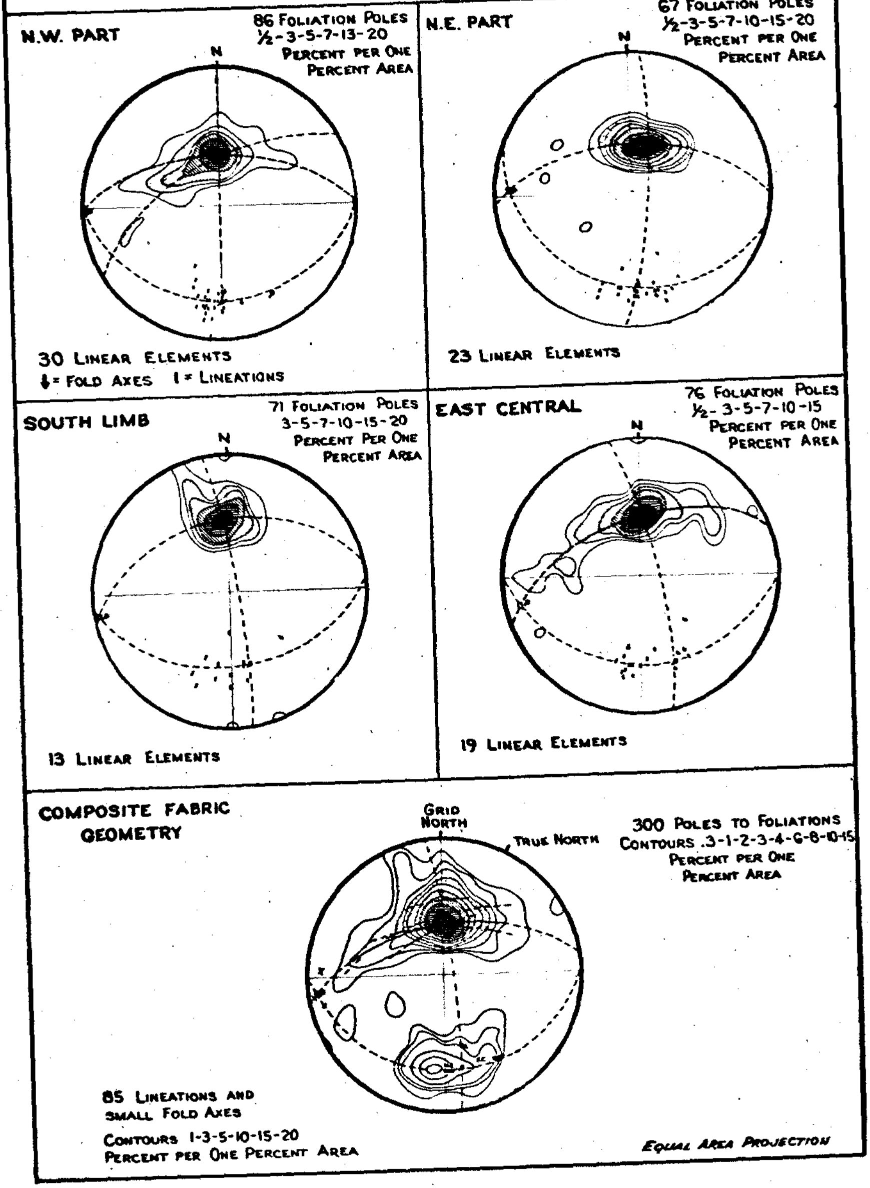
The plot of the foliation and lineation attitudes, figure 4, shows a polar maximum with about 25 degrees of dip dispersion and about 60 degrees of elongation of poles to foliation. The fabric can be related to a set of orthorhombic symmetry planes where two planes divide the pole distribution and two divide the lineation field, Turner and Weiss, (1963), p.65, p.505. The eastward elongation parallels an orthorhombic symmetry plane, but the southwestward elongation suggests the possibility of a second symmetry plane. Three possible intersection axes are suggested by the distribution, west and horizontal, south and S30E at about 30 degrees each. Two observed small fold axes are known, they plot near the south axis, but both are somewhat east of the lineation field which generally corresponds with down dip lineation with respect to the major part of the polar maximum.

Northeast Domain. This area exhibits an arcuate pattern. Although the magnetically indicated contact of the iron formation along 9750E trends north, the magnetic pattern to the east is so strongly northeast that northeast trending submembers must underlie the overburden. The orientation diagram shows an egg shaped polar maximum that can be divided by orthorhombic symmetry planes. The lineation is spread through about 40 degrees of direction and appears to be down dip lineation.

East Central Domain. The arcuate pattern from the northeast area continues into the east central area where a fold is well indicated by the distribution of the ferruginous quartzite band around 10500E-10500N that contains three southeast plunging small folds. The orientation data shows an incomplete girdle that can be divided by orthorhombic symmetry planes, however, the 90 degree elongation spread suggests a partial monoclinic distribution as well. The dip dispersion is about 30 degrees and there appears to be a slight directional irregularity about the attitudes whose poles plot near the ends of the elongation. The lineations

FIGURE 4

ORIENTATION DIAGRAMS - JULIENNE DEPOSIT



are down dip from the major part of the maximum and about 30 degrees west of the intersection axis suggested by the distribution.

South Limb Domain. The south limb of the syncline exhibits a linear pattern that is weakly arcuate northeast of hole 4. Steep to vertical attitudes and contorted foliation laminae are found in an easterly trending zone passing through the area around 9500E-8700N. The orientation diagram exhibits a polar maximum with a tendency for steep dips on both sides of the northwest symmetry plane passing through the maximum. The small fold observed in the south limb is contorted and its orientation is only approximate. The fold axis from figure 3 is not plotted, but it would plot close to the west, near horizontal intersection, likewise for the fold found near 10730N and 10100E.

Composite Orientation. The fabric geometry for the entire deposit is shown in the composite diagram where the principal parts of the symmetry from each domain is included. The dip dispersion is greatest near the center of the maximum and decreases to about 40 degrees or less along the approximately 90 degrees of elongation.

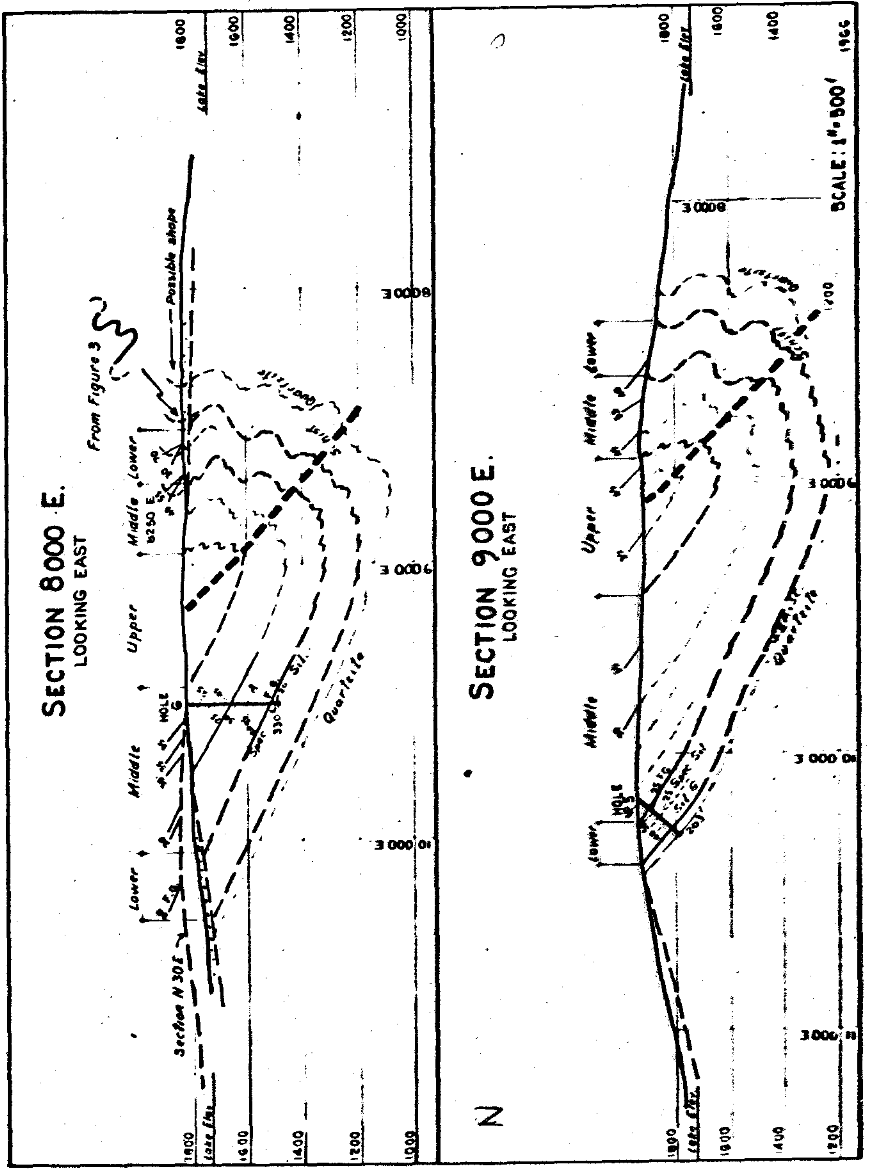
The center of the maximum is nonsymmetrically positioned in the dip dispersion plane because about 75 percent of the attitudes are taken from the north limb of the syncline. The average intersection axes plunge a few degrees along S80W, and 30 degrees along S10E. The linear elements lie in a field normal to the major portion of the maximum but centered about 15 degrees west of the average southerly plunging intersection axis.

The diagrams suggest that the axes plunging slightly west may represent the approximate orientation of the fold axes of the syncline and may represent the fold axes observed to be discordant with respect to the lineation. The south plunging axes seem to conform with most of the observed concordant small folds, large scale folds with this axial orientation would appear to account for the arcuate pattern. The axial traces of the concordant fold set trend north to northwest and are evident only in the north limb of the syncline.

Sub Surface Evidence

Sections 8000 and 9000E. Hole 6, figure 5, shows that the north limb of the syncline dips south. A band of the fine grained blue hematite variety, overlying specular-silicate rock at depth 300 feet, can be correlated up dip with the outcrops situated near 8250E-10100N. The same sequence appears in hole 5 above the siliceous goethite member that

JULIENNE LAKE DEPOSIT **FIGURE 5**



is underlain by the muscovite schist and quartzite.

The scale of the folds which may form the South Limb is shown on section 8000E. The shapes shown between elevation 1750 and 1900 feet were derived by west, horizontal projection of member contact positions as far east as 9000E. The projection suggests the presence of folds whose hinges may be about 100 feet apart, and whose axial plane may dip very gently south, though little weight can be placed upon the latter. The interpretation is that the syncline is constructed of innumerable small folds with normal and overturned south dipping limbs arranged in combination to form the larger folds. These group to yield a generally vertically standing south limb that likely progressively migrates northward at depth to eventually reach the bottom of the syncline.

The small fold of figure 3 exhibits a separation between the normal and overturned limbs that ranges from about 20 to 50 degrees, they are approximately symmetrical with respect to the axial planes which dip between 45 and 55 degrees. Thus, normal limbs dip from about 20 to 45 degrees and overturned limbs dip 55-80 degrees south.

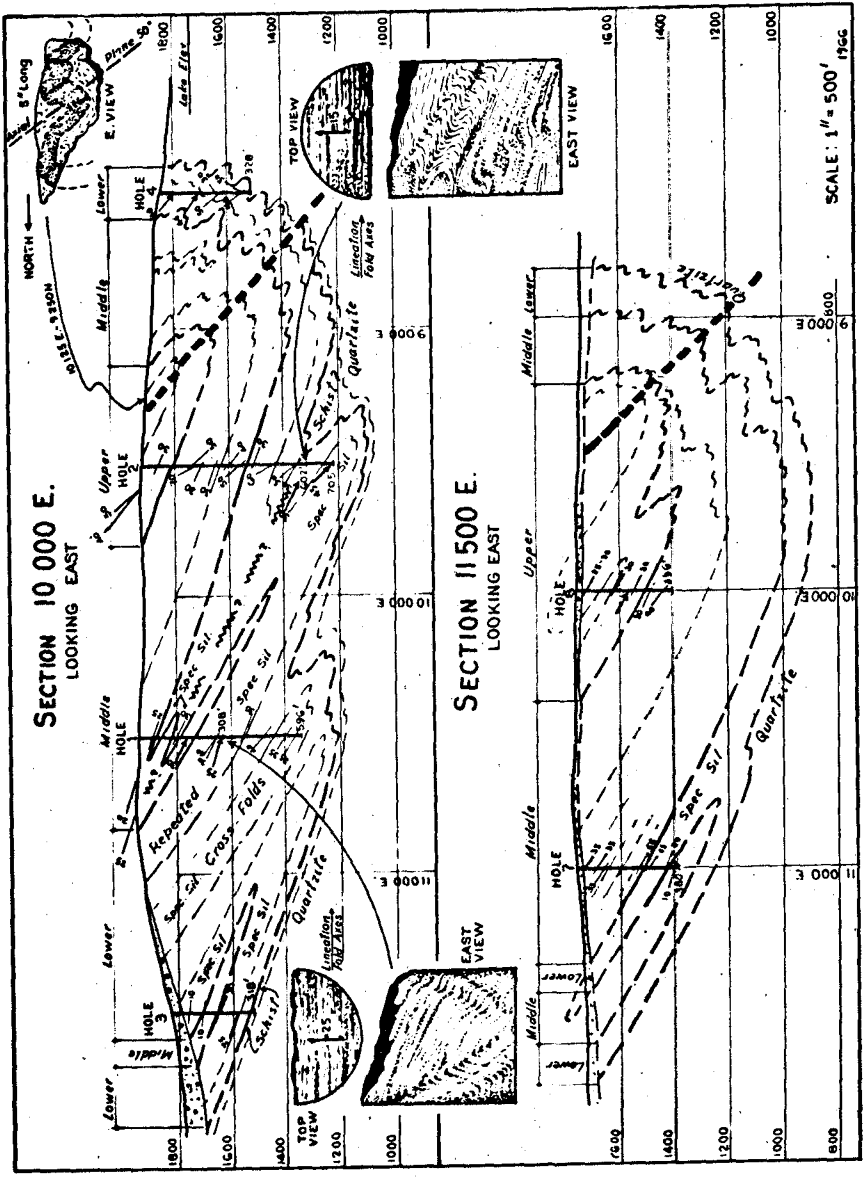
A similar, though less pronounced feature, is expressed by the surficial geometry. North limb dips are in the 25-35 degree range and south limb dips are in the 40-60 degree range. The statistical averages are 30 and 45 degrees. On the assumption that the majority of south limb dips are derived from overturned limbs, or normal limbs angularly close to the axial surfaces, it would appear that the axial planes of the synclinal folds probably dip about 40 degrees south, at least on the surface.

The shape of the syncline at depth is a matter of conjecture, it may exist somewhat as shown or be more V shaped. The shape of the fold cannot be deduced from preferred dip information alone when the relative proportions of normal and overturned limbs is unknown. About all that can be done is to project large scale evidence to depth and fit in a reasonable fold form.

<u>Section 10000E</u>. This is the section, figure 6, that illustrates the complicated patterns that can be formed when two fold sets are present. Hole 4 penetrated to the Wapussakatoo quartzite, though no schist was encountered. Hole 2 penetrated the upper and middle members, but in the lower portion the specular-silicate member appears twice. The sketch, 602 feet, illustrates one of the concordant folds observed in the core. The core is split parallel to the lineation direction that may be assumed to trend parallel with the section.

Hole 1 encountered three bands of the specular-silicate

JULIENNE LAKE DEPOSIT FIGURE 6



rock; a sketch of one piece is included to illustrate the style of folds that commonly appear in the core. A westward inclined axial surface is indicated in this fold. The fold axes in these two specimens parallel the lineation, but the fold found in outcrop south of hole 2 is another discordant fold whose subhorizontal axis trends easterly.

Hole 3 encountered two bands of specular-silicate before reaching the schist and quartzite. The only information between holes 1 and 3 regarding the subsurface pattern is the strong northeast trending magnetic pattern. As the typical pattern related to the southeast plunging fold set is arcuate, the northeast pattern in this area might be related to synclinal folds plunging easterly. But if this is so, it offers no explanation for the repeated occurrences of the specular-silicate member in holes 1, 2, and 3, far south of the outcrop area. Outcrops in the vicinity of suspected hinge areas in the linear pattern area are scarce and a search in the area around 11500N-10500E to 10750E disclosed nothing more than south plunging lineations. A cyclographic solution derived from 38 attitudes in the area of the northeast trending linear pattern shows that axes plunging about 25 degrees along S30E could reasonably accommodate the attitude variations.

Two bands of specular-silicate are present in the northwest end of the stripped area. Further west, and in the south limb, there is only one band of leached silicate bearing iron formation. On the assumption that there is only one major stratigraphic member containing appreciable amounts of the leached anthophyllite, then the several bands cut by the drill holes must be explained by folding. The lack of evidence for easterly plunging folds, plus the evidence of southerly plunging folds throughout the deposit, strongly indicates that these "extra" bands are present due to the effects of south plunging folds.

The interpretation is that these bands are very tightly folded about south plunging axes in the style shown by the specimens on section 10000E, such that the two bands present in the stripped area appear as the two upper bands in holes 1 and 2. The lower band in hole 1 is probably the fold hinge interpreted to exist near 10000E-11300N, and the two bands in hole 3 appear to be due to another similarly folded structure that accounts for the iron formation occupying the area north of hole 3.

In brief, the interpretation is that section 10000E is a cross section with respect to the syncline in the southern part and upper portions of holes 1 and 2, but that it is also a longitudinal section with respect to the south plunging folds.

<u>Section</u> <u>11500E</u>. This section lies east of the zone in which the arcuate pattern is strong and is probably about normal to the syncline. The interpretation of the syncline's shape is speculative due to the existence of only two drill holes which do not cut the same members. Hole 8 locates the ferruginous quartzite in the upper iron formation. Hole 7 has cut one band of specular-silicate and probably would have cut another at depth judging from the amount of iron formation that is present to the north, where the magnetics suggest some sort of southeast trending subsurface pattern. Hole 9 on 13000E adds nothing to the structural picture and is not presented.

Folds and Patterns

The scarcity of attitudes in the stripped area reflects the fact that although bulldozers create more exposures, they also ruin the little third dimensional relief there is. The exposures are very dirty and it is difficult to observe anything other than foliation trends and mineralogic composition. The situation with respect to the folding suspected in the northwest end of the stripped area led to a cleaning project in the fall of 1966. Several spots were cleaned with a shovel and broom; three places were located where folds could be observed.

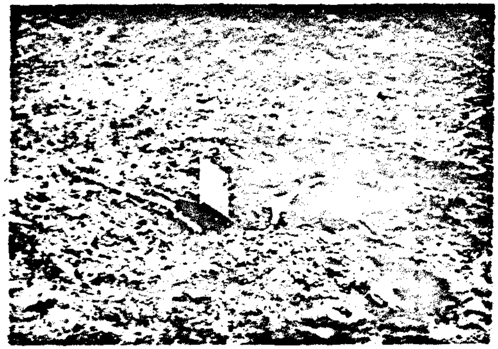
The fold located at locality A is shown in figure 7a. The fold is marked by the trace of the specular-silicate layers on the gently northwesterly sloping surface. One bed of specular hematite rich material was outlined with paint for the pictures. Pencils were placed in various parts of the fold area parallel with the lineation exhibited by the leached silicates on the foliation surfaces. The clip board was placed in a position approximately representing the configuration of the fold and with its hinge oriented so as to trend about parallel with the lineation expressed at the hinge. Lineations varied between about S10E and S10W in the area uncovered. The picture faces S10W towards the man who is standing on outcrop B. Figure 7b shows fold A looking southeast along the axial trace to show the near parallel plunge of the lineations. Lineations appear everywhere in this outcrop, the pencils are merely a sample. This is considered as a concordant fold as subsidary fold axes were found to be parallel with the lineation.

South plunging crenulations are found in the lineated specular-silicate about halfway between outcrops A and B. A weak fold or roll is found at outcrop B in which a lineation is exhibited in nearly silicate free quartz-specular rock. Figure 8 shows this outcrop looking east. The roll is not developed well enough to yield a reliable

Figure 7a

Locality A, looking S10W
Concordant Fold

Figure 7b



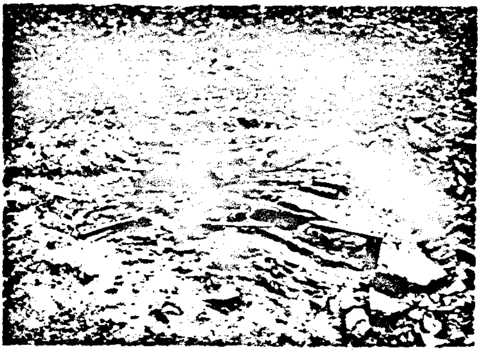
Locality A, looking southeast
Pencils parallel lineation

geometric solution for the attitude of its axis, but it appears to plunge about 20 degrees easterly. The lineation attitude is represented by the sticks that trend S10W. The lineation plunges from a few degrees south through horizontal to a few degrees north. This is considered as evidence of the plunge of lineation being dependent upon other folds and the roll is discordant with respect to the lineation.

Figure 9 shows another concordant fold. It is seen in the south side of test pit 1 at 9770N-10850E. The darker areas are specular hematite rich rock, the lighter areas are composed of quartz-specular hematite sand. The pencil is oriented parallel with the ubiquitous lineation. The folded layer is marked and exhibits an M shaped intrafolial pattern in which the axial traces lie in the acute angle between the two preferred attitudes of the foliation surfaces, one of which is more prevalent than the other. The surrounding outcrop area exhibits evidence of two or more prevailing schistose orientations that cross each other in the lineation. The outcrop is crenulated on a very small scale and compositional layering is nearly absent.

These, and the preceding illustrations show several of the small concordant folds contained within the deposit. Most of the south plunging folds are too large to be directly observed. Some folds observed in outcrop are open folds in

Figure 8



Outcrop B. Discordant Fold
Sticks parallel lineation orientation.

Figure 9

Test Pit 1. Concordant intrafolial fold.
Pencil marks lineation.

which the limbs change strike through about 40 degrees or less, those illustrated are tighter forms. The surficial patterns produced by these concordant folds are arcuate or sublinear. The existence of many similar, larger scaled concordant folds could accommodate the displacements required to produce the arcuate pattern indicated by the distribution of the stratigraphic members, and the variations of attitudes observed from place to place.

Interpretation

Superposed Folds

The interpretation is that a large, overturned, appressed syncline exists which is constructed of innumerable, subisoclinal folds that are too large to be directly observed. They may have shapes somewhat similar to that seen in figure 3. The limbs of these folds are probably planes and one limb cannot be distinguished from the other except for the tendency of the overturned limbs to be more inclined than normal limbs. The axial plane of the syncline trends easterly and the fold axes are predominately subhorizontal. The lineation appears to be down dip with respect to the major portion of the polar maximum in the orientation diagrams, and could be interpreted to be subnormal to the fold axes of the syncline. The lineations are not down dip in many outcrops however and certainly are not normal to the discordant fold axes in figure 3. With only three small discordant folds discovered, it is impossible to determine what the actual relationships are between the lineation and the axes of the syncline. The lineations in plane foliation laminae acquire their plunge from the intersection of some nonvisible surface and the attitude of the foliation surface upon which they are formed. As in the fold of figure 3, where the foliation attitude is a function of a fold form whose axis is not normal to the lineation, it is believed that the lineations and the concordant small folds are structures superposed upon the syncline, at least in space if not in time.

The superposed folds are preferentially developed in the north limb of the syncline, which was probably formerly subplanar. This is in agreement with the geometric requirement that cylindrical superposed folds must be smaller than the folds from which they have formed. They must have formed from the planar limbs of the larger folds if they are to exhibit monoclinic or higher symmetry in their poles to foliation distribution.

The superposed folding produced an antiform that plunges south, down and within the north limb of the syncline in the general area between holes 2 and 5. The corresponding synform is situated in the northeast part of the north limb. The synclinal folds probably plunge gently northeastward between the antiform and the synform, as at locality B, so that the bottom of the syncline lies at a greater depth east of the superposed antiform. This is probably the principal reason why the deposit is 1200 feet wider to the east than to the west. It reflects the approximately 300 feet of amplitude between the antiform and synform hinges as indicated from a structural profile examination of these forms.

The superposed folding did not seriously affect the south limb of the syncline as indicated by the more linear pattern and the lack of elongation in the orientation diagram. Most of the metamorphically introduced veinlets of quartz and iron oxides are found in the hole 4 area, and some occupy north trending fractures.

Movement

The few concordant folds small enough to be directly observed are similar folds and appear to be flow folds. However, many are exposed over such short axial trace distances, or are so open that their full scale form can seldom be observed. Passive, cross foliation flow is believed to be the predominating mechanism responsible for the superposed folds.

The quartz-specular-silicate rock seems to be the most highly deformed variety, though simple quartz-specular is also highly deformed. Although no folds are observed in the specular-silicate at 11500N-10500E, the rock is very schistose and exhibits a strong foliation fissility not seen elsewhere in the deposit. The rock contains features suggesting strong shear movement in the foliation planes, compositional banding appears to have been "wiped out". No direct evidence of the sense of movement is shown except that the south plunging lineation probably represents some directional component of the movement picture.

A fault was found in a small exposure in the stripped area near 9160N x 10000E. The fault is exposed for about a foot along its generally west strike and for about a half a foot along its undulose, gently south dipping surface. It is a post metamorphic fault and the red hematite gouge exhibits plucked slickensides indicating that the north side has moved along minus 15 degrees, S55W.

Breccia is seen in a few places, the fragments are normally recrystallized quartz-specular or granular hematite rocks. They are interpreted to be breccias formed syntectonically with respect to the high rank metamorphism because the space between the fragments is filled with quartz, crystalline hematite, and goethite probably derived from magnetite. The breccia zones parallel the foliation and do not exhibit evidence of significant displacement.

The hard, fine grained, blue hematite bands behaved brittely during deformation. They locally are completely shattered into innumerable fragments that fit together like pieces of a puzzle. Specular hematite usually cements these pieces together.

The kinematic interpretation of lineations in passively folded rocks has long been a subject of controversy, the problem usually involves the question of whether the linear fabric elements represent the "a" or "b" direction of the movement picture. The total fabric geometry, the scale of homogeneous movements, the geometry of various strains and the mechanisms of deformation should be examined to properly interpret the kinematic meaning of lineation. Knowledge on these subjects is presently too limited to permit rigid interpretations of naturally deformed rocks.

For the general situation of pure, passive, cross foliation flow, the axes of folds and other linear fabric elements need not have any axial kinematic significance and they may be inclined to both the "a" and "b" kinematic axes, Ramsay, (1960), p.89, Turner and Weiss, (1963), p. 485. In this situation, the deformation plane need not correspond with a fold form symmetry plane, though it may correspond with a sub fabric plane such as the lineation plane. The symmetry of the fabric may be the same as the symmetry of movement, but if the fabric contains asymmetric inherited fabric elements, the total fabric will have symmetry lower than the symmetry of movement, Turner and Weiss, (1963), p.388.

If however, the lineations represent kinematically active physical anisotropisms, as when flexural deformation is accompanied and followed by slip-flow on surfaces inclined to the bedding-foliation, and with the formation of axial plane cleavage-foliation and crenulation-lineation at the intersection with bedding, such lineation is kinematically significant. In this connection, Turner and Weiss, (1963), p.494, write, "where crenulation lineation maintains a constant attitude over areas of many square miles and is even the dominant element of a monoclinic tectonite fabric, as in parts of southern New Zealand, it may be identified with confidence as the "b" kinematic axis". On the other hand, if the folding has predominately been by passive flow, the kinematic significance of lineation is ambiguous.

In the Wabush Lake area, where amphibolite rank metamorphism is widespread, mesoscopic slip surfaces are lacking. Deformation has apparently proceeded by flow mechanisms on a microscopic scale. It is concluded that the lineation alone has no identifiable relationship with kinematic axes where evidence is lacking to demonstrate what the directions of glide or external strain movements were within the body in space, scale, and time. The presence of a lineation that is perhaps a late stage mimetic recrystallization feature need not have any kinematic significance in relation to the several directions of transport that probably operated variably in scale, time, and orientation to produce the bulk movements expressed by the form of the folds.

The orientation of kinematic "a" could be examined if there were a significant number of partially reoriented early fold axes present. The plane, in passive deformation, containing such reoriented linear elements should intersect the superposed axial plane in kinematic "a", Ramsay, (1960).

If kinematic "a" consistently lies somewhere in the superposed axial surface, inhomogeneity of movement direction is expressed by the non uniformity of orientation of these axial surfaces. The axial traces of the large, open folds trend north to northwest, while the axial traces of the intrafolial folds trend westerly as in figure 9, and presumably also in the hole 1-3 area. Whether these different fold forms represent genetically different deformations or related deformations is not known. Perhaps the northwest trending axial traces locally curve westward to merge with the intrafolial axial traces.

The orientation of foliation surfaces is changed by differential flow during passive deformation such that the poles to foliation migrate toward the pole to the axial plane along great circle paths; the effect is apparent rotation about the fold axes, not physical rotation as a cause and migration of the pole an effect. The apparent rotation is shown by the elongation of the poles to foliation distribution from some initial distribution. If the syncline was formed of cylindrical plane folds with subhorizontal axes, the initial distribution should ideally have been longer in the dip dispersion direction than across the distribution and would have exhibited orthorhombic symmetry by bisection of the polar maximum. If they were somewhat non-cylindrical plane folds, the pole to foliation distribution may have been more circular in form and would have exhibited axial symmetry. The passive development of superposed cylindrical folds whose axes plunge south on the variously dipping foliation surfaces would have elongated the initial pole distribution along a family of great circle paths that occupy a range equal to the dip dispersion. No unique axis of superposed folds exists, though a preferred axis appears that is derived from the center of the initial distribution.

When the superposed folds are fairly open, with the limbs limited to about 30 degrees of being normal to the superposed axial plane, the elongated distribution is limited to about 60 degrees from end to end and contains the inherited polar maximum. The symmetry remains orthorhombic when the superposed axial plane is parallel with the dip dispersion plane of the early folds. The symmetry is also partially monoclinic with respect to those poles that have been significantly rotated beyond their initial distribution. The orthorhombic symmetry would reduce to monoclinic only if the foliation orientations were such that their poles were uniformly distributed along the length of the elongation, or the two fold sets were asymmetric with respect to each other.

The large scale intrafolial pattern in the hole 1-3 area, contrasted with the arcuate pattern found elsewhere, is difficult to understand. It would appear to represent folding on a large scale in the style exhibited in figure 9. This would suggest a large component of westward apparent movement of the lower beds. While the genetic relation of the intrafolial pattern to the arcuate pattern is not shown by the available evidence, a sequence of events can be imagined whereby differential lateral displacement, perhaps by interlayer slip-flow, occurred approximately normal to the south plunging axes fairly early in the superposed folding sequence of events. This may have primarily affected the lower members of the iron formation situated near a boundary condition. The muscovite schist exists immediately below these intrafolially folded and perhaps strike slip faulted members. A difference in rheologic behaviour could be expected in the schist lying between massive iron formation and quartzite, and the schist may be much more severely folded than the iron formation. It is hard to imagine how these large intrafolial folds could have developed concurrently with or later than the more open arcuate folds seen elsewhere in the deposit.

The small scale intrafolial folds in figure 9 may be a small part of the larger, arcuate pattern, fold in the area. Although the direction of flow in the figure 9 fold is not known, the shape of the fold would suggest that movements were largely subhorizontal in the axial surfaces and may well have been about normal to the pencil that marks the lineation.

Space and Time Considerations

The statement was made that the lineations lay in a plane in the fold shown in figure 3. For the deposit as a whole, it cannot be shown that the lineations lie in a plane because of the lack of north dipping foliations in which the lineations should plunge.

The directional scatter of the lineations is believed to be due to the nonplane form of the superposed axial surfaces. If they range between about N30W - vertical, to north - vertical to dipping 60 degrees west, the intersection with foliation surfaces that dip south through a range of 40 degrees would lie between about S70E to S20W as observed.

There appears to be a definite tendency for the lineations to trend about 15 degrees west of the foliation intersection axes and most of the observed concordant fold axes. This might be interpreted to mean that the superposed fold axes are not parallel with the lineation. The lineation surrounding some concordant folds is closely parallel with the fold axis as best can be measured; but in others, as in figure 7a, the lineation is somewhat variable in direction. The writer has not been able to find a concordant fold that could be excavated far enough to see if the lineation is or is not closely parallel with the fold axis for any significant distance along the axis.

There may be several reasons for the apparent tendency of the lineations to lie somewhat west of the fold axes.

1) The domains may extend beyond smaller areas where the lineation and fold axes may be closely parallel.

2) The possibility that the lineation orientation may

to some extent be inherited from or otherwise related to the folding that formed the syncline and that this feature is only subparallel with the superposed fold axes.

3) The fabric geometry resulting from fold movements may not be quite conformable with the geometry of concurrent recrystallization lineation.

4) The lineation may be genetically later than the folding and is a mimetic tectonite fabric feature whose geometry was slightly different than the folding tectonite geometry.

A certain degree of inhomogenity of geometric relationships is to be expected in a superposed fold situation, Weiss, (1959), especially when the scale of examination is larger than the scale of the early folds. For all practical purposes, it is concluded that the presence of a prevailing statistically homogeneous lineation is sufficient to indicate the existence of a deformational event characterized by linear geometry. If the attitude variations yield intersection axes generally parallel with the lineation, then both of these fabric elements are likely a product of such a fold system and the resulting patterns indicate the fold form.

Where such fabric is shown by other evidence to be geometrically and physically discordant with respect to larger folds, then the concordant folds were imposed upon the larger folds and folds superposed in space are present. The deformational sequence is believed to be as follows:

1) The development of the syncline with subhorizontal axes now trending east and whose axial plane dips south. Although the south limb stands about vertically, the foliation surfaces dip south in a range of about 40 degrees. The folds were probably nearly cylindrical plane folds with a similar form and a sublinear surface pattern.

2) The development of superposed, cylindrical folds whose axial surfaces are nonplane and seem to be variously oriented with respect to folds of either arcuate or intrafolial pattern. The fold axes trend south and take their plunge from the inclination of the foliation surface on which they have formed. The folds are passively folded similar folds related to antiform and synform structures preferentially developed in the north limb of the syncline. The foliation attitudes vary systematically, exhibit partially developed monoclinic symmetry of orientation, and describe intersection axes generally parallel with observed south plunging small folds. The superposed axial plane suggested by the orientation tends to coincide with one of the symmetry planes of the early fold system, and the two fold systems are approximately normal to each other.

3) The formation of a late stage, mimetic fabric that is parallel to subparallel with the superposed fold axes. The small folds whose axes are about normal to the lineation are probably small folds of the syncline if the lineation represents superposed kinematic "b" axes. If the lineation represents kinematic "a", the small discordant folds may have formed syntectonically with the superposed deformation. For this reason it is difficult to interpret age relationships before examination of the regional structural pattern.

It is reasonable to conclude, however, that the superposed fold stages are related generations of the orogeny that affected the Grenville province. The lineation is a metamorphic recrystallization feature widespread throughout this part of the Grenville province where amphibolite rank metamorphism is common. Whether or not the syncline is related to this orogeny is not shown by any evidence yet discovered within the deposit.

REGIONAL STRUCTURAL SETTING

General Information

The existence of cross folds in the Wabush Lake - Mt. Wright district was recognized by the writer and his associates during regional mapping programs in 1956 and 1957. A set of small weakly developed folds whose linear elements trended northwest-southeast were interpreted to be older than a prominent set of larger folds trending northeasterly in the paper by Gastil and Knowles, (1960). The age interpretation was based upon scale, relative development, and trends subparallel with the northeast trending Grenville front and the much older, northwest trending fold system in the central Labrador trough.

A small deposit of iron formation southwest of Mt. Wright was found to be tightly folded about axes parallel with a metamorphic lineation plunging southeast during a drilling program in 1958. The 1959 investigation of the Julienne deposit disclosed that the northwest trending fold set, with southeast plunging folds and lineations, was superposed upon the northeast trending fold set. This led the writer to suspect that the age relationships between the two fold sets was the reverse of that previously held. Subsequent work at another locality southwest of Mt. Wright disclosed that a much larger deposit existed whose form was highly dependent upon fold axes parallel with a northwest plunging lineation, but whose surficial trends were both northwest and northeast.

Recollection of southeast trending lineations in many parts of the Wabush Lake area led the writer, in view of the above mentioned features, to suspect that the northeast trending fold set might be the older and that the northwest trending fold set might be more widespread than had been previously recognized. The regional structural analysis examines this suspicion.

Several regional mapping programs were conducted in the Wabush Lake area during the period from 1950 to 1958. These programs were sponsored by exploration companies for the general purpose of evaluating the iron formation. Fahrig, (1960), examined the area in 1959 as part of a regional mapping program for the Geological Survey of Canada. Local investigations have been conducted in recent years in some areas related to mining operations.

The results of the work of many geologists appear in numerous private and public reports and maps on scales as large as 1000 feet per inch. Regional aerial magnetics were available to some to help interpretations. The geologic information contained in these reports and maps has been examined by the writer to compile the geologic map enclosed.

Although there are some parts of the map area where the geology is but poorly known, the general geologic construction of the area is sufficiently well defined to support a qualified structural examination.

To the writer's knowledge, none of the geologists working in the area gave serious attention to the lineation. Many recognized the presence of two fold sets but were unable to devote the time to examine the relationships. The regional and local maps available to the writer do not contain information about lineations, only a few of the more obvious folds appear upon the maps.

The writer spent about 10 days in August and September 1966 visiting localities in accessible parts of the area to specifically examine outcrops for structural information. About 100 localities were visited, 95 exhibited lineations or folds with axes parallel with the local lineation. These localities, plus nine localities where fold axes were shown on old regional maps, are shown in bold symbols on the regional map.

The number and distribution of the localities visited is but a small sample of the innumerable outcrop areas where fabric data is available for examination. The fact that none of the localities visited exhibited lineations trending in any direction other than southeast or northwest, combined with previous observations, convinced the writer that sufficient information is available to justify the regional examination and that the two fold sets are real structural features present throughout the area.

Regional Geology

The formations are regionally distributed in such a manner that six northeast trending zones, each characterized by a particular general geologic construction, may be distinguished on the map.

Geologic Zones

Zone 1 contains large bodies of Shabogamo gabbro surrounded by coarse grained granulite and biotite gneiss. The granulite locally appears in the lit-par-lit biotite gneisses in zone 2 where little gabbro is found. The gneiss in zone 2 represents the Katsao formation; and lacking evidence to the contrary, all gneiss in Zone 1 is interpreted to represent the Katsao formation.

Zone 3 contains much lake and lowland areas. The Duley marble underlies most of this zone along the east side of Wabush Lake, no other formations appear in the exposed portion near Lake Leila Wynne. The existence of the marble in Shabogamo Lake is inferred from the physiography and lack of magnetic anomalies. It outcrops a mile east of the northeast corner of the map.

Zone 4 contains ridges and valleys of tightly folded Katsao, Wapussakatoo and Wabush formations, plus isolated gabbro intrusions and one band of gneiss believed to be the Nault formation. Zone 5 is largely lowlands underlain by folded Wabush and Nault formations. Several areas of granitic gneiss appear along the southeast side that are probably granitized Nault rocks. The biotite isograd, recognized by Fahrig, (1960), trends northeasterly, perhaps in a more irregular manner than shown. Areas of gneiss, believed by Fahrig, (1960), to be outliers of the charnockitic basement gneiss of zone 6, are found to be surrounded by iron formation and graphitic argillites and arenites of the Nault formation northwest of the biotite isograd.

These zones continue for many miles to the northeast and southwest and are an expression of a major stratigraphic-structural unit that is present throughout the entire district between Mt. Wright and Sawbill Lake, figure 1. Occurrences of marble and iron formation in the Katsao in zone 2 are believed to represent down folds of these overlying formations. As the stratigraphic sequence is Katsao, Duley, Wapussakatoo, Huguette (not shown on the map), Wabush, and Nault; and the distribution of the sequence is older on the southeast to younger to the northwest, the formations appear with a reversed sequential distribution that is probably due to structural reasons. Pronounced breaks appear in the boundary between zones 2/3 and 4/5 where younger formations appear on the northwest side. These may be expressions of folds that are deeper on the northwest side, or easterly dipping thrust faults.

Interfolded Formations

That zones 4 and 5 contain large scale, regional folds whose axial traces trend generally northeastward is expressed by the distribution of interfolded formations. The formations occupying the limbs of these folds trend generally parallel with each other across the countryside for distances measureable in miles. The general pattern, expressed particularly by the iron formation, is characterized by long, continuous isolated bands lying between older formations, and which only locally are connected in hinge areas with the next band of iron formation.

Although the surficial pattern alone is incapable of demonstrating whether the axes of these folds are generally subhorizontal or steeply plunging, the general lack of connections between bands of iron formation suggests that subhorizontal axes may predominate in many parts of the area. The Julienne fold is believed to be a syncline with subhorizontal axes, the iron formation occupying the core of the syncline can be traced continuously for over 15 miles. It's continuity under Wabush Lake is shown by aerial and surface magnetic anomalies, it has been cut by two drill holes, and it forms the Wabush Mountain deposit three miles south of the map area.

Large scaled, similar folds probably exist in areas containing only one formation, such as in the marble, the Katsao of zone 2, and the large areas underlain by iron formation northwest of Shabogamo Lake. The formations may be so thick, or the erosional level is such that the overlying or underlying formations do not appear at the surface. Dip slopes are partly responsible for some of the large areas underlain by the Wabush formation northwest of Shabogamo Lake. Interfolds would appear on the map of this area had the writer been allowed to distinguish between the upper and lower Wabush formations. This distinction has been shown in the Wapussakatoo Mountains through the courtesy of the Iron Ore Company of Canada. Most of the folds in this northeasterly trending system are overturned towards the Superior province.

Structural Pattern

The distribution of the formations across the map area forms a surficial structural pattern characterized by sublinear trends that become arcuate somewhere along their extension. They are so arranged within the map area that they appear to be only a part of a larger, regional arcuate pattern outlined by the distribution of the Duley formation. The northwest trending zone in which the arcuate pattern is consistently convex to the northwest is herein referred to as the Julienne depression; the zone in which the convex side faces southeast is called the Shabogamo rise and is situated 6 miles to the east.

The regional arcuate pattern is similar with the arcuate pattern exhibited at the Julienne deposit. The difference is one of scale plus the fact that the regional pattern also includes expressions of the interfold pattern related to the northeast trending fold set whose limbs variably trend from north through northeasterly to east and southeast, then back to northeast proceeding from southwest to northeast across the map. The dips indicate that the interfolded formations are usually overturned to the west, northwest, north, or northeast. These general observations lead to considerations of a regional, northwest trending fold set that may be superposed upon the northeasterly trending fold set.

Regional Structures

The area has been divided into fifteen subareas that each exhibits a particular pattern. These domains are larger than the scale of the interfolds and the fabric geometry can only suggest the general nature of the geometric relationships.

Area A

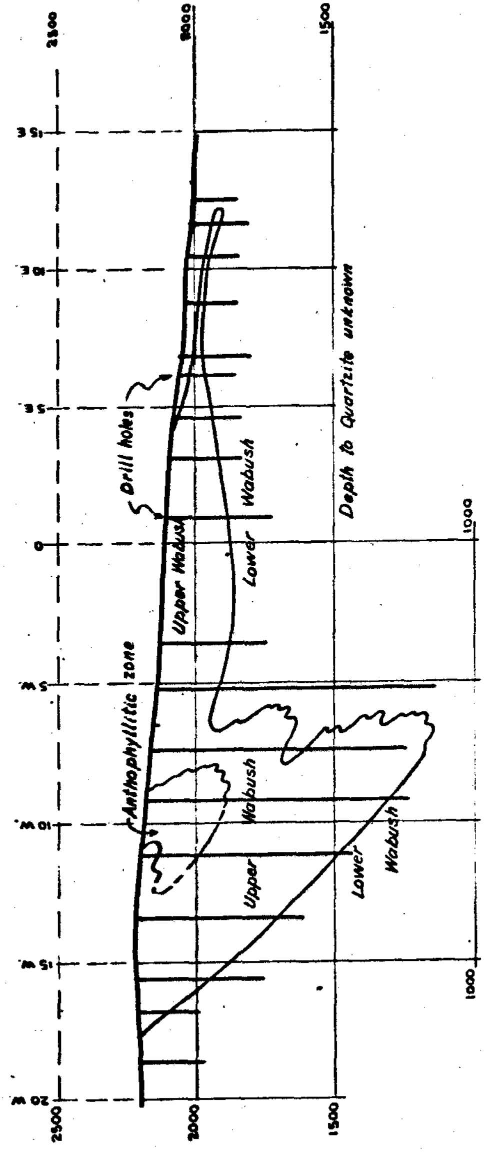
The geology of the Wapussakatoo Mountains is known better than any other part of the Wabush Lake area. Exposures are plentiful in the highlands, and considerable drilling has been done in local areas. Mining operations have been conducted on the Smallwood deposit for several years.

<u>The Smallwood Deposit</u>. The Smallwood deposit is a deep, overturned syncline flanked on the southeast side by a nearly recumbent fold form. There may be a fault between the syncline and recumbent forms. It is underlain by the lower Wabush formation except for a portion along the northwest limb where gabbro is present. The deposit strikes about N50E and most foliation surfaces dip southeast. A representative cross section in the center of the fold is shown in figure 10.

Mr. George Hamilton conducted a structural examination of the south knoll of the deposit in 1962 after the overburden had been stripped and washed off. The south knoll is the area covering the widest part of the deposit situated mostly south of section 380. He collected over one thousand attitude determinations and divided the twenty two acre area into sixteen domains. Intersection axes in each domain plunged 20-30 degrees between about N60E and N80E. Most of the seventy two observed small fold axes plunged similarly but trended in a wider range between about N40E and S80E. Three axes plunged gently southwest and five plunged about 40 degrees to the southeast. Examination of cross sections of the deposit demonstrates that the bottom of the syncline becomes nearly horizontal near section 380 and plunges gently southwest further northeast. The writer visited nine localities in the mine and its immediate vicinity. The lineation on the foliation surfaces at each locality was southeast over all parts of the exposures examined.

The 2100 foot bench of the mine exposed a face several hundred feet long in the anthophyllite bearing quartz-specular hematite iron formation. Examination of this face showed that the lineation described by the parallel orientation of clusters of anthophyllite trended within about 10 degrees of S25E everywhere along the length of the face. Examination part way up the 50 foot high face showed that

FIGURE 10



SMALLWOOD MINE
SECTION 380
Looking N.20 E.
Scale 1"=500'

Courtesy of I.O.C.C.

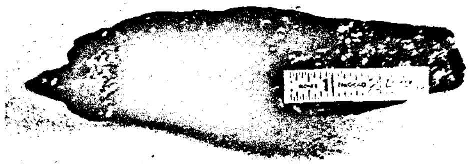
the lineation direction remained nearly constant vertically as well. Thousands of lineations exist in this rock, but directional references at a few places are sufficient to determine the azimuth of the lineation suite. A lineation is also expressed in normal quartz-specular hematite rock.

The plunge of the lineations is not constant. The plunge is as variable in the lineation planes as the folded foliation surfaces are in dip. At the location exposed at the time of the visit, the predominating foliation surfaces dipped between 10 and 30 degrees S25E, but there were numerous small folds present in which the lineations plunged at various angles while maintaining the uniform directional orientation.

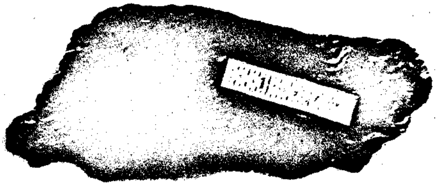
The axes of most of the small folds trend subhorizontally northeast, parallel with the strike of the foliation and nearly normal to the lineation plane. The fold forms include well developed crenulations, open folds, kink bands, and appressed folds. The foliation and lineation follow the fold form and the axial planes dip around 45 degrees southeast. Other small folds are found whose axes plunge southeast. Three specimens are presented to illustrate the fabric features.

Figure 11 shows a kink band in anthophyllite bearing quartz-specular hematite iron formation. The top view shows

Figure 11



Top view



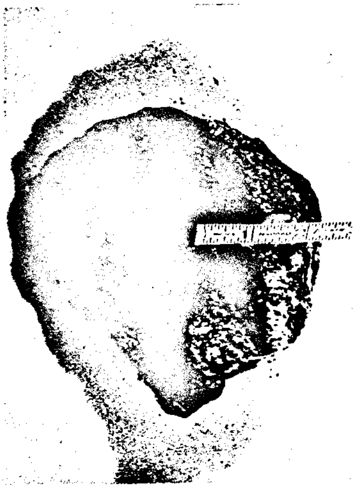
S.W. end view
Kink band in anthophyllitic quartz specular
hematite iron formation
Smallwood Deposit

the prominent anthophyllite lineation. The anthophyllite clusters curve part way around some hinges, in others the crystals are straight and meet at sharp angles. Figure 12 shows another fold from this locality. The scale lies approximately parallel with the lineation plane in each picture.

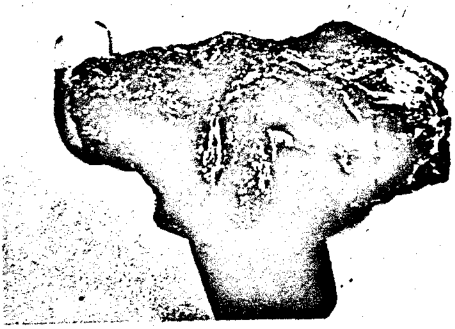
Figure 13 illustrates another fold; there is very little anthophyllite in this specimen. The scale in the top view is parallel with the lineation which is actually a micro-crenulation parallel with the fold axis. The southeast view shows this fold from about 20 degrees above the fold axes, the scale is oriented approximately parallel with the axes of the folds shown in figures 11 and 12.

The fold axes in figures 11 and 12 are discordant with respect to the lineation while the fold in figure 13 is concordant with respect to the lineation. The specimens of figures 11 and 12 were about 100 feet apart along the bench and the axial plane of each fold dipped about 45 degrees southeast. The lineations lie in planes approximately normal to the fold axes, but the most commonly exhibited lineation plunges 10-30 degrees along S25E and lies in the upright limb of the fold. The specimens of figures 11 and 13 were about six feet apart and the lineation direction of each fold was S25E. The plunge of the concordant fold of

Figure 12



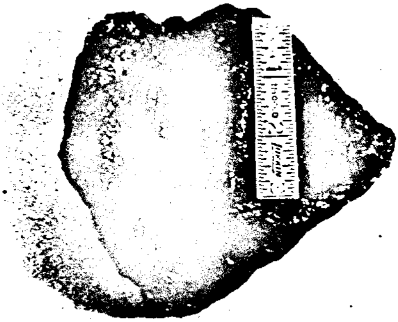
Top View



S.W. End View
Appressed fold in anthophyllitic
quartz-specular hematite iron formation
Smallwood Deposit

Figure 13

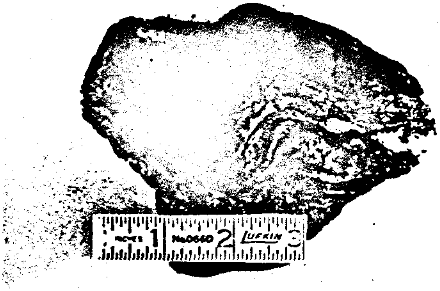
N.E.



S.W.

Top View
Micro-crenulation lineation in
foliation surface

N.E.



S.W.

View looking southeast
nearly parallel with fold axis
quartz-specular hematite iron formation
Smallwood Deposit

figure 13 was about 30 degrees.

The age relationships between these folds are unknown. The folds of figures 11 and 12 might be small folds of the syncline and the lineation superposed, or if the lineation represents flow movements in the lineation plane, the folds might have formed during the superposed folding. It may be that the kink band of figure 11 is a superposed fold and the appressed fold of figure 12 is an early fold. Some geologists might consider that there are two folds present in the specimen of figure 13, an early, somewhat attenuated isoclinal fold whose axial surface trace is shown by the quartzose zone in the right half of the specimen, plus a later wave like fold whose axial plane dips steeply southwest. They might suggest from this that the earliest folds in the area plunge southeast. It is the writer's opinion that there is only one fold in the specimen and that the quartzose seam represents silica introduced during metamorphism. The fold itself could be a synclinal fold reoriented through about 90 degrees, or, as seems most likely to the writer, a fold developed during the period of superposed deformation.

It is difficult to visualize how the folds of figures 11 and 13, which share a common lineation plane, could both be folds of the same deformational event. The situation is similar to that at the Julienne deposit where an interpretation of age relationships between concordant and discordant folds is dependent upon the kinematic significance of the lineation. The interpretation of age relationships to be brought forth later, is based upon regional, large scale spacial and physical relationships rather than isolated small scale features whose structural significance is ambiguous.

A deposit known as the north outlier is situated immediately northeast of the Smallwood deposit. The two deposits are separated by a band of lower Wabush formation. The north outlier is known from drill hole information to extend under the Smallwood deposit, and is separated from it by the band of lower Wabush formation as far southwest as section 396. The shape and underground extent of this lower body has not been established and the structural relationships between the Smallwood syncline and the north outlier are unknown.

Figure 14 illustrates part of the largest natural exposure of the northeast trending folds known to the writer. The exposure is on the southeast side of the north outlier. The face is a nearly vertical joint surface trending southeast; the picture faces southwest. The fold is anticlinal and exhibits the low dips found in the southeast limb of the nearly recumbent structure responsible for the shelf in the Smallwood Mine. The fold is bounded on the northwest by a fault zone about a foot thick containing very coarse specular hematite with very little quartz and is probably a premetamorphic structure. The fault dips about 60 degrees southeast and strikes parallel with the southwest trending foliation. The iron formation above and around the fold is well exposed and exhibits an ubiquitous lineation trending S30E. Examination of the face shows that the lineation follows the folded foliation surfaces so as to lie in a plane approximately parallel with the plane of the photograph.

Figure 14

Discordant Fold
Smallwood Deposit, North Outlier

Faint laminae dipping about 40 degrees southeast can be seen in the picture. These laminae appear to represent the remains of axial plane cleavage. This is the only instance known to the writer of any fabric element other than bedding foliation having survived amphibolite rank metamorphism in the Wabush Lake area. These surfaces are foliated and are mineralogically lineated in the same manner as the rest of the rock, and the lineation on these surfaces trends parallel with the lineation that appears in the folded foliation surfaces.

The <u>entire</u> knob that forms the hinge of the north outlier exhibits southeast trending lineations on foliation surfaces that strike and dip in all directions. The hinge area is intensely deformed, southwest and southeast trending strikes predominate, and the lineation <u>direction</u> is clearly the only homogeneous fabric element.

About 200 feet northwest of the fold in figure 14, the folds shown in figure 15 were found in the hinge area. There are folds with two different geometries present in this picture. The fold in the center near the compass appears to be larger than the wrinkle to the right, but the wrinkle is merely a small fold within a fold too large to be included in the same photograph. The fold near the compass is actually smaller than the predominating fold which has a form similar to the fold in figure 14. The lineation throughout the entire area is S30E parallel with the tape on the left. The lineation plunges between gently southeast, horizontal, to gently northwest depending upon the dip of the foliation surfaces. The view looks down the 15 degree plunge of the concordant fold that displays left lateral displacement. The lower limb strikes northeast, dips southeast; the other limb stands vertically, but is composed partly of overturned foliation surfaces dipping southwest. The only way to describe the fold geometrically is use of line element axes, attitudes are as variable about the fold axes as one cares to look for. This fold is similar with that of figure 9.

Figure 15

N.E.

S.W.

Concordant and Discordant Folds
Smallwood Deposit, North Outlier

The tape on the right is parallel with the axial trace of the discordant fold set. The axes of this fold, and others nearby, plunge 10-15 degrees along S50W. The axial plane strikes southwest and dips southeast. The two folds share a common limb, the southeast limb of the discordant fold merges with the upper limb of the concordant fold.

Here is a situation where in one location, two folds with completely different geometry and form exist side by side and share a common foliation surface as one limb of both folds. One fold is discordant, while the other is concordant with the lineation which exists throughout the entire area and has a homogeneous S30E trend.

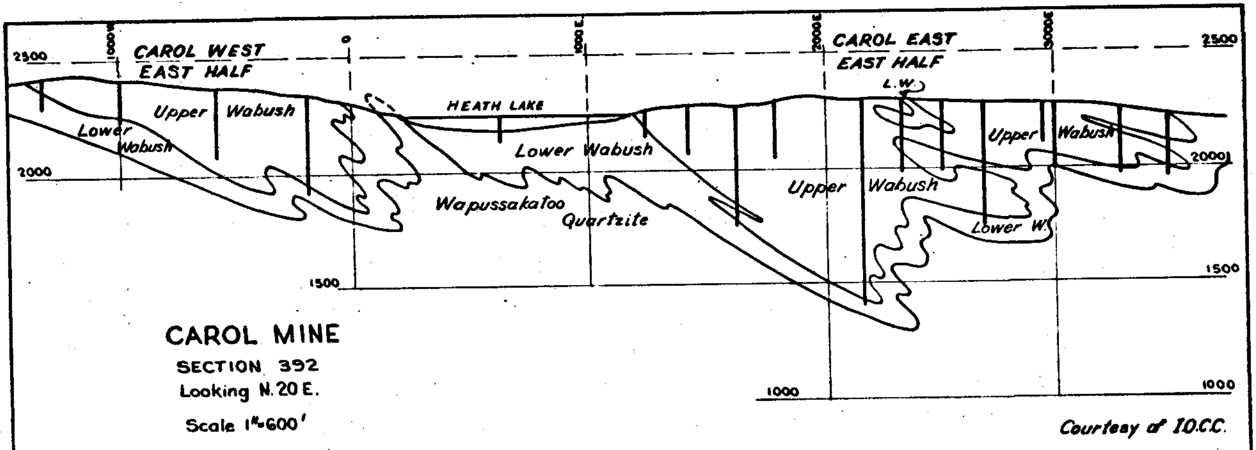
There can be little question about the sequence of folding events here. The lineation serves as a convenient marker for fold event reference. It has the properties of position, ubiquitous in the hinge area; space, directional uniformity; and time, synmetamorphic (mineralogic recrystallization) and syntectonic (parallelism of lineation and fold axes) with respect to the folding that produced the concordant folds. The lineation also exists, in space and position, discordantly upon larger folds with completely different orientation, not only upon the folded form (figure 15, right) but also upon their axial plane cleavage surfaces (figure 14). The lineation, syntectonic with respect to concordant folds, is therefore younger than the discordant folds. It is concluded that the concordant folds are truly superposed, in both space and time, upon the older discordant folds.

Carol East. The deposit known as the Carol East, east half, is the long syncline trending N25E that is situated northwest of the Smallwood deposit on the other side of the anticline which brings the Wapussakatoo and Katsao formations to surface. The relationships of this deposit to others immediately west are shown in figure 16. The shape and size of the syncline as shown is typical of the forms seen on other sections. The bottom of the syncline is approximately horizontal northeast of section 404 and lies near elevation 2000 feet to well beyond section 456. Southwest of section 404, the fold begins to plunge southerly; two drill holes in the hook southwest of section 392 penetrated over 1500 feet of upper Wabush formation.

Seven localities in this area exhibited lineations. Five localities in quartz-magnetite iron formation did not exhibit lineations. All lineations trended between S20E and S30E and plunged 30-50 degrees southeast depending upon the dip of the foliation surfaces.

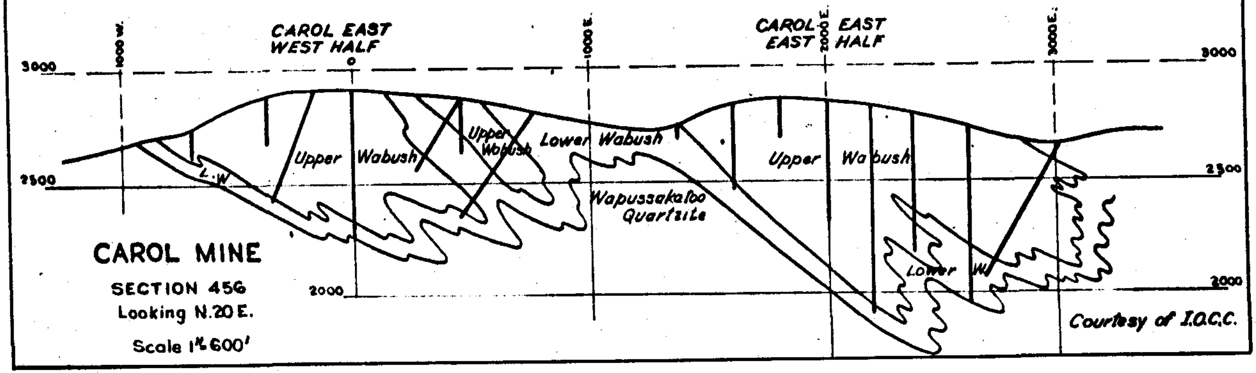
Figure 17 shows a specimen of lineated quartz-specular hematite rock from the central part of the area. The lineation is mineralogic, not broken ends of foliation surfaces. The angle of rake of the lineations is about 60 degrees to

FIGURE 16



CAROL MINE
SECTION 392
Looking N. 20 E.
Scale 1"=600'

Courtesy of I.O.C.C.



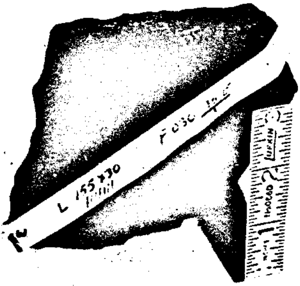
CAROL MINE
SECTION 456
Looking N. 20 E.
Scale 1"=600'

Courtesy of I.O.C.C.

the strike.

Although no folds were observed in this area, the form of the deposit virtually requires that the synclinal fold axes trend southwest and are subhorizontal to southwestward plunging. The lineation is probably discordant with respect to these axes. In order for the lineation to be normal to the synclinal fold axes, they would have to plunge 15 degrees along N25E.

Figure 17



Lineated Quartz-Specular Hematite
Carol Deposit, East half

Carol West. One other locality is worth mentioning in detail. This is the area around the north end of the Carol West deposit in the vicinity of section 392. The northwest trending arm of upper Wabush formation is tightly folded and constructed of numerous folds whose limbs strike southeast and dip steeply either northeast or southwest and rapidly change dip across the strike. A strong lineation is present that trends uniformly S20E and all lineations plunge about 35 degrees southeast regardless of the local attitude of the foliation. The only homogeneous fabric element present in this area of good exposure is the lineation. While the writer did not attempt an orientation plot of the foliation attitudes, there is little doubt but that they would intersect in space parallel with the lineation. This folded area is intensely folded about axes plunging towards Heath Lake, and extensions of the body at depth will likely conform with monoclinic symmetry as long as the fold remains smaller than the earlier fold upon which it is developed, or it was formed from.

About a quarter of a mile to the west some peculiar forms appear in carbonate iron formation near the contact with the upper Wabush formation. These forms are elliptical to circular in outline and several feet wide. They are folds of some form that plunge 35 degrees approximately S10E. They appear to have been formed by having been rolled between oppositely moving bodies.

South of section 392 a road and power line exist on the well exposed, overturned limb of the lower Wabush formation which forms the east side of the Carol West, east half, deposit, figure 16, upper left. The well lineated cummingtonite-grunerite schist is exposed for about a half mile and dips uniformly about 50 degrees east. The direction and plunge of the lineation was checked at about a dozen places along this area, directions were compared against the straight power line. The lineations plunged within a few degrees of 35 degrees along S20E everywhere in this area, and are clearly homogeneous.

<u>The Wapussakatoo Mountains</u>. The Wapussakatoo Mountains as a unit are constructed of large, northeast trending, overturned anticlines and synclines with subhorizontal axes. They exhibit a linear to locally arcuate surface pattern. The lineation trends southeast throughout the areas examined and this probably applies to the entire area.

The orientation diagram for the entire area appears on the map. Poles to foliation are distributed about a broad polar maximum. Northwest dipping attitudes opposite the maximum, and the average N20E trend of the large folds with a linear surface pattern, suggests that the set of orthorhombic symmetry planes best represents the geometry of the northeast trending fold set, the axial plane dips about 35 degrees southeast.

There is no strong elongation quality of the distribution to clearly indicate superposed fold geometry.

A superposed axial plane trending N40W and steeply inclined so as to pass through the maximum and the lineation field has been drawn. Passive flow folding may have rotated some of the poles to foliation along a family of great circle paths toward the pole of the superposed axial plane, with each path being different and dependent upon the attitude of the foliation surface involved. It is not possible to estimate how far the poles have migrated, most have probably been little affected by the superposed events. There can be no unique superposed axes, they lie in a field in the southeast quadrant. The field should be rather narrow if the inclination of the superposed axial surfaces is constant. Superposed linear fabric plunging northwest could be locally expected as was observed in the north outlier of the Smallwood deposit. The linear fabric elements are <u>not</u> down dip with respect to the maximum and conform with the raking pattern shown in figure 17.

The interpretation suggests that attitudes striking between about N55E and S40E, dipping southeast to southwest; and attitudes striking north to N40W, dipping east to northeast, may represent attitudes that have been significantly rotated out of early fold orientation by the superposed folding. Such areas would include the southwest end of the Carol East syncline, parts of the north end of the Carol

West fold, the east limb of the north outlier of the Smallwood structure, the northwest trending folds southeast of Luce Lake, and the northern part of the synclines trending along the west shore of Wabush Lake. Early structures trending between about north and N50E would appear to have not been significantly affected by the superposed folding.

Klein, (1960), and the writer have observed that lineation is not everywhere present. Two places along the west shore of Wabush Lake were found where the silicate iron formation was not lineated; the iron silicates existed in random orientation on the foliation surfaces. Both of these places were slightly south of where the name Wabush Lake is printed. The interpretation placed upon this observation, and the lack of lineations at a few other places, is that the existence of lineation is dependent, not only upon the existence of a favorable mineralogy so as to be visible, but also that superposed strain had to be of sufficient magnitude to induce a preferred mineralogic arrangement even in mineralogically favorable rocks.

The orientation of the lineation is viewed as representing the orientation of superposed fold axes had deformation developed sufficiently to produce observable folds. Small concordant fold axes are observed to be closely parallel with the lineation. The lineation plane is thus believed to represent the superposed axial surfaces. The lineation orientation is one point on these surfaces.

The trace of the regional superposed axial surfaces is best expressed by the Stevens-Luce Lake lineament. This lineament is physiographically expressed by a pronounced valley transecting the Wapussakatoo Mountains, and it is geologically expressed as a zone toward which the synclinal and anticlinal folds plunge. The formation present at the surface in this synform is the Wabush formation. It exists continuously along the length of the depression several hundred feet lower than surrounding hills that expose older formations. This is a major sized structure that cuts across the northeast trending fold set.

A northwest trending gabbro intrusion is situated at the southeast end of this depression; further to the northwest, gabbro again appears in the depression, but it is oriented across the depression parallel with the anomalously oriented Smallwood structure. The lineation direction in the schistose border of the gabbro is S20E, the plunge ranges from vertical to about 55 degrees and is directionally the same as the lineation in carbonate iron formation less than 50 feet away.

Iron Ore Company geologists have mapped an odd shaped, faulted structure east of the north end of Lorraine Lake.

The fault trends northwest, and northwest trending gabbro has intruded the Katsao nearby. Another northwest lineament may be present that is marked by the northeast ends of the deposits, though this is perhaps partly physiographic. It may extend from the bend in the northern part of the Carol East syncline to the hook in the aerial magnetics over Wabush Lake where some sort of a disruption in the Julienne syncline is probably present. This disruption conceivably could be a north trending fault zone extending through Wabush Lake.

Just south of the map area, the Wapussakatoo Mountains change to a more southwesterly trend and continue towards Mt. Wright. The general pattern remains similar however.

Area B

This area exhibits open to U shaped arcuate patterns. A break in the stratigraphic pattern may be caused by a fault zone between areas A and B, and one between areas B and C, though no direct evidence of these suspected faults is known. The area is underlain by Katsao gneiss containing an interfold of quartzite. The quartzite apparently thins out so that the iron formation rests directly upon the Katsao along the northwest side. Three localities are known where south to southeast plunging folds or lineations exist.

Figure 18

W.

E.

Lineated Wapussakatoo Quartzite
Wabush Lake

Figure 18 shows outcrops of the Wapussakatoo quartzite near Wabush Lake. The quartzite strikes west and dips 20 degrees south. The picture was taken N30W parallel with the southeast plunging lineation. The lineation is mesoscopically expressed as brownish colored streaks contained within the quartzite. Hand lens examination shows a slight elongation of quartz grains plus a linear arrangement of an unidentified, altered platey mineral. The altered mineral forms thin laminae in the quartzite to define the foliation. An examination of the outcrops shows that the lineation is not related to the joint pattern. One joint set appears as lines inclined gently left in the picture, the lineation is the faint streaking plunging directly towards the camera.

The orientation diagram shows two polar maxima and indications of a second pair. The distribution suggests a bilateral distribution on each side of two of the orthorhombic symmetry planes such that the center of the pole symmetry is nearly vertical. Superposed folding is believed to have rotated an early fold pole distribution, formerly located along the northwest symmetry plane, toward the pole of the northwest trending superposed axial plane to produce the northwest trending gap in the distribution. The early fold axes now plunge about 20 degrees southwest or 10 degrees northeast; they probably were once nearly horizontal and normal to the northwest symmetry plane which is interpreted to be the dip dispersion symmetry plane of the original distribution, and it is also believed to be the axial plane of the superposed folds.

The early pole distribution is spread over about 40 degrees, with the surfaces that once dipped about 20 degrees southeast predominating. Whether the early fold distribution represents gently dipping limbs of open folds with a vertical axial plane, or tightly folded, nearly recumbent folds is not known. The superposed axes should lie in a narrow field of variable plunge inherited from the early fold attitudes if the superposed axial surfaces closely followed the older symmetry plane, but this may or may not be true because little lineation information has been collected.

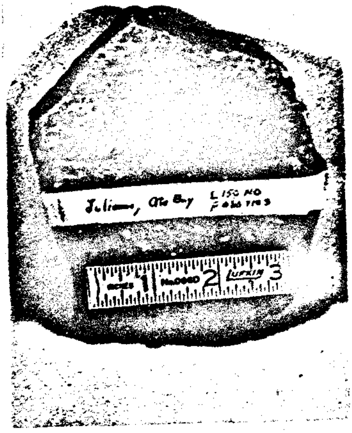
The 20 degree small circle shown about the center of symmetry is only a possibility in this diagram, but such a distribution does appear in some areas to the southeast. The folds in the area are certainly more complex than the orientation diagram would suggest. Mount Bondurant is composed of highly deformed Katsao gneiss rising over 500 feet above the quartzite to the southeast.

Area C

This area exhibits mainly east to southeast trending formations and south to southwest dipping attitudes. It contains several interfolded synclines and anticlines overturned to the northeast. Eight localities are known where southeast plunging folds or lineations exist. At the locality just south of Almond Lake, a bulldozer road has exposed a band of biotite-muscovite schist immediately below the quartzite. The schist contains a small anticlinal fold that trends northeast. Smaller, superposed folds are found on the variously dipping foliation surfaces. The lineations and fold axes lie in a vertical plane trending N10W. The linear elements plunge between 15 degrees southeast through horizontal to about 35 degrees northwest.

The quartzite outcrops near the entrance to Goethite Bay are strongly lineated, figure 19. Some time was devoted to examination of the outcrops and fragments of the rock on the beach for some clue as to the cause of the lineation, which is not due to foliation surfaces intersecting the face of the rock. No fabric element can be observed, even under a hand lens, that cuts across the foliation surfaces. Some quartz crystals are only slightly elongated. The lineation is actually an expression of small weathered out channels or grooves, as though there has been differential leaching of some mineral, perhaps a carbonate, that was once present in the quartzite in linear arrangement.

Figure 19



Lineated Wapussakatoo Quartzite
Quartzite Bay - Julienne Lake

The orientation diagram shows an elongated polar maximum that can be divided by two of the three orthorhombic symmetry planes. The dip dispersion is about 25 degrees, but there is a suggestion of a small circle distribution whose center is virtually the same as in area B. The early fold axes are indicated to plunge about 5 degrees S65W. The superposed axial surface is believed to have generally followed the northwest symmetry plane of the early folds. The attitudes have preferentially changed by apparent rotation so as to dip southwestward towards the Julienne depression, particularly in the southern part of the area.

Area D

This area is the east half of the Shabogamo rise and is roughly a mirror image of Area C. Part of zone 5 was included in the domain. The linear pattern is locally arcuate. Six localities are known where lineations or folds plunge southeast or northwest. Contorted folds overturned to the north were found years ago in the iron formation near the gabbro in the southern part of the area. The axes of these early folds trend west, are approximately horizontal with limbs dipping both north and south. The lineation on these forms has not been recorded. About a mile to the northeast, northwest plunging folds have been recorded.

The orientation diagram shows a polar maximum with about a 30 degree dip dispersion. The interpretation is made in the same manner as in other areas, namely that the superposed axial plane corresponds with the northwest trending symmetry plane of the early fold set. The superposed axial surface in Area C is steeply inclined to the northeast, in Area D it is steeply inclined to the southwest.

Area E

The Duley marble contains numerous planar, quartzose stringers that probably represent cherty seams in the dolomite, figure 20. These seams usually exhibit a rough surface on the quartz-carbonate boundary and the roughness defines a lineation. These lineations are directionally parallel with the lineation expressed by clusters of tremolite crystals, and the lineation expressed elsewhere by mesoscopic scale elongate lenses of quartz plunging southeast.

Figure 21 illustrates one of the localities where the elongated quartz lenses may be observed. The exposure is across about 20 feet of marble that dips about 45 degrees towards the camera. The quartz lens lineation appears on several of the dip slopes exposed by the steplike surface.

Small folds are apparently rare in the marble. One poorly developed fold was seen near the little pond north of Lake Leila Wynne; it is irregular in form and appears to plunge south. One of the outcrops at the north end of

Lake Leila Wynne exhibits foliation dipping 40 degrees east to near vertical a few feet away across strike. This probably indicates a fold too large to be directly observed.

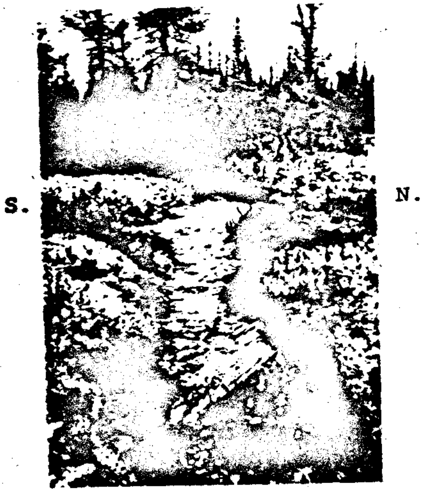
Figure 20

Planar Quartz Seams
Duley Marble - Lake Leila Wynne Area

The lineations in the marble area were found to everywhere trend between S10E and S30E. More lineation orientations were collected in this area because the examination could be continued here when lake travel was impossible due to high winds.

Area E was confined to one formation to see if the marble exhibited geometry significantly different than other areas. Unfortunately, most of the exposures are situated in the western half of the arcuate pattern and the orientation data is probably not representative of the geometry of the full arc fold. The interpretation of the geometry has been made in the same manner as Area A. The polar maximum is assumed to represent the pole to the axial plane of the early folds and that a set of early fold orthorhombic symmetry planes best represents these folds exhibiting the usual 30-40 degree dip dispersion. There is no way of telling how far the maximum may have been rotated from some early position due to the superposed folding.

Figure 21



Elongated Quartz Lenses
Duley Marble - Lake Leila Wynne Area

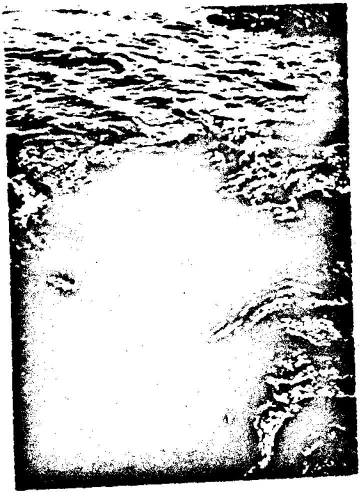
The superposed axial surface is drawn through the lineation field and the maximum; its pole falls in a generally vacant field, towards which the distribution seems to be elongated. As in Area A, the lineations are not down dip from the maximum. If the eastern half of the full arc were equally represented in the diagram, full girdle monoclinic symmetry would probably appear about axes plunging southeast, and a second maximum might appear in the vacant field to develop a bilateral distribution on either side of a more vertical superposed axial plane trending closer to north.

Area F

This area contains the southeastward continuation of the arcs forming the axial zone of the Julienne depression. The southwest side of the area has been arbitrarily selected along a zone that exhibits a reversal of dip that may separate two basin forms. Eight localities are known from the area that exhibit folds or lineations.

Figure 22 illustrates a small part of a severely folded outcrop of Katsao gneiss on the southwest shore of Julienne Lake. The fold forms nearby are variable and are locally tightly appressed or intrafolial with their axial traces trending west to southwest and dipping southeast. The axial surface is essentially parallel with the prevailing foliation in the intrafolial forms.

Figure 22



Katsao Gneiss - Julienne Lake

The picture shows a small area where the folds are more open and regular in form. The picture looks down the fold axes at 35 degrees along S40E. The dark bands are weathered biotite rich seams. The axial surface strikes N60W and dips about 55 degrees southwest, but this geometry is valid only for the picture area because the fold curves to the west and becomes lost in the general intrafolial foliation. The fold forms exhibit curvi form shapes suggestive of what Wynne-Edwards, (1963), calls refolded folds developed through unsteady flow. These forms all share common axes but their axial surfaces are curved and the folds are nonplane cylindrical folds. Foliation attitudes in this outcrop area are completely heterogeneous, the only homogeneous fabric element is the southeast plunging fold axes and lineations. The outcrop area distinctly shows that the axial surfaces of the folds can systematically vary as well as the foliation surfaces; all intersect in homogeneously plunging fold axes.

Further down the lake, open folds were observed where the limbs were 30 degrees or less apart and form a chevron pattern. While the fold axes-lineation direction is S40E at both localities, the trace of the axial surfaces is southwest at the southern locality. Massive granulite appears further south and no lineations were found there.

Figure 23 illustrates a large exposure of a fold of arcuate form found near the little lake west of the southwest arm of Shabogamo Lake. The axes of this fold plunge about 20 degrees along S50E, the axial surfaces strike S80E and dip southwest. This fold illustrates the fact that attitudes taken from small exposures of the gneiss may be completely useless as a geometric description that is at all reasonably representative of the general attitude of the rocks. The Katsao is so severely folded in some areas that attitudes are valid only if the scale of the attitude is defined in position. It was felt that the attitude of the lineation or observed fold axes were the only fabric elements homogeneous enough to warrant collection at some places.

Figure 23

Katsao Gneiss
S.W. Arm, Shabogamo Lake

The orientation diagram shows an S shaped distribution that could be interpreted in terms of two halves of a 20 degree small circle distribution, or a distribution that was once elongated in a northwesterly direction that has been split and rotated northeastward and southwestward such that a plane of bilateral separation symmetry inclined about 80 degrees to the northwest may exist. The distribution appears to be partially symmetric with respect to two great circles that intersect in what is interpreted to be the pole of a northwest trending axial plane such that superposed intersection axes plunging southeast to gently northwest are indicated.

The southeast arm of Julienne Lake represents the position of the trace of the axial zone of the Julienne depression. Many of the attitudes in the southeastern part of the area strike parallel with this trend, however it appears that the geometry of small folds is more dependent upon local conditions than upon regional scale deformation conditions.

Area G

This area includes the remaining part of the Katsao situated west of the Lac Michelle area. Two folds had been previously found in the area, two were located by the writer. Figure 24 shows a group of similar folds in biotitic gneiss. The photograph is overexposed. The axial traces strike due south and dip steeply east. Lineations on nearby outcrops plunge 25 degrees along S50E on less regular shaped folds that contain small folds composed of feldspar whose limbs are attenuated in the north-south foliation direction. The southeast plunging lineation is present throughout the 200 foot long outcrop area where most of the foliation surfaces strike south to southeast. The general impression received from the area is that the gneiss is so severely folded that the foliation is nearly parallel with the axial surfaces.

The orientation diagram shows a distribution of poles to foliation that appears to describe a 30 degree small circle in the northeast quadrant and a 20 degree small circle in the southwest quadrant. The significance of these features is not understood. They might represent an early distribution that has been modified during apparent rotation toward the pole or poles to the axial plane, or perhaps the small circles have some deformation relationship with the axial surfaces, possibly the centers of the small circles are poles to two preferred axial surfaces.

Figure 24

N.

S.

Mile 12 - Julienne Road

Whatever the relationships may be, the distribution strongly suggests that most attitudes are within about 30 degrees or less of being parallel with the northwest trending axial planes. No elongation appears that can be classified as being preferred so no preferred orientation of fold axes is shown. The planes represented by the principal clusters of poles intersect the axial plane in a field ranging from about 40 degrees southeast to horizontal to about 20 degrees northwest, but intersections outside of this range also occur.

Area H

This area includes most of the area containing the Shabogamo gabbro. Information is scarce in this area; the gabbro often exhibits no fabric and the gneiss occupies the lowlands. Seven localities were visited in the southwestern part of the area that represents the southeastern extension of the Julienne depression. The marble east of Lac Michelle is a strongly lineated calcium-silicate gneiss; silicate iron formation appears in association with it further north. Whether the formations are continuous between these outcrops is unknown. The gabbro in the island in the southwest arm of Shabogamo Lake has folded biotite gneiss on the west side of the island. No lineations appear in granulite to the east, though a weak foliation is locally present.

The interpretation of the distribution of the gabbro is admittedly tenuous. Aerial magnetics are not available to the writer for this area. The general pattern of the gabbro bodies is linear to arcuate with a tendency to trend either northeast or northwest. The several sheet-like bodies that trend northeast may have intruded along some structural anisotropism associated with the northeast trending fold set, not unlike the Carol Lake gabbro in Area A. The northwest trending bodies may lie along surfaces associated with the northwest fold set.

The orientation diagram shows a cluster of poles in one field that is probably close to the pole of the axial plane, interpreted to be inclined 80 degrees northeast. As in other areas, observed linear fabric plunges southeasterly. Most of the data is from the Lac Michelle area and reflects the southeastward increase of deformation.

Area I

This part of the area containing gabbro is somewhat better known than Area H, the outcrops are more plentiful and ground magnetic traverses have helped outline the gabbro. Two folds were noted in the 1956 work, one in amphibolitized gabbro. The other localities visited all exhibited southeast plunging lineations.

The large body of gabbro that apparently forms one long continuous intrusion exhibits both northeast and northwest trending patterns and attitudes, and it locally is decidedly foliated. The interpretation is that this gabbro may have been a sill that has been folded about southeast trending axes.

The orientation diagram exhibits several clusters of poles best related to an incomplete girdle field indicating the possibility of folds plunging southeasterly with a northwest trending axial surface.

Area J

This area contains the Wabush and Nault formations and is roughly bisected by the biotite isograd. The pattern is arcuate to the northwest, low to moderate dips are common. Whether the interfolds are open folds or nearly recumbent forms is not known.

The orientation diagram contains one principal polar maximum and three subsidiary clusters in a doubly bilateral arrangement somewhat similar to Area B. The superposed axial plane in Area J appears not to have followed the early symmetry system but cuts diagonally across it. The majority of poles appear to have rotated southwestward, but it is possible that the major maximum represents the early distribution position and the smaller clusters have been rotated northeastward. There is no way of knowing what the orientation of the early fold system was, so the orientation shown for the early fold axes may represent an early position or a superposed position. The early fold axial plane may have been steeply inclined to the northwest and associated with open folds, or gently inclined to the southeast and associated with tightly appressed folds if the major maximum represents the initial position. Otherwise, the early axial planes may dip about 30 degrees southwest or stand nearly vertical, trending northeast, following the orthorhombic symmetry planes shown. The doubly bilateral symmetry may represent an early symmetry pattern that has been modified by the superposed folding without a change of orientation, or it may be an early pattern that has been changed in orientation by the superposed deformation. It is unlikely that such a pattern would develop as a result of one deformational event.

The axial traces of the early fold system in the area trend, as indicated by the distribution of the iron formation, between about N20E and somewhat south of east. These limits approximately correspond with the strikes of the east and southwest dipping orthorhombic symmetry planes. Perhaps the orthorhombic symmetry set changes its orientation from place to place and the relationships between the early and superposed fold systems are variable. It is concluded that the center of symmetry is the only geometric feature common to both fold systems.

Area K

Little is known about this area, there are only about 44 outcrops recorded. Part of the area is underlain by granitic gneiss believed to be granitized Nault formation. The change of foliation trends outlines an arcuate pattern with the same sense of convexity as further southeast in the Julienne depression. Dips are low to moderate and dip either southeast or northwest.

The orientation diagram shows two maximum with weak subsidiary clusters, all separated by gaps in the distribution so that a bilateral symmetry pattern is again present. The early fold system is interpreted to trend N10E. The superposed fold axial plane cuts across the early symmetry planes, reflecting the northeastward elongation. Superposed axes should preferentially plunge gently southeast or northwest.

Areas L, M, N and O

The tightly arcuate pattern of interfolded Wabush and Nault formations in these areas can hardly be interpreted in any manner except through superposed folding. The alternating anticlines and synclines may be locally open and opposed dips are common in some parts of the area. The axial traces of these folds swing arcuately through the area and locally change direction by almost 180 degrees. Bisection of the arcuate patterns yields a family of suspected superposed fold axial traces that curve across the area to vanish against the basement, in one area converging to form a V shaped pattern abutting the gneiss. Five folds were observed in this area by other workers, the axes plunge south or north and probably represent early fold axes.

Fahrig, (1960), reports that cataclastic zones exist in the basement gneiss where the gneiss is in close proximity to the trough rocks and that the cataclastic cleavage is parallel with the contacts. He interprets his observations to suggest that basement-trough rock contacts are faults and that the outliers of basement gneiss are faulted into position rather than being windows. He shows a few fault symbols on his map to indicate the presence of cataclastic zones.

Although the writer has not seen the particular cataclastic zones that Fahrig, (1960), refers to, he has seen cataclastic zones west of Mt. Wright in charnockitic gneiss. There is no evidence of fault movement in these zones, the gneiss is simply somewhat crushed and broken. Fahrig, (1966), reports that large areas of gneiss around Lake Ashuanipi, 30 miles to the east of Wabush Lake, and well within the Grenville province, contain cataclastic structures in an area traversed by the sillimanite isograd. Wynne-Edwards, (1961), reports a similar situation south of Ossokmanuan Lake that involves gneiss and large bodies of gabbro south of the Grenville front. Duffell and Roach, (1959), and Jackson, (1962), recognized cataclastic structures in the basement gneiss that are metamorphically healed.

The presence of cataclastic cleavage does not necessarily mean that major fault zones exist in zone 5. The arcuate distribution pattern of the iron and Nault formations in the area around Flat Rock Lake is not cut by any recognizable lineament or lineament set trending in any direction. The formations and structural patterns are essentially continuous across the area from zone 6 to southeast of the biotite isograd. There may well be local faults in the area associated with the folds, but there is no evidence of a regional, post folding, crosscutting fault system associated with the Grenville front zone to the writer's knowledge.

The orientation diagram from area L shows the doubly bilateral symmetry pattern. The large separation between the distributions on either side of the west trending symmetry plane leads one to wonder if there may have been another deformation that is responsible for this 50 degree separation. If the distribution had been along the west trending symmetry plane immediately prior to the folding associated with the northwest trending axial surface, the northern distribution would be expected to lie more to the east than it does. If an intermediate period of deformation did not occur, then the early fold distribution must have been considerably larger than the 55 degrees now indicated between the east and west set of maxima.

The orientation diagram for area M shows numerous isolated clusters of poles that can be related to the doubly bilateral and diagonal northwest trending superposed axial plane as in the other areas. The diagram of area N indicates that the two symmetry systems may share a common symmetry plane as in some areas to the southeast. The diagram for area O is a single maximum that is probably fairly representative of the orthorhombic distribution that the early fold system is believed to have produced. The distribution may be divided by two symmetry planes normal to each other and normal to a third between the upper and lower hemispheres of projection. There is no quality of the distribution that clearly indicates the orientation of any superposed folding, though irregularities in the distribution indicate that a northwesterly trending fold system might possibly be weakly present.

Review

The set of large scale, regional folds outlined by the distribution of formations trends variably but systematically northeastward through the map area. The axes of these folds are regionally subhorizontal. This is shown by the continuous parallelism of their limbs for distances exceeding 10 miles, locally observed subhorizontal folds, variation of foliation attitudes, and subsurface drill hole confirmation in three areas. These folds are usually overturned and are constructed of tightly folded smaller folds whose limbs are about 40 degrees apart, nearly recumbent forms are known to exist and may regionally be present in one part of the area.

Small folds are found whose axes are oriented approximately parallel with the axes of the larger folds. At least one of these is known to be physically related to the northeast trending fold set, is discordant with respect to the lineation and nearby smaller concordant folds, and has been shown to be older than the concordant folds whose plunge is variable and partly dependent upon the local attitude of the northeast trending fold set.

The lineation and fold axes of the superposed concordant folds lie at the intersection of superposed axial surfaces and the foliation surfaces of the larger fold. Near vertical superposed axial surfaces cut across the foliation in many places where open to appressed similar folds are observed. In some areas however, the axial surfaces are nonplane and curve so as to tend to lie parallel with the prevailing foliation in folds of intrafolial form. The fold axes of both forms are observed to be parallel to each other.

Although the mineralogic lineation is most likely a late metamorphic-deformational stage mimetic feature, and is variably expressed from place to place in different rock types and structural situations, it is felt that the lineation is significant in that it is the most widespread expression of the superposed deformation. The intimate association of lineated rocks and mesoscopic concordant folds, plus the congruency of larger scaled surficial patterns, orientation data, and other evidence cited previously, all signify to the writer that a period of deformation has affected all parts of the area which has superposed, in space and time, various deformational features related to axial surfaces trending northwest upon the older northeast trending fold set.

The regional interference pattern formed by the two fold sets is variably linear to arcuate with the local development of crescent and lobate figures. The patterns are comparable with patterns figured by Ramsay, (1962), in his type 2 interference structures where the general direction of superposed tectonic transport lies at a high angle to the axial plane of the early folds, and the superposed axial surfaces lie at high angles to the axes of the early folds. He illustrates the progressive reorientation of subisoclinal early folds in this superposed folding arrangement, and it may be observed from his figure 8 that the orientation of the early fold axes is highly dependent upon the amplitude of the superposed folds. The axes of early folds are systematically oriented anywhere in the 90 degrees between their initial orientation and essentially parallel with the superposed axial plane in his illustration; and there is a corresponding change of the interference pattern from linear parallel with the axial plane of the early folds, through a variable combination of linear and arcuate forms, to linearily subparallel with the axial trace of the superposed folds.

The amplitude of superposed deformation has not been great on a regional scale in the Wabush Lake area where northeast trending structures underlie much of the map area. Changes of strike are gradual and generally limited to about 90 degrees in much of zones 3, 4 and 5. The intensity of superposed deformation increases southeastward however, and much of the Katsao gneiss exhibits geometry more closely associated with the superposed folding trends than the early fold trends.

Under these circumstances regarding zone 4, it is felt that the early fold axes have not been significantly reoriented and in general that large, early folds which initially had subhorizontal axes still have generally subhorizontal axes, as the Smallwood and Carol East synclines for example. The open concordant folds with near vertical axial-lineation planes are believed to represent new folds of the superposed generation. The pattern exhibited on the profile face of the fold of figure 13 is remarkably similar to the regional pattern, and the southeast plunging synform on the left of the specimen could easily represent the Julienne depression.

The tight appressed, M shaped, southeast plunging concordant folds, of the style represented by figures 7, 9, 15 and some folds in the figure 22 area, may have a different history. The axial surfaces of these folds lie, or tend to lie parallel with the prevailing foliation, and are nearly normal to the near vertical axial plane of the open superposed folds. These folds, which lie on their sides so to speak, might be partially to completely reoriented early folds developed in situations where superposed deformation was, at some stage, locally quite intense.

Thus, all southeast plunging concordant folds need not have necessarily originated as new superposed folds, though their southeast plunging orientation would be due to superposed event reorientation. Reoriented early folds might exist among and parallel with new superposed concordant folds of more open form, or among refolded superposed folds, or even among new folds tightly appressed against the superposed axial surfaces as in the figure 24 area. And, as pointed out previously, discordant folds need not necessarily all be early folds, some could be new superposed generation folds, particularly if the lineation represents the "a" kinematic axes.

These considerations illustrate the complexity of the structural problems that are inherent in a first attempt to unravel the structural history of the Wabush Lake area. Much more detailed work, including petrofabric studies, should be done in order to determine what fabric features are structurally and kinematically significant, and on what scale they are applicable, before the real significance of structural data can be established. But on a regional basis, which is the scale of this investigation, it is felt that the identity of the two fold sets is significantly expressed by the northeasterly trending older linear pattern as modified regionally and locally by the younger superposed fold set characterized by northwest trending axial traces.

The observed superposed folds are but individual folds of a northwest trending fold set that is regional in extent. Regional expressions of this set include the Stevens-Luce Lake depression, the axial zones of the Julienne depression and Shabogamo rise, and numerous smaller scaled arcuate patterns that reflect recognizable deformation by the northwest trending fold set.

Both the northeast and northwest trending fold sets are viewed as major, regional fold sets that are continuous across the map area along their respective trends. The folds of the northeast trending set are generally uniform along their trend, but change form southeastward. This variation is reflected in the geometry of the superposed folds, and there is also a southeastward increase in the intensity of superposed folding that is due to changes of rock type and the general southeastward increase in the metamorphic rank.

The deformation associated with the northwest trending fold set, and the metamorphism, have both been physically superposed upon older structures and rocks. They are physically associated with each other and are confined to the Grenville province. As there is no evidence for post tectonic-metamorphic activity other than secondary alteration, it is reasonable to conclude that the superposed deformation and metamorphism are two manifestations of the orogeny that affected the rocks in the Grenville province. The age of the northeast trending fold set has not been dated by geochronologic methods. Evidence is brought forth in the following chapter to indicate that the northeast trending fold set is probably considerably older.

STRUCTURAL DEVELOPMENT INTERPRETATION

The preceding chapters have presented a sample of the evidence concerning the large scale structural fabric of the Wabush Lake area and such interpretations that the writer considers are justified by the evidence. The following chapter deals with structural development considerations of a general and more interpretative nature, and their possible geotectonic significance.

Northeast Fold System

It has been shown that the northeast trending fold set is considered to be older than the northwest trending superposed fold set. The question is, are they a product of a single orogenic event or two unrelated orogenic events? One method with which to examine this question is to look for similar structures elsewhere and attempt a structural correlation. Before this is done, it will be necessary to show that the northeast trending folds in the Wabush Lake area are but part of a regional fold system.

Extent in the Grenville Province

The map by Gastil and Knowles, (1960), illustrates the general geology in the Wabush Lake-Mt. Wright district. The northeast trending fold set is readily recognizable on this map. Local northeast trending fold sets are but parts of a regional northeast trending fold system that can be followed at least to Mt. Wright.

The map by Duffell and Roach, (1959), shows the distribution of trough formations further south and west in a region characterized by gneiss domes and elliptical basins in the central part of their map. The iron formation is more continuous than shown on their map. Clarke, (1964), examined parts of the Mt. Wright and Lac Gras areas. He recognized northeast and northwest trending regional fold systems and concluded that the northeast trending folds are older than the southeast or northwest plunging folds. The writer's experience in the Tuttle Lake area, 18 miles southwest of Mt. Wright, also indicates that the northwest or southeast plunging folds appear to be superposed upon a northeast trending fold system. The superposed deformation is locally so severe as to obliterate much evidence of the other fold system however, and northwest structural trends predominate in much of this region. It is concluded that the northeast trending fold system is an expression of a major, regional scale deformational event whose effects are recognizable throughout much of the southern Labrador trough.

Structural Correlation

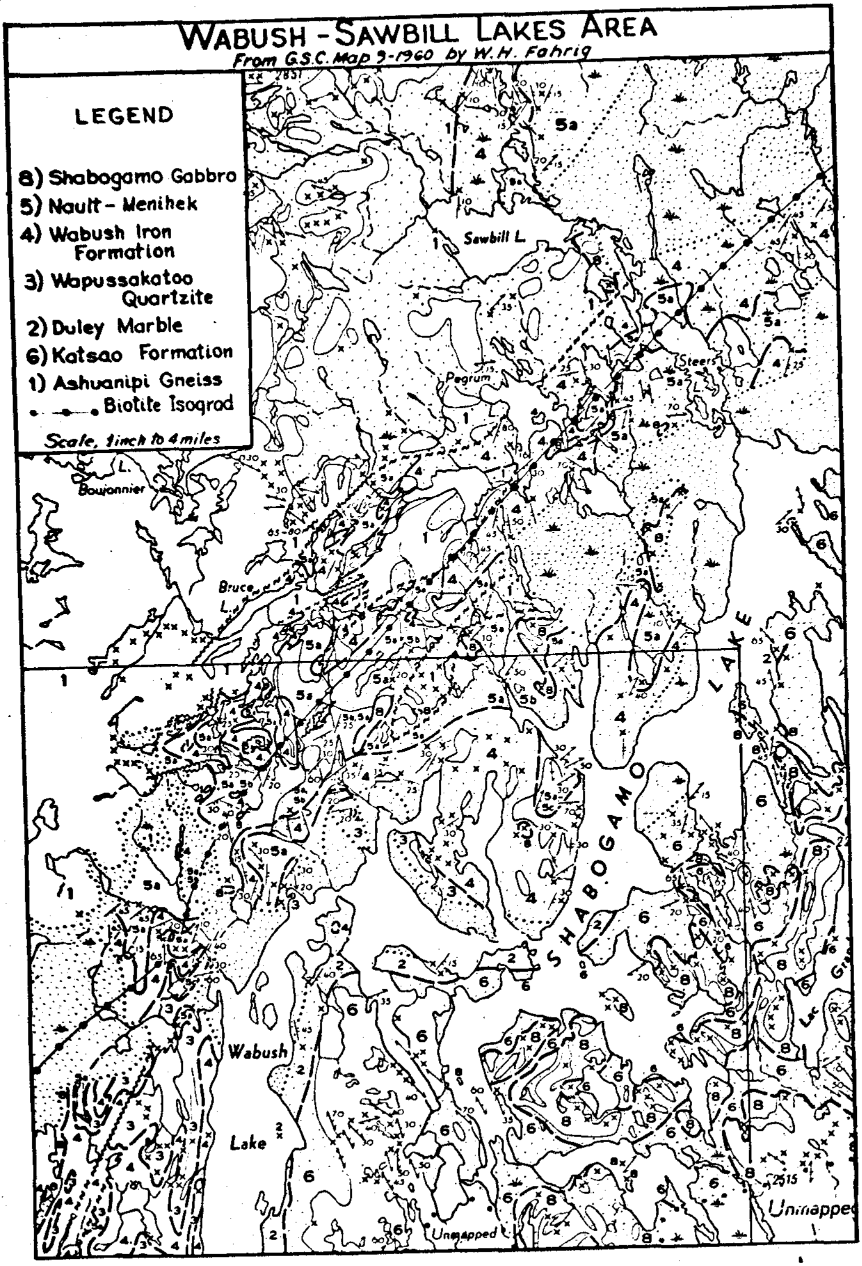
The northeast trending fold system in the Wabush Lake area can be recognized for only a few miles northeast of the map area due to the scarcity of outcrops in the lowlands north and east of Shabogamo Lake. Figure 25 shows the southwest part of the map by Fahrig, (1960). Part of the structural correlation path to be followed is contained within this map area. Unit 6 on this map is the Katsao formation, believed to be the oldest trough formation present in the area.

The northeast trending folds in the Wapussakatoo Mountains are a part of the stratigraphic-structural unit designated as zone 4 on the regional map. That zone 4 is structurally related to zone 5 is apparent because both zones were involved in the superposed deformation.

Zone 5 can be followed northeasterly in figure 25 beyond the Wabush Lake sheet with but little change in general pattern along the Grenville front zone to a lake about 4 miles northeast of Steers Lake at the edge of the map. Zones 4 and 3 may exist between this unnamed lake and outcrops of marble off the map about 3 miles further northeast. The biotite isograd marks one of the metamorphic discontinuities that exist in this zone.

Northwest of Steers and Pegrum lakes, the only known exposures between the iron formation of zone 5 and the iron formation north of Sawbill Lake consist of basement gneiss and gabbro. Neither Fahrig, (1966), or the writer has seen the aerial magnetics of this area, but geologists of the

FIGURE 25


WABUSH - SAWBILL LAKES AREA
From G.S.C. Map 9-1960 by W.H. Fahrig
LEGEND
8) Shabogamo Gabbro
5) Nault - Menihek
4) Wabush Iron Formation
3) Wapussakatoo Quartzite
2) Duley Marble
6) Katsao Formation
1) Ashuanipi Gneiss
Biotite Isograd
Scale, 1 inch to 4 miles
Sawbill L.
Pegrum
Steers L.
Bouvonnier L.
Bruce L.
SHABOGAMO LAKE
Wabush Lake
Lac Gr
Unmapped
Unmapped

Iron Ore Company of Canada have reported on several occasions that there is a 4 mile gap in the continuity of aerial magnetic anomalies south of Sawbill Lake.

Fahrig, (1960), shows several fault lines trending northeast on his map. These symbols are intended to designate areas where the cataclastic cleavage in the basement gneiss is more pronounced. Fahrig, (1966), has reported that he did not observe evidence of significant displacement in these zones, and that they are common and widespread has already been mentioned in the discussion of areas L, M, N and O.

The writer's interpretation of the Sawbill Lake gap situation is that the break in continuity of the iron formation and the overlying Nault-Menihek formation is due to a structural disturbance related to the Grenville front zone that extends northwest of zone 5 and which has raised the trough rocks above the erosional level across the gap. Note that the attitudes are irregular and moderately to steeply dipping in the Pegrum-Steers Lake area, suggesting a greater degree of deformation than in that part of the Grenville front lying within the Wabush Lake map area. The gabbro in the gap is the only gabbro body known to lie northwest of the biotite isograd in this region.

Across the gap, the iron and Menihek formations outcrop north of the north shore of Sawbill Lake. They exhibit the same stratigraphic relationships to each other and to the basement gneiss as in zone 5. The difference is structural in that north of Sawbill Lake the formations dip at low angles easterly in a homoclinal structure whose eastern extent is unknown. The homocline extends in a northeast, north, and northwesterly direction for over 100 miles along the west side of Menihek Lake to the Knob Lake area.

The relatively undeformed homocline gradually approaches the northwest trending main fold zone of the Labrador trough, proceeding northerly along the gently curved eastern edge of the Superior province, figure 1. The area between the Superior province and the main fold zone of the trough appears to represent a structural platform in which little tectonic activity has taken place. The homocline is in contact with the main fold zone northwest of Margaret Lake, see Frarey, (1961). The contact is probably a thrust fault that extends through Stakit Lake in the Knob Lake area. Younger trough formations appear northeast of the Stakit Lake fault so that a reversed sequential distribution of trough formations is present that is very similar to the reversed distribution between zones 4 and 5 in the Wabush Lake area.

The main fold zone of the Labrador trough has a strong linear pattern that is the result of numerous, large scale, faulted folds with subhorizontal axes; most are overturned towards the Superior province. Representative sections of these folds are shown in figure 26, reproduced from Stubbins, et al, (1961). Schwellnus, (1957), studied three areas in the Knob Lake area and showed that although the deformation was apparently accomplished in two or more related phases, the geometry was similar in each phase. The fold axes trend northwest and plunge at low angles northwest of southeast. He felt that the deformation plane was near vertical, trending southwest. Northeast of Schefferville there are two additional zones in the main fold zone that exhibit similar structures and a reversed sequential distribution of formations across their boundaries.

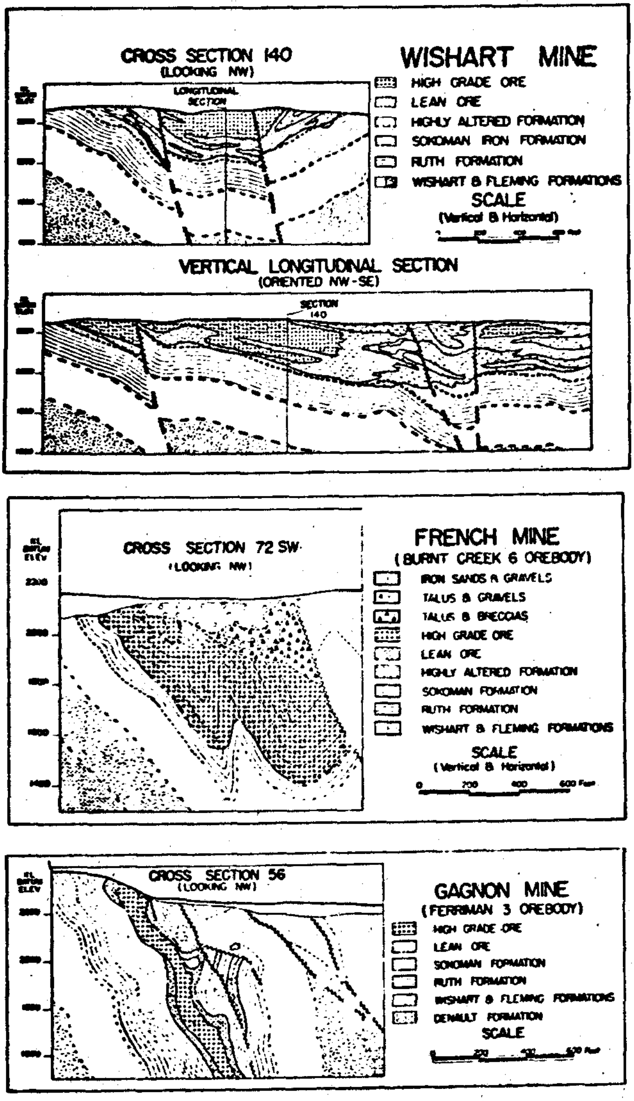
These folds in the main fold zone are quite similar in structural setting and form with the early folds in the Wabush Lake area. They can be indirectly structurally correlated via the structural correlation path outlined. They are similar in most respects except direction. The directional differences may, perhaps, be a manifestation of an unusual geotectonic situation associated with the Labrador trough.

The northwesterly trending structures in the main fold zone in the central trough continue southeasterly in a linear fashion to the McKay-Gabbro Lake area about 50 miles northeast of Sawbill Lake. The trough formations and structures

FIGURE 26

REPRESENTATIVE STRUCTURES – KNOB LAKE AREA

From Stubbins et al, 1961.



appear to merge into the Grenville province in this area, trending more easterly as the Grenville province is approached. Wynne-Edwards, (1961), writes;

> "The regular pattern of northwest trending folds found in the Labrador trough to the north is obscured around McKay and Gabbro Lakes, where a second deformation is marked by east-west cleavage which becomes more prominent southward. In places this cleavage is superimposed on an earlier foliation, both in the Kaniapiskau (trough) rocks and in the gneisses to the east. The interference of this second period of folding with the first has produced a pattern of minor folds and lineations too complex for study on the present (one inch per four miles) scale of mapping."

He does not relate the second period of folding to any specified deformational event. He continues;

> "The Grenville Front in this area is represented by a broad, roughly east-west belt of deformation marked by cleavage and low-grade metamorphism in the Gabbro Lake area, and by cataclasis and thrusting in the more metamorphosed rocks to the south."

He considers that northward thrusting has brought deeply buried gneiss to the surface south of the Grenville front.

Northwest to nearly west, and northeast to nearly east trending bands of iron formation and associated formations, several to tens of miles long, occur along the Grenville front zone in an area extending from around McKay Lake to Ossokmanuan Lake and further west towards Evening Lake in the area mapped by Fahrig, (1960). It would appear to the writer that there is a <u>possibility</u> that the northeast to nearly east trending structures in these areas might represent structures tectonically complementary with the northwest to nearly west trending folds in the main fold zone instead of the northeast to east trending structures being a manifestation of the deformation associated with the Grenville province.

Could these northeast trending structures be the northeastward extensions of the northeast trending fold system in the Wabush Lake area? The writer does not have an answer for this question. The idea is presented only as a possibility of structural patterns developed from an orogeny that may have produced northwesterly trending structures overturned towards the Superior province in the central trough that are related in time and space with northeasterly trending structures overturned towards the Superior province in the southern trough, with both areas exhibiting similar structural features. The interpretation that the northwest trending fold set in the Wabush Lake area is superposed upon the northeast trending fold set leads the writer to the belief that if any structural trend is to be classified as a trend representing the structural grain of the deformation that last occurred in the Grenville province, this trend is northwest, nearly normal to the Grenville front, not parallel with the front.

The shortest structural correlation path between Wabush Lake and Knob Lake is along the curved western margin of a large triangular shaped shelf that may have been little affected by the deformational events that produced similarly deformed but directionally different structures in each area. The northeast trending folds produced by this event in the Wabush Lake area were involved in a later deformation that produced the northwest trending superposed fold set. This is one possibility of sequential development, it could account for a northeast trending fold system already in existence along the Grenville front before becoming involved in the metamorphism and deformation found in the Grenville province.

The other possibility is that the northeast trending fold system in the Wabush Lake area is not orogenically related whatsoever with the deformation in the main fold zone of the central Labrador trough. If not, then the two fold systems in the Wabush Lake area are probably two directionally different manifestations of the orogeny that affected the Grenville province, with later generations of deformation being superposed upon earlier developed folds trending parallel with the Grenville front.

Age Relationships

The preceding considerations of structural correlations and possible sequences of relative deformational events raise the subject of the age relationships.

The writer will not attempt to analyze the extensive geochronological evidence applicable to the area; to do so would be repetitious. The Tectonic Map of the Canadian Shield by Stockwell, et al, (1965), shows the various parts of the shield within which major, regional, orogenic events have taken place that have been dated in broad time terms.

and then he proceeds to do just that!

The Superior province forms the core of the Canadian shield and exhibits a mean K-Ar age of approximately 2500 million years. The eastern side of the province lies immediately west of the Labrador trough and includes the Ashuanipi complex. The nearest dated locality of these rocks is about 60 miles north of Julienne Lake. Rocks of this age extend beyond the boundaries of the Superior province as rocks with similar age dates are locally found along the Labrador Coast, Stockwell, (1965). That Archean rocks also occur within the Grenville province has been demonstrated near Lake Timagami, Ontario, by Grant, (1964). He showed by whole rock isochron analysis that Superior province granite, with a primary age of approximately 2.2 b.y., exists within the Grenville province, and that it was there subjected to orogeny and metamorphism at approximately 1 b.y. This work only confirms what others have advocated for years since the appearance of Quirke and Collins' classic work in 1930 on "The Disappearance of the Huronian".

The Labrador trough began to develop during some unknown period. The depression became filled with sedimentary formations exhibiting most aspects of normal geosynclinal development. The Kaniapiskau Supergroup of trough formations is bracketed between 2440 and 1800 m.y., Stockwell, (1964). The extensive distribution of the Lake Superior Type iron formation in the sequence is a not unusual feature of early Proterozoic sedimentary sequences. Isostatic uplift and orogeny in the eugeosynclinal zone of the geosyncline is probably the basic cause of the deformational features present in the main fold zone of the Labrador trough. Stockwell, (1964, 1965), indicates this orogeny to be Hudsonian, with a mean age of 1735 million years in the Churchill province. The eastern limits of this event are but poorly known. A younger, Elsonian orogeny, averaging about 1370 million years, occurred over large areas in the Nain province. Wynne-Edwards, (1961), reports that basement rocks east of the trough were deformed and metamorphosed along with trough formations and that both lie in the same structural province. Elsonian dates lying within the Labrador trough amid Hudsonian dates lead Beall, et al, (1960), and Gastil, et al, (1960), to also conclude that the central Labrador trough had been affected by two orogenic events. The Elsonian Nain province is viewed to be partially overlapped upon the Hudsonian Churchill province. These may be related orogenic events, a generally northwest to north trending structural grain throughout the Nain and parts of the Churchill provinces may be more than geotectonic coincidence. It is interesting to note that Hudsonian ages also appear on the coast of Labrador lying between an area exhibiting Archean dates and the Grenville province, Stockwell, (1965).

Stockwell, (1964), tentatively places the Sims formation of cover rock clastics, lying upon unmetamorphosed trough formations north of the Grenville province, as post Hudsonian-pre Elsonian. He classifies large bodies of anorthositic gabbro in the Gabbro Lake area as Elsonian. These intrusions are unaltered north of the Grenville front, but similar gabbro in the Grenville province has been altered and sheared, Wynne-Edwards, (1961).

The Grenville province occupies the entire southeastern side of the Canadian shield and has a mean age of 945 million years, likely representing terminal stage metamorphism. The time of beginning of the orogeny in the Grenville province has not been geochronologically established.

These dated orogenic events provide the time reference for interpretation of the sequence of deformational events in the Wabush Lake area. Stockwell, (1964), has presented a working hypothesis for the orogenic history of the Grenville province, he recognizes that the age of intrusion of anorthosites and related rocks is one key to the problem. The key to the age interpretation of the two fold systems in the Wabush Lake area also lies with gabbroic intrusions.

The gabbro intrusions have been retrogressively metamorphosed and deformed, the smaller intrusions to a greater degree than the larger intrusions. Some are known to have foliated schist borders that are lineated in the same manner as enclosing rocks. The gabbro was intruded before the deformation that produced the lineation. It has been shown that the lineation is one manifestation of the northwest trending superposed fold system. Elongate gabbro intrusions are found trending northwesterly in several places; at the southeast end of the Stevens-Luce Lake lineament, east of Lorraine Lake, in the Julienne depression, a series of plugs situated just east of the Shabogamo rise, and parts of the gabbro southeast of Shabogamo Lake trend northwest. It is believed therefore, that the gabbro was intruded syntectonically with one or more of the early stages of deformation associated with the northwest trending superposed fold system because gabbro lies in structural trends of the system and has also been deformed in the same manner as the rest of the system.

Gabbro intrusions also lie parallel with the northeast trending fold system; examples include parts of the large gabbro bodies southeast of Shabogamo Lake, the Smallwood intrusion, and the long northeast trending body that passes through Carol Lake just west of the Wapussakatoo Mountains. The rocks in the vicinity of the Carol Lake gabbro have apparently suffered little superposed deformation. Some of the large bodies of gabbro southeast of Shabogamo Lake are distributed along both northeast and northwestward trends.

On the assumption that there was only one orogenic period of gabbro intrusion, it would appear that gabbro intruded syntectonically with the northwest trending (superposed) fold system, and which follows physical anisotropisms of both the superposed fold trends and the northeast fold trends, including northeast trends that were little affected by the superposed deformation, strongly suggests that the northeast trending fold system was already in existence at the time of intrusion.

The age of the intrusion of the gabbro is unknown. Fahrig, (1960), and Wynne-Edwards, (1961), both believe that the anorthositic gabbros are post trough in age and are orogenically related with the Grenville province. Stockwell, (1964), considers the anorthosites in the Grenville province in the Ossokmanuan Lake area to be Elsonian. He believes that the Labrador trough formations in the Wabush Lake area were "folded during the Hudsonian, modified during the Elsonian, and reworked during the Grenville orogeny", Stockwell, (1964), p.20. This is based upon the assumption that the Shabogamo gabbros are genetically related with the Elsonian intrusion of anorthosites and anorthositic gabbros further northeastward in the Nain province. If the syntectonic and at least pre-late metamorphic Shabogamo gabbros are really Elsonian intrusions, then the Elsonian was probably the period of the early to middle stages of the orogeny of the Grenville province that affected the rocks of the Wabush Lake area.

The writer's concluding interpretation is that there is a distinct possibility that the northeast trending fold system in the Wabush Lake area may be a Hudsonian fold system that was intruded by Elsonian gabbro syntectonically with the development of the northwest trending superposed fold system, and that the deformation in the Grenville province may have continued over a period of about 300 million years to cease before or around the time of late stage metamorphism around 1000 million years ago. None of the students of the Wabush Lake area have recognized any significant evidence of two episodes of regional metamorphism of trough rocks. This suggests that the metamorphism in the Grenville province was largely progressive, though it naturally was retrogressive with respect to the intrusive gabbro and basement granulite rocks. The age of early stage metamorphism is not suggested by any known feature, though it would be reasonable to assume that the processes of metamorphism and deformation were mutually interdependent and perhaps were episodically related in the manner discussed by Sutton, (1964).

Four K-Ar age determinations have been made from rocks in the Wabush Lake-Mt. Wright district. Three were collected and reported by Jackson, (1962). Composite samples from biotite rich layers in Ashuanipi complex rocks yielded 1580 million years. Samples from either Katsao or Ashuanipi rocks yielded 1120 million years, and samples of Katsao gneiss yielded 1250 million years. Fahrig collected samples of the Katsao gneiss along the southwest side of Julienne Lake that are reported by Lowdon, (1961). Muscovite, appearing to be younger in thin section than biotite, yielded an age of 980 million years, biotite yielded an age of 1125 million years. The samples reported by Jackson, (1962), illustrate the usual situation where K-Ar age determinations near the Grenville front yield ages intermediate between the Archean and the more uniform ages found within the Grenville province.

Development of the Superposed Fold System

The preceding interpretation of sequential development indicates that the northeast trending fold system was already in existence at the beginning of the superposed fold deformation. A certain, unknown, depth of cover is assumed to have been present, consisting of the up dip continuation of the presently exposed folds and probably a cover of post trough rocks. Such rocks are found as erosional remnants on the trough in the platform area and upon the main fold zone in the central trough. Stockwell, (1964), interprets the Sims formation of arenaceous clastics as post Hudsonian-pre Elsonian. Similar rocks exist in the Evening Lake area near the Grenville front. These rocks trend northeast and contain a south dipping fracture cleavage which Fahrig, (1960), ascribes to the effects of the deformation in the Grenville province. They lie 4-6 miles north of the biotite isograd and northeast trending, large gabbro intrusions are also present. It would be reasonable to assume that similar cover rocks may also have been present in the Wabush Lake area.

While the structural development probably was accomplished through a series of deformational phases that likely changed character in time and position as the metamorphic environment changed, the available evidence does not permit a sequential interpretation. It is possible only to suggest the manner in which the superposed folds may have generally developed to their present form through the agencies of external strain movements. A discussion of the physical environment and the structural situation regarding the environment will be presented later.

The existence of the older northeast trending fold system, whether it is a Hudsonian or later system, permits a certain amount of assumption about the former position and orientation of the northeast fold set. Large scale, external strain movements involving wholesale translation and rotation can be visualized by assuming that the northeast trending fold system once had a regionally linear pattern trending about N30-40E, roughly parallel with the average regional trend of the fold system between Mt. Wright and the Sawbill Lake area. The overall pattern was perhaps not greatly different than that presently exhibited in the Knob Lake area. The trough formations were probably distributed in three principal zones, zones 1-2, 3-4, and 5, as a result of the early deformation. The formations are believed to have not been metamorphosed to any significant degree.

It is not possible to infer very much about the effects of the early stages of the superposed deformation and metamorphism. The observed folds and metamorphism reflect the end results of the metamorphic and deformational processes and early stage effects are largely obliterated. It is not known whether the suspected northwest trending faults are early or later features; or if the gabbro follows early or later stage northwest trending features. It may only be concluded that most gabbro was emplaced before the period of intense metamorphism and at least some degree of deformation.

There may have been an early period of superposed flexural deformation. Suggestions of flexural folding appear in the orientation diagrams of some areas where the presence of partly developed small circles might reflect a period of dome or basin development that distributed poles to initially subparallel beds in a cone of about 20 degrees from the axis of tectonic transport passing through the center of the circles. It is also possible that dome and basin development is a later feature, though later stage deformation seems to be generally exhibited in the elongation of the pole to foliation distribution.

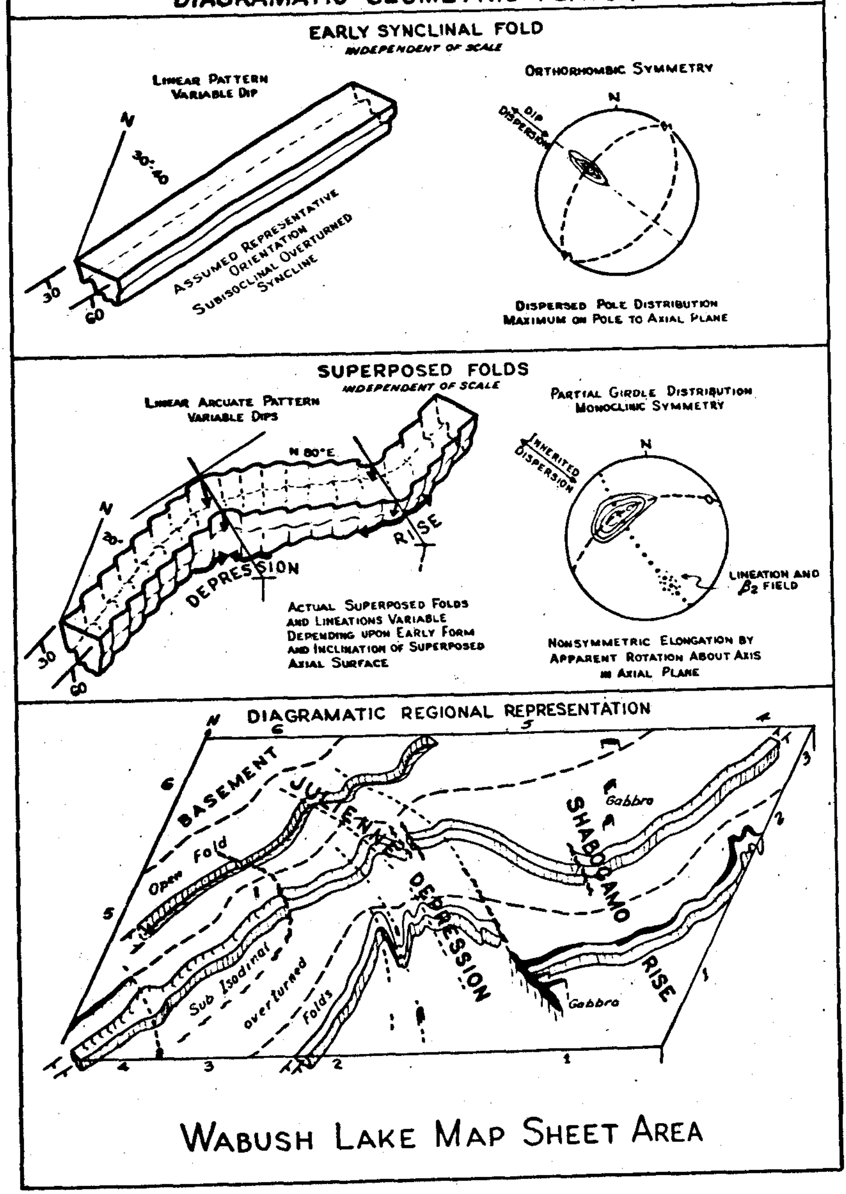
The general idea of the development interpretation is diagramatically represented on figure 27. The early fold system is assumed to have trended about N30-40E as a compromise between a N20E trend if the early folds trended parallel with the western margin of the trough and about N50-60E if they trended towards the Gabbro Lake area. The early fold system is represented by an overturned, subisoclinal, horizontal syncline as may have existed in zone 4. Regardless of the scale of the fold, its orientation diagram determined from outcrops would be like the one shown, with a polar maximum elongated in the dip dispersion direction due to the variation of dips produced by the small folds in the syncline. The pole distribution would be narrow if the strikes remained fairly constant. It could be divided by two of the three orthorhombic symmetry planes. Significant local changes of strike would serve to produce a more circular distribution of poles and destroy the suggestion of a girdle distribution normal to the early fold axes. The polar maximum would be centered around the pole to the axial plane of the syncline.

If it can be divided by 2 it must also be divided by 3

The fold has a shape of near infinite length compared to its depth and width. It is constructed of innumerable subparallel surfaces that dip southeasterly except in the hinges of its small folds. Its gross shape and internal mechanical anisotropisms would be such that the direction of least resistance to deformation by flexural bending would be directed normal to the bedding anisotropisms. The movements would be down to the northwest or up to the southeast providing that boundary conditions were such that the body was free to choose its own displacement path; that is, that the responsive displacement of this fold predominated and

FIGURE 27

STRUCTURAL DEVELOPMENT
DIAGRAMATIC GEOMETRIC FEATURES



controlled the displacement of adjacent folds.

The superposed fold diagram attempts to portray how the early fold may have looked after translation and rotation had developed to a point where the limbs trend about 60 degrees to each other. The fold may have initiated as a flexural fold wherein the movements were entirely internal, between or within the bedding surfaces, but part of the displacement may also be due to cross bedding-foliation passive flow. The fold is shown with an apparent 10 degree rotation of the southwest limb, and a 30 degree apparent rotation of the center limb about the average superposed fold axis. The superposed fold axes can be linear only upon the planar parts of the early fold. The position of fold hinges across the early fold would define axial traces trending northwest. Superposed fold axes and lineations would lie in the axial planes that are shown as vertical or steeply inclined. Not only would a linear-arcuate surface pattern be produced, but the displacement would have raised the syncline on either side of the superposed synform such that the early fold would lie lower in the synform hinge area and would form a depression relative to a rise in the antiform area. Fold axes of the syncline should plunge toward the depression, the degree of plunge however would be low unless the displacement had continued much further than shown.

The effects of apparent rotation of foliation attitudes appear in the orientation diagram through the migration of the poles from their former position along great circle paths toward the pole of the superposed axial plane, in passive deformation, by an amount proportionate to the degree of apparent rotation. The center of the maximum has become nonsymmetrically elongated as there was more elongation in one direction than in the other. Some poles have migrated beyond the 40 degree apparent rotation to spread the poles over a longer elongation, but a full girdle distribution could hardly be expected from such an open fold. The dispersion inherited from the syncline is still present, so the distribution will be rather wide.

Early fold axes are dispersed depending upon the fold mechanisms. If the reoriented early fold has fairly straight trending limbs as shown, two maxima may appear in the distribution that significantly reflect the two axial plane trends of the syncline; if the superposed fold has a generally curved form with an arcuate surface pattern, there is likely to be only a single maximum. The partially developed girdle is centered through the poles to the axial planes of the syncline, so that the superposed intersection axis so described lies at the intersection of the axial planes of the syncline and the superposed axial plane. Actual superposed axes would take their plunge from the dip of the foliation surfaces on which they have formed. As displacements with a parallel sense of movement cannot take place in a confined volume about two axes some 30 degrees apart without creating space problems when anistropisms of the early fold are actively influencing the movement picture, the actual superposed folds probably would preferentially develop only in one limb of the syncline where the superposed axes could be generally parallel, as was shown in the Julienne syncline, or on a smaller scale as in figure 15.

The early fold system is believed to have significantly influenced the development of local superposed folds. Only the large scale, northwest trending axial zones appear to be more or less independent of the early fold system.

The diagramatic regional representation of the superposed fold system in the Wabush Lake sheet area is presented to help illustrate the general structural construction of the area. The representation is viewed simply as a much larger scaled version of the superposed fold diagram.

The representation includes an open fold in zone 5, and subisoclinal, overturned folds in zones 4, 3 and 2. The increasingly arcuate pattern from northwest to southeast is viewed as a reflection of a greater intensity of superposed deformation in the amphibolite rank area, and particularly along the Julienne depression in zone 2 where space problems perhaps were acute due to translation of the limbs of the depression toward the axial zone. The faults are interpreted to be features developed on the flanks of the Julienne depression and Shabogamo rise. Gabbro, known to be metamorphosed and at least locally folded, appears to have intruded along or near these fault zones or in the major axial zones of the superposed system. Most of the gabbro is found over the southeastern part of the Shabogamo rise as might be expected in an area where dialational displacements above an antiform structure may have significantly reduced the effects of confining pressure. Although some of the gabbro is older than much of the superposed deformation, one small gabbro plug outside of the map area is believed to be a late deformational intrusion. No gabbro is known to exist beyond the biotite isograd in the district except southeast of Sawbill Lake.

The highly quartzose formations in the Wapussakatoo Mountain area, particularly the quartzite, are probably stratigraphically thicker than elsewhere. The tightly folded formations are believed to have behaved as a block more resistive to superposed deformation than other blocks; this is expressed by a predominantly linear pattern. Perhaps the Julienne depression is not a depression in the sense of the axial zone having moved down and west, but is perhaps a hinge area wherein most displacement occurred in the limbs, particularly in the east limb. Significant large scale superposed deformation in the Wapussakatoo block is largely confined to the Stevens-Luce Lake depression. Why the Smallwood syncline happens to lie askew in this area is not known. Any consideration of this problem would have to involve a study extending further south where similarly trending folds predominate.

If the early fold system once trended more or less uniformly northeastward, then wholesale translational and rotational external strain movements, systematically arranged with respect to the Julienne depression may have occurred. The displacements are viewed to have been largely upward to the southeast, or downward to the northeast approximately normal to the southeastward dipping early fold system. They were probably accomplished through cross layer, passive, differential flow so as to cause apparent rotation of limbs through about 40 degrees. If the early fold system had a less uniform northeast trend, the displacements need not have been as large to develop the present surficial pattern.

The Julienne depression is viewed to be the major, regional superposed structure in the area. The axial zone is recognizable as areas in which the attitudes trend northwest and dip steeply in zone 2, and by the distribution of hinge areas in the several formations described by the most arcuate pattern. The depression seems not to be a single, continuous axial zone. The axial trace zone in the Katsao, assumed to trend through the southeast arm of Julienne Lake, appears to curve westward, passes through the hinge area in the Duley marble, and dies out in area B. The Julienne deposit-Mt. Bondurant trace appears to curve west and dies out in area K. A similar curvature appears in the Julienne deposit and was observed on a mesoscopic scale at the figure 22 locality.

Areas L, M and N are the most arcuate parts of zone 5. The tight patterns indicate the presence of several synform and antiform fold sets trending northwestward, but some of their traces curve northward or westward and converge or diverge in the northwest part of the area. They appear to try to follow the trend of the early fold system west of Flat Rock Lake, but traces trending nearly west in area L can also be observed. The writer has not drawn traces in these areas due to the already crowded map and the problem of curved secondary axial traces that appear to become parallel with the trends of the early fold system. The problem is compounded by the low plunge of the folds in this area, the surface presents, in effect, nearly a longitudinal view of the folds. The tightly arcuate pattern does not signify a great deal of deformation.

A zone extending from near the basement gneiss of zone 6 in areas L, M, and N, and extending southeastward through Mt. Bondurant, the Julienne deposit, the southeast arm of Julienne Lake and into the Lac Michelle area is considered to be the zone of most intense superposed deformation. Synforms plunging southeast occur in most of this zone, but antiforms are also present. This zone trends about N30W. The trend of the superposed axial surfaces derived from the orientation diagrams of areas H, G, F, Julienne deposit, B, M, and N are also close to N30W. The superposed axial surfaces are interpreted to closely correspond with the dip dispersion plane of the early fold system in the orientation diagrams of the Julienne deposit and areas B and N.

The southwest limb of the Julienne depression exhibits a linear to weakly arcuate pattern in areas A, E, J, K, and parts of L and M. The early fold symmetry set in these areas is oriented about N15-20E. The plunge of the early folds, interpreted from the center of symmetry of the pole distribution, is subhorizontal in each area except in area J. The orientation data in area J seems to be a combination of the single maximum exhibited in area A and the doubly bilateral arrangement characteristic of zone 5. The diagram was interpreted in the same manner as the other diagrams in zone 5; but if it had been interpreted using the major maximum as in area A, the plunge of the early fold system would be more consistent with the other areas.

The superposed symmetry set in each of these areas cuts diagonally across the symmetry set of the early fold system. The superposed axial planes trend between N40W and N55W in these areas, area J again excepted as drawn. The superposed fold system appears to have been nonsymmetrically imposed on the early fold system throughout these areas where the superposed deformation was apparently relatively weak except in the Stevens-Luce Lake depression.

The central limb of the regional superposed fold system is best displayed in area C where the trends are east to southeast. Further north, the trends progressively change to more northeast in area O and no line of demarkation can be identified that separates early fold trends from superposed fold trends. The lack of interfolded formations in zone 2 does not permit recognition of early fold trends except that the northeast trending gabbros may mark these trends.

The west and east limbs of the Shabogamo rise are best displayed in the southern parts of areas C and D. The symmetry sets of each area are nearly identical except for the inclination of the superposed axial surfaces; for the rise as a unit they probably are about vertical.

Superposed deformation in areas G and H has been so severe as to obliterate traces of the early fold system, foliation oriented within about 30 degrees of the axial surfaces is indicated. This feature is less pronounced in areas F and I. Superposed axial surfaces trending about N20W are indicated from the orientation diagrams. Similar trends appear on the map locally, but parts of some of the larger bodies of gabbro trend N45W to N60W.

The principal feature of regional extent that appears on the map is the systematic arrangement of the linear to arcuate patterns. The patterns reflect the end result of a long period of complex metamorphic and deformational events that have herein been interpreted in terms of two regional fold systems developed at high angles to each other. The axial trends of the superposed system are approximately normal to the early fold system in zone 4 east of the Julienne depression and in one part of zone 5. West of the depression in zones 3, 4, and 5, the superposed fold system lies diagonally upon the early fold system. The regional superposed fold system trends approximately uniformly northwestward.

If the early fold system also once trended uniformly, the relationship between the two fold systems should be the same in all areas. The fact that the relationships are regionally different, that is normal or diagonal, suggests that one of the two relationships is the result of superposed reorientation. As the western areas, where the two fold systems are diagonally related, exhibit the least degree of superposed deformation; it is believed that the superposed fold system was diagonally imposed upon the early fold system and that the areas exhibiting a normal relationship between the two fold systems have been significantly reoriented by the superposed deformation. This argument would be invalid if the early fold system originally trended nonuniformly northeastward. As there seems to be some evidence to support this in comparing the nearly linear trends in the northern parts of the area against trends in the western part of the area, it may be that there is more of an element of coincidence in the areas of normally related fold systems than there is of significant wholesale regional reorientation. Significant superposed deformation is clearly apparent in the Julienne depression and Shabogamo rise areas however, even though the rocks may not have been displaced great distances from their former position.

The trough formations apparently exist as a relatively thin cover lying upon basement gneiss in zone 5. The biotite isograd lies on or near the southeast side of exposed areas of the gneiss in areas L, M, N, and O. Southeast of the isograd, the formations are thicker, or lie deeper as no iron formation is exposed until zone 4 is reached. The strip between the isograd and zone 4 contains several areas of leucocratic granitic gneiss. These gneisses are believed to be granitized trough rocks, though they might be basement gneiss.

These general relationships do not apply in area J however, and in area N the iron formation also lies astride the biotite isograd. This would suggest that the metamorphic isograd is a thermally induced metamorphic feature perhaps not physically related to a structural change present along the length of zone 5, such as an abrupt increase in the depth to the basement, which may have influenced the position of the isograd.

interesting!

The cataclastic aspects in the basement gneiss northwest of the isograd suggests brittle behaviour during deformation, as though confining pressures and temperatures were relatively low, though probably they were sufficiently high to permit ductile deformation of trough formations. Fahrig, (1960), makes no mention of cataclastic features in the trough formations in these areas. The writer does not know whether the trough formations in zone 5 have deformed flexurally or passively as he has not examined the area. It is suspected that the ductility contrast between the gneiss and the trough formations was high in an environment conducive to low to moderate mean ductility. A difference in deformational behaviour could be expected under these circumstances, which is perhaps the reason for the development of folds in the trough formations and cataclastic cleavage in the basement gneiss. A thorough examination of the structures to determine the mechanism or mechanisms of deformation that have operated along the Grenville front zone would be of great value to help infer what the physical conditions were during the period of development of the front. Criteria for distinguishing fold classes and the general relationships between these and the mechanical properties of the rocks and the physical environment are summarized by Donath and Parker, (1964).

The Labrador trough formations are viewed to continuously exist along zone 5 and to rest upon the basement gneiss. They were folded by the early deformation into folds trending generally parallel with the length of the zone. The Grenville front zone is believed to have followed this pre-existing zone. Superposed metamorphism was approximately equal along the length of the zone, but increased southeastward across the zone. Superposed deformation produced cataclastic features trending generally parallel with the front or contact with trough rocks in basement gneiss. It produced folds in trough rocks trending about normal to the front zone with deformation increasing in intensity southeastward. The temperatures and confining pressures were probably relatively low along the zone in the low rank metamorphic areas, temperatures at least increased southeastward. There is no macroscropic evidence of large scale, fault lineaments that disturb the continuity of the formations or fold patterns.

Implications Regarding the Grenville Province

The indicated metamorphic and structural relationships between the Superior province, the Labrador trough, and the Grenville province are such that the present position of the Labrador trough, as a structural unit within and without the Grenville province, must be accounted for in the operation of the orogenic events that are responsible for the geology of the Grenville province.

The classic concept of high rank regional metamorphism involves the idea of deep burial of the metamorphosed rocks in the earth's crust so that they were brought to a high pressure-temperature environment that was conducive to regional metamorphism. The reason is that the environmental conditions required by petrologic evidence can be found at great depths according to geophysical evidence. Geotectonic processes are called upon to accomplish the mass transport.

Fyfe, Turner and Verhoogen, (1958, p.237), indicate a temperature in the order of 600 degrees centigrade and 600 bars of load-water pressure as the minimum order of magnitude for the environment necessary to produce amphibolite rank metamorphic rocks from water saturated sediments. They consider, p.183, that such a situation could exist at about a minimum depth of 20 kilometers where fluid pressure equals load pressure and temperature is a normal function of load. If water were able to escape from the system, they suggest about 12 kilometers as a minimum depth for the greenschist-amphibolite transition. In considering their tentative stability fields, they ask, p.239, "Should not progressive regional metamorphism in some cases lead to metamorphic zones characterized respectively by glaucophane schists, greenschists and amphibolite in order of increasing grade?", wherein temperature increase as a normal function of depth is what they mean by "in some cases". This arrangement is basically present in the Wabush Lake-Mt. Wright area in the Grenville province. Regionally distributed metamorphic facies range from greenschist through the amphibolite to lower granulite facies in some areas, there are also gneiss domes and suggestions of metasomatism. From the classic metamorphic point of view, the Labrador trough rocks are supposed to have been buried at least 12-20 kilometers in the earth's crust in order to have been so metamorphosed. From a structural point of view, this would have required such burial with subsequent erosional exposure. This is the mechanism adopted by Wynne-Edwards, (1964), in his analysis of the tectonic aspects of the Grenville province, he emphasizes the heterogenity of the province and concludes that much of the Grenville province is composed of recycled basement rocks.

The classic concept of deep burial for regional metamorphism and deformation has been questioned by several European geologists. Sutton, (1964), p.21-25, reviews some of the broad aspects of metamorphic areas and believes that regional metamorphism results, not from burial, but from the accession of heat; that deep burial alone does not necessarily result in metamorphism; and that metamorphism, being basically a thermal phenomenon, may be independent of depth of burial. Part of the question involves the fairly recent recognition that there are several series of metamorphic mineral assemblages which are believed to reflect different combinations of pressure-temperature increase rates ranging from low temperature gradients at high pressure to steep temperature gradients at low pressures. He, and Pitcher, (1964), question the significance of pressure-temperature estimates for natural rocks. They point out that present estimates are based upon the stability of individual minerals, not with physical systems, and that the stability relationships of naturally occurring minerals have yet to be simulated close enough to make reliable estimates of the pressure-temperature conditions.

Under these circumstances, the broad geologic relationships exhibited along the Grenville front in the Wabush Lake area may be considered to see if the idea of deep burial for the classical concept is consistent with the available evidence. The considerations that follow deal largely with masses of rock from a structural point of view. Sufficient evidence is, unfortunately, not available to attempt to properly assess the significance of the biotite isograd and other metamorphic and structural evidence that should be examined before rigid conclusions can be reached about the development of the Grenville front.

The formations and structures of the Labrador trough serve as a time-position marker on both sides of the Grenville front. A time marker in the sense that the trough formations were in existence before the orogeny in the Grenville province, and a position marker in the sense of an elevation and geographic marker.

The trough formations were deposited in a near shore environment and extended far north and south of the later Grenville front. These formations were subsequently deformed in an environment not conducive to metamorphism in the western part of the central trough, but they were metamorphosed in the eastern parts of the central trough. The western parts of the central trough were, accordingly, probably closer to the surface that the eastern parts. As the trough formations and structures in the Wabush Lake-Sawbill Lake area are part of the western Labrador trough, it would seem reasonable to conclude that the trough formations and structures were probably relatively near the surface and extended continuously across the Grenville front zone prior to the orogeny in the Grenville province.

The trough may have had an unknown thickness of cover rocks lying upon it, but this cover was apparently not responsible for the metamorphism in the Grenville province because remnants of cover rocks lie upon unmetamorphosed trough rocks north of the Grenville province.

The classic concept for regional metamorphism and deformation would next require that the trough formations within the Grenville province be transported, "en masse", to a depth of about 12-20 kilometers. There would have to have been created a zone of differential transport along the zone where the Grenville front crosses the Labrador trough because just north of the front the trough rocks are unmetamorphosed and undeformed. At least they were not carried to a depth as great as those south of the front assuming that the metamorphic environment at depth extended uniformly and horizontally on either side of the front.

Further, as the trough formations and structures exist at the present surface far within the Grenville province, later or post orogenic events would have had to return transport the trough, "en masse", metamorphosed and folded but preserving earlier structures, upwards, right back to the same level in the crust that they started from because the Labrador trough now exists at the same level in the earth's crust on both sides of the Grenville front. This situation would seem to be a most remarkable geotectonic feature that would have required the Grenville front to be a zone of tremendous differential movement with respect to rocks on either side of the front.

The evidence exhibited by the geology along the Grenville front in zone 5 seems to be in disagreement with a concept of differential burial. Any scheme involving about 10 or more kilometers of differential transport, down and up, in a zone about 4-6 kilometers wide, and involving formations and structures only a few hundred feet thick, would have so completely shredded these markers that all continuity would be destroyed.

The Grenville front zone exhibits completely opposite features. The metamorphic rank more or less systematically increases southeastward from greenschist to amphibolite facies in trough formations. Not only are the formations and early fold structures relatively continuous along the front zone, the northwest trending superposed fold system locally appears to be continuous across the front zone. Even if the rocks in the Grenville province had become deeply buried without structurally disturbing the Labrador trough, it would seem that post deformation, differential return transport should have developed displacement lineaments of some sort that could be recognized in the distribution of the trough formations.

Differential transport along the trough-basement contacts could be called upon so as to not cut across trough rocks. But as the basement-trough contacts appear to be nonplane, irregular surfaces, they could hardly be discreet, return fault surfaces. Although a large amount of differential displacement could probably be accommodated by slight displacements in numerous distributed cataclastic zones in the basement gneiss, these displacements would accumulate in trough formations and be expressed in a breakup of their continuity anyway. There seems to be no escaping the fact that the preservation of formational and structural continuity of the Labrador trough along the Grenville front in zone 5 precludes any significant amount of differential displacement between the Superior and Grenville provinces along the Grenville front in the Wabush Lake area. Neither Fahrig, (1960), or Duffell and Roach, (1959), noticed any major northeast trending structural breaks in the basement gneiss of the Superior province.

The evidence regarding the relationships between the Superior province, the Labrador trough, and the Grenville province in this area indicate that the Labrador trough formations and structures within the Grenville province now exist at essentially the same level, relative to the Superior province, as they did before and during the period of orogeny in the Grenville province. It is felt that the orogeny was imposed upon the formations and structures of the Labrador trough, and the basement gneiss, "in situ", and without significant relative vertical movements between the rocks of the Superior and Grenville provinces.

If the rocks in the Grenville province have not been transported to the site of the metamorphic and deformational environment, then the environment probably came to the site of these rocks. The rocks conceivably could have been affected at a depth perhaps not significantly greater than the amount of general erosion that has taken place over the Canadian shield since the middle Proterozoic.

The distribution of imposed features ascribed to the orogeny in the Grenville province is, from northwest to southeast, low rank metamorphism of trough formations, metasomatism, and fairly uniform higher rank metamorphism over large areas; deformational aspects change from cataclastic features in the basement gneiss to increasing deformation characterized by passive flow in the amphibolite rank area.

Metamorphically healed cataclastic aspects in gneiss, believed to represent basement rocks and situated well within the Grenville province in the Wabush Lake-Mt. Wright region, have been reported by several workers. Synmetamorphically brecciated iron formation is locally found in many places in the amphibolite rank areas around Wabush Lake. These features are interpreted to indicate that a relatively low temperature-pressure environment once affected these rocks preceding a period of higher pressures and temperatures.

These general relationships across the front zone, and features within the Grenville province, indicate that the metamorphic and deformational environment changed position in space and time during the course of the orogeny.

As the evidence along the Grenville front seems to discount the possibility of significant physical differential movements of the rocks that became involved in the imposed environment, then the environment must have been nonphysical in form, that is, that it had the capacity to migrate through nonmoving media.

Energy, manifested in terms of heat and pressure, would seem to be the environmental control factor that has migrated. The flow of heat imposed upon the rock system was perhaps systematically variable, reflecting dynamic changes at depth.

The implication of the general situation would suggest that the geology of the Grenville province in the Wabush Lake area is a result of the operation of metamorphic and deformational processes upon existing rocks, "in situ", as a result of the variable imposition, in space and time, of energy from outside sources related to regional, long term crustal diastrophism.

Some of the probably significant expressions of the diastrophism with respect to the Grenville province in general, include:

1. The broadly uniform amphibolite rank metamorphism on a geographic scale intermediate between that of older shield areas and younger orogenic belts.

2. The presence of numerous large bodies of anorthositic intrusions which probably represent additions of material to the crust, perhaps largely as extensively distributed cover rocks now eroded away.

3. The apparently indiscriminate superposition of diastrophic processes upon rocks of older provinces, and a possible space-time association with the Elsonian-Nain province, which also contains anorthositic intrusions.

4. The possible remobilization of basement rocks and the development of gneiss domes in many areas.

5. The narrowness and gradational aspects of the Grenville front zone with the preservation of pre and syn-orogenic features along the front zone in some areas.

6. The pronounced, broad gravity low associated with the front zone, Innes, (1957). Note, the gravity survey has been extended through the Wabush Lake area but has yet to be published.

7. Axial zone trends of the last deformational event which trend about normal to the Grenville front in some areas.

8. The possibility of migration of the metamorphic and deformational environment in time and space resulting from the variable imposition of heat, probably from outside sources presumably lying at depth.

Interpretation of the historical development of the Grenville province must be able to account for these features, and such others that are as yet unrecognized.

The writer wishes to emphasize that the preceding implications about the development of the Grenville province in the Wabush Lake area, and the points about the province in general, are merely preliminary thoughts based upon the available information. As even general knowledge about the province is very scarce, and an integrated examination covering all genecic expressions in any one area has not been conducted, the preceding considerations are useful only as points to be evaluated in future investigations of the geologic problems associated with the Grenville province.

SUMMARY AND CONCLUSIONS

The rocks present in the Wabush Lake area consist of Archean, Superior province gneisses and early Proterozoic, metasedimentary Labrador trough formations. Both of these rock systems have been involved in regional metamorphic and deformational events that differentially affected these rocks in the Grenville province.

Six Labrador trough formations are present; they are systematically distributed and are readily distinguishable. They provide a most unusual opportunity to examine the effects of regional metamorphism and deformation upon older rock systems. They serve as time, lithologic, and position markers that exhibit the results of these events. Amphibolite rank regional metamorphism affected much of the area, but the rank decreases to lower greenschist facies across the Grenville front zone. The metamorphism progressively metamorphosed trough formations and retrogressively metamorphosed basement gneiss and gabbro intrusions. The distribution of the Labrador trough formations permits recognition of northeast and northwest trending fold systems in the metamorphic tectonites.

The Julienne deposit of metamorphosed iron formation in the center of the area is known from stratigraphic, structural, and drill hole evidence to be a large northeast trending overturned syncline with subhorizontal axes. Mineralogic variations within the deposit mark stratigraphic members that can be followed across, and to some extent within, the deposit to outline the shape of the folds. General foliation is parallel with the stratigraphic layering and compositional banding. The foliation laminae locally exhibit a small scale schistose arrangement of platey, specular hematite crystals. A lineation is formed by the intersection axes of the arrangement, and these axes are parallel with the length of elongated quartz crystals. Lineation is also defined by parallelism of silicate crystals. The lineations are observed to be parallel with crenulations and the axes of some small folds. Other small folds exist however, whose axes are oriented at high angles to these linear fabric elements. The lineation is probably a mimetic feature and evidence to demonstrate its kinematic meaning is lacking.

The linear fabric elements consistently plunge southeast on foliation surfaces that vary in strike from east to north and dip south, southeast to east at variable angles. The submembers of the iron formation have a linear to arcuate surficial pattern along and across the deposit. The pattern suggests that folds are present with northwest trending axial traces. Analysis of fabric orientations shows that the foliation surfaces tend to intersect in space parallel with the southeast plunging linear fabric elements. Other evidence shows that the deposit has been significantly deformed about axes plunging southeast only in one limb of the syncline. The southeast plunging fold set is interpreted to have been superposed upon the larger, northeast trending syncline.

An examination was undertaken to investigate the regional structural setting of the area to determine, if possible, the extent of the northwest trending fold set and its relationship to the northeast trending set. The 350 square mile area had been previously mapped and the general geology reasonably established. A survey was conducted believed to be sufficient to strongly indicate that the southeast plunging lineation and small folds are present throughout most of the area.

The regional distribution of Labrador trough formations outlines a large scale, northeasterly trending fold set that extends across the map area. It is known that these folds are part of a northeast trending fold system that is present throughout much of the southwestern extension of the Labrador trough in the Grenville province.

The northeast trending fold system exhibits an arcuate pattern not unlike the smaller scale pattern observed in the Julienne deposit. The prevailing trends throughout the area are northerly, northeasterly and easterly, most dips are moderate to the east, southeast or south as a result of the overturned character of the northeast trending fold system. The general absence of splits in the formations indicates that most of these folds have subhorizontal axes.

One fold was found in the regional survey that conclusively demonstrates that the southeast plunging folds are superposed in space, time, and position upon one limb of the larger northeast trending fold system. Lineations in the same area are consistently directionally parallel with the superposed axes, but take their plunge from the dip of the foliation surface upon which they lie. The axial planes of some superposed folds tends to lie parallel with the foliation of the early folds, but open, similar superposed folds exist whose axial traces trend northwest across the foliation. These two types appear to be closely related in some areas, the first may represent reoriented early folds, but such large reorientation is believed to be insignificant on a regional scale in most parts of the area.

The area was divided into 15 large subareas for examination on the basis of the regional pattern. These areas are larger than the scale of the northeast trending folds and monoclinic symmetry of orientation cannot ideally exist. The generally subisoclinal nature of the early folds permits use of large domain areas however due to the limited dip dispersion. The superposed intersection axes described by the pole distribution generally represents the orientation of the intersection of the superposed regional axial-lineation surfaces and the axial plane of the early fold set. The regional examination shows that the superposed folds consistently plunge southeast, or locally northwest where the early fold limbs dip in that direction. The interpretation of the orientation data indicates that the northwest trending fold system has been diagonally superposed upon the northeast trending fold system west of a northwest trending axial-hinge zone that regionally crosses the northeast trending fold system. The two fold systems exhibit a normal relationship in this zone and in areas to the east. At least parts of the areas where the two fold systems are normal to each other are believed to have been significantly reoriented during the superposed deformation by passive flow mechanisms.

The northeast trending fold system can be structurally correlated with the northwest trending, Hudsonian fold system in the central Labrador trough. A possible explanation of the nearly 90 degree difference in trends between the two areas is presented. The gabbros in the Wabush Lake area follow both the northeast and northwest structural trends and are known to have been affected by superposed metamorphism and deformation. Although these intrusions have not been geochronologically dated, there is reason to believe that they may be Elsonian intrusions. If so, this is perhaps about the time of early to middle stage metamorphism and deformation in the Grenville province.

The Grenville front is a northeast trending zone about 4 miles wide that follows the northwestern side of the Labrador trough for over 30 miles in the Wabush-Sawbill Lake area. The metamorphic rank in trough rocks increases southeastward across the zone, superposed deformational effects range from cataclastic features in Superior province basement gneiss with folds in trough rocks, to passive folds of variable amplitude in amphibolite rank areas.

The formations and structures, both early and superposed, are basically continuous along the Grenville front zone. They are not cut by any recognizable regional, post metamorphic-deformational fault system. The presence of sedimentary trough formations on both sides of and along the Grenville front must be accounted for in the operation of the metamorphic and deformational processes that affected the Grenville province in the Wabush Lake area. The relationships between the Superior province, the Labrador trough and the Grenville province are inconsistent with a concept involving differential transport of the rocks in the Grenville province relative to the Superior province so as to carry Grenville province rocks to depth to reach an environment conducive to regional metamorphism and deformation.

The structural situation implies, as a working hypothesis, that the environment migrated to the site presently occupied by the Labrador trough in the Wabush Lake area. The geology of the area is believed to be a result of the operation of metamorphic and deformational processes upon existing rocks "in situ" as a result of the variable imposition, in space and time, of heat from outside sources related to the regional, long term, crustal diastrophism that is responsible for the development of the Grenville province.

It is concluded that deformation associated with regional metamorphism in the Grenville province in the Wabush Lake area produced a fold system of regional extent that trends northwest approximately normal to the northwest edge of the province, and that the structures and metamorphism were regionally superimposed upon the formations and northeast trending fold system of the Labrador trough, and also upon Superior province basement rocks.

REFERENCES

Beall, G.H., Sauve, P., and staff, 1960, Age Investigations in New Quebec and Labrador; Variations in Isotopic Abundances of Strontium, Calcium, and Argon and Related Topics, N.Y.O. - 3941: Eighth Ann. Prog. Report for 1960, Dept. Geol, Geophys., Mass Inst. Technology, pp. 245-253.

Clarke, P.J., 1964, Geology in the vicinity of the Grenville front, Mount Wright district, Quebec: Unpublished PhD. thesis, University of Manitoba, Winnipeg.

Dobell, J.P., 1957, Petrology of selected specimens from the Wabush Lake district of Newfoundland-Labrador: files of Canadian Javelin Ltd., Ottawa, Ontario.

Donath, F.A., and Parker, R.B., 1964, Folds and Folding: Geol. Soc. America Bull., v.75, p.45-62.

Duffell, S., and Roach, R.A., 1959, Mount Wright, Quebec-Newfoundland: Geol. Survey of Canada, Map 6 - 1959.

Fahrig, W.F., 1960, Shabogamo Lake, Newfoundland and Quebec: Geol Survey of Canada, Paper 60-9.

_______________, 1966, personal communication.

Frarey, M.J., 1961, Menihek Lakes, Newfoundland and Quebec: Geol. Survey of Canada, Map 1087A.

_______________, and Duffell, S., 1964, Revised Stratigraphic Nomenclature for the Central part of the Labrador Trough: Geol. Survey of Canada, Paper 64-25.

Fyfe, W.S., Turner, F.J., and Verhoogen, J., 1958, Metamorphic Reactions and Metamorphic Facies: Geol. Soc. of America, Memoir 73.

Gastil, G., Blais, R., Knowles, D.M., and Bergeron, R., 1960, The Labrador Geosyncline: Int. Geol. Cong., Report of 21st Session, part IX, Pre Cambrian Stratigraphy and Correlations, Copenhagen, p.21-38.

_______________, and Knowles, D.M., 1960, Geology of the Wabush Lake Area, Southwestern Labrador and Eastern Quebec, Canada: Geol. Soc. America Bull., v.71, p1243-54.

Gill, J.E. Bannerman, H.M., and Tolman, C., 1937, Wapussakatoo Mountains, Labrador: Geol. Soc. America Bull., v.48, pp 567-586.

Grant, J.A., 1964, The Nature of the Grenville Front near Lake Timagami, Ontario: Unpublished PhD. Thesis, Calif. Inst. of Technology, Pasadena.

Gross, G.A., 1955, The Metamorphic Rocks of the Mount Wright and Matonipi Lake Areas of Quebec: Unpublished PhD. Thesis, University of Wisc., Madison.

________________, 1960, Iron Formations and the Labrador Geosyncline: Geol. Survey of Canada, Paper 60 - 30.

Harker, P., 1965, Guide for the Preparation of Geological Maps and Reports: Geol. Sur. of Canada.

Harrison, J.M., 1952, The Quebec - Labrador Iron Belt, Quebec and Newfoundland: Geol. Survey of Canada, Paper 52-20.

Henderson, E.P., 1959, A Glacial Study of Central Quebec - Labrador: Geol. Survey of Canada, Bull. 50.

Innes, M.J.S., 1957, Gravity and Isostacy in Central Quebec: Trans. Amer. Geophys. Union, v.38, pp. 156-165.

Jackson, G., 1962, The Geology of the Neal (Virot) Lake Area, West of Wabush Lake, Labrador, with Special Reference to the Iron Deposits: Unpublished PhD. Thesis, McGill University, Montreal.

Klein, C., 1960, Detailed Study of the Amphiboles and Associated Minerals in the Wabush Iron Formation, Labrador: Unpublished M.Sc. Thesis, McGill University, Montreal.

Knowles, D.M., and Gastil, G., 1959, Metamorphosed Iron Formation in Southwestern Labrador: Bull. Can. Inst. Min. and Met., v. 62, pp. 503-510.

Kranck, S.H., 1961, A Study of Phase Equilibria in a Metamorphic Iron Formation: Jour. Pet., v.2, pt. 2, pp. 137 - 184.

London, J.A., 1961, Age Determinations by the Geological Survey of Canada: Geol. Survey of Canada, Paper 61-17.

p 150

Mueller, R.F., 1960, Compositional Characteristics and Equilibrium Relations in Mineral Assemblages of a Metamorphosed Iron Formation: Amer. Jour. Sc., v. 258, no. 1, pp. 449-497.

Mumtazuddin, M., 1958, Geology of the Area between Carol Lake and Wabush Lake, Labrador: Unpublished M.Sc. Thesis, McGill University, Montreal.

Pitcher, W.S., 1964, The Aluminium Silicate Polymorphs: Chapter 19, Controls of Metamorphism, Pitcher, W.S., and Flinn, G., Editors. Oliver and Boyd, Edinburgh and London.

Ramsay, J.G., 1960, The Deformation of Early Linear Structures in Areas of Repeated Folding: Jour. Geol., v. 68, p.75-93.

_______________, 1962, Interference Patterns Produced by the Superposition of Folds of Similar Type: Jour. Geol., v. 70, p. 466-481.

Rast, N., 1964, Nucleation and Growth of Metamorphic Minerals: Chapter 4, Controls of Metamorphism, Pitcher, W., and Flinn, G., Editors. Oliver and Boyd, Edinburgh and London.

Schwellnus, J.E.G., 1957, Ore Controls in Deposits of the Knob Lake Area, Labrador Trough: Unpublished PhD. Thesis, Queen's University, Kingston, Ontario.

Stevenson, I.M., 1964, Lac La Jannaye, Quebec - Newfoundland: Geol. Survey of Canada, Paper 64-8.

Stockwell, C.H., 1964, Age Determinations and Geological Studies: Geol. Survey of Canada, Paper 64-17, part 11.

_______________, 1965, Tectonic Map of the Canadian Shield: Geol. Survey of Canada, Map 4-1965.

Stubbins, J.B., Blais, R.A., and Zajac, I.S., 1961, Origin of the Soft Iron Ores of the Knob Lake Range: Trans. Can. Inst. Min. and Met., VLXIV, pp. 37-52.

Sutton, J., 1964, Some Recent Advances in Our Understanding of the Controls of Metamorphism: Chapter 2, Controls of Metamorphism, Pitcher, W., and Flinn, G., Editors. Oliver and Boyd, Edinburgh and London.

Turner, F.J., and Weiss, L.E., 1963, Structural Analysis of Metamorphic Tectonites: McGraw-Hill, New York.

Weiss, L.E., 1959, Geometry of Superposed Folding: Geol. Soc. America Bull., V. 70, p. 91-106.

Wynne-Edwards, H.R., 1961, Ossokmanuan Lake, Newfoundland: Geol. Survey of Canada, Map 17-1961.

__________________, 1963, Flow Folding: Am. Jour. of Science, v. 261, pp. 793 - 814.

__________________, 1964, The Grenville Province and its Tectonic Significance: Proc. Geol. Assoc. of Canada, v. 15, part 2, pp. 53-67.

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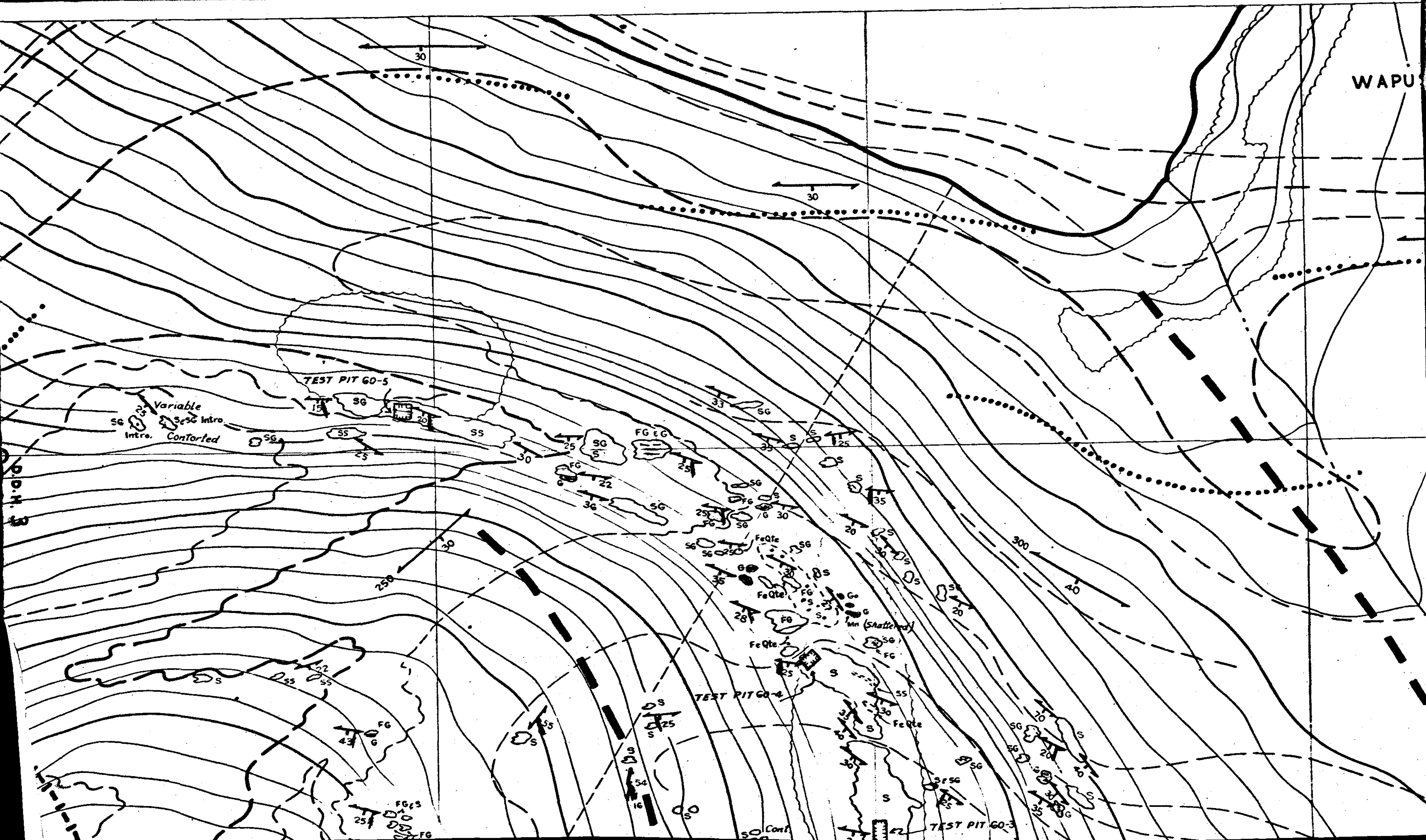
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TEST PIT GO-4
TEST PIT GO-3
D.D.H. 3
Variable
SeSG Intro.
Intro.
Contorted
SG
SS
S
FG
G
FG & G
FeQte
Mn (Shattered)
Cont
250
300
30
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20
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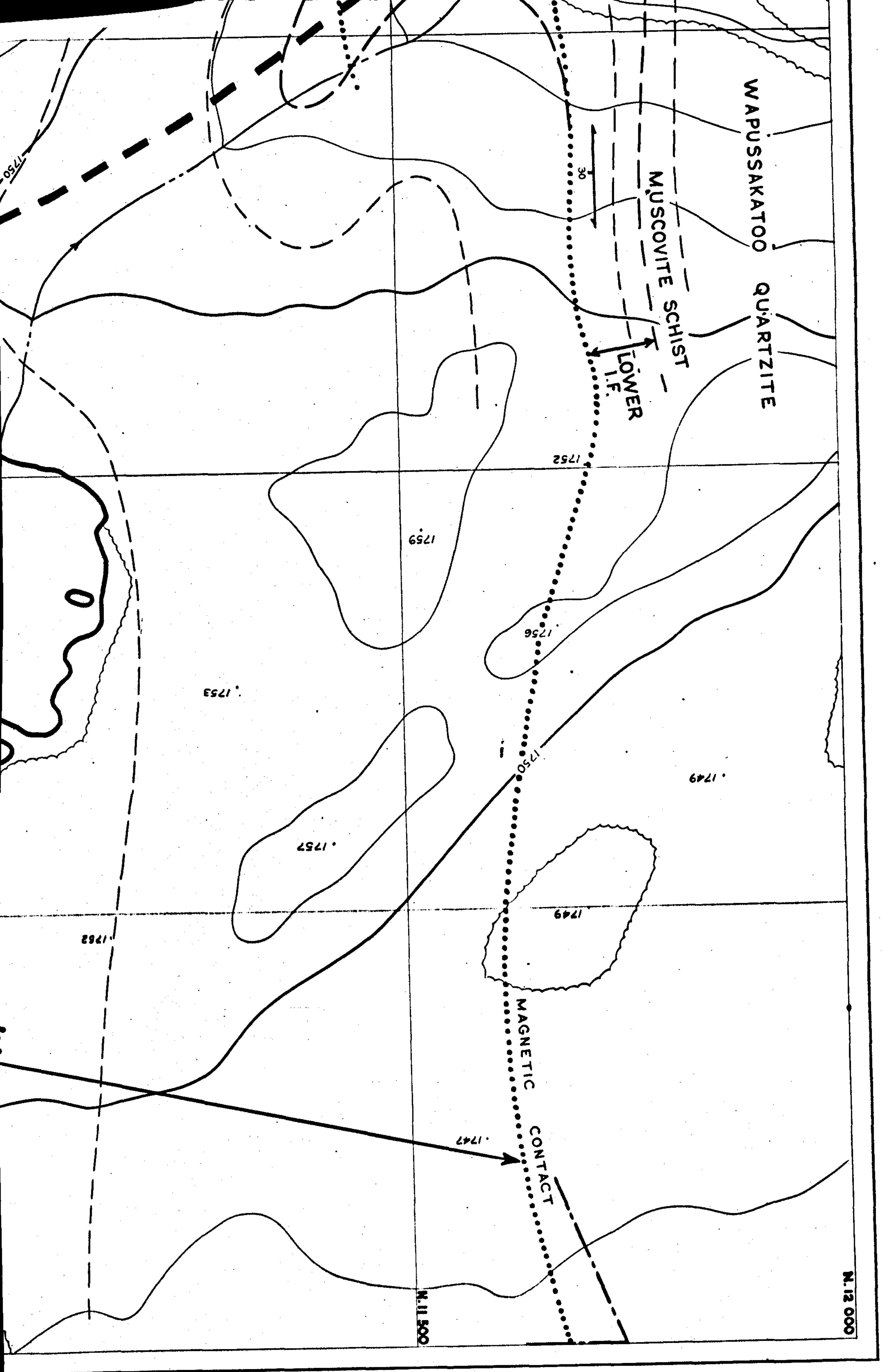
43
54
16
70


WAPUSSAKATOO QUARTZITE
MUSCOVITE SCHIST
LOWER I.F.
30
MAGNETIC CONTACT
1750
1752
1759
1756
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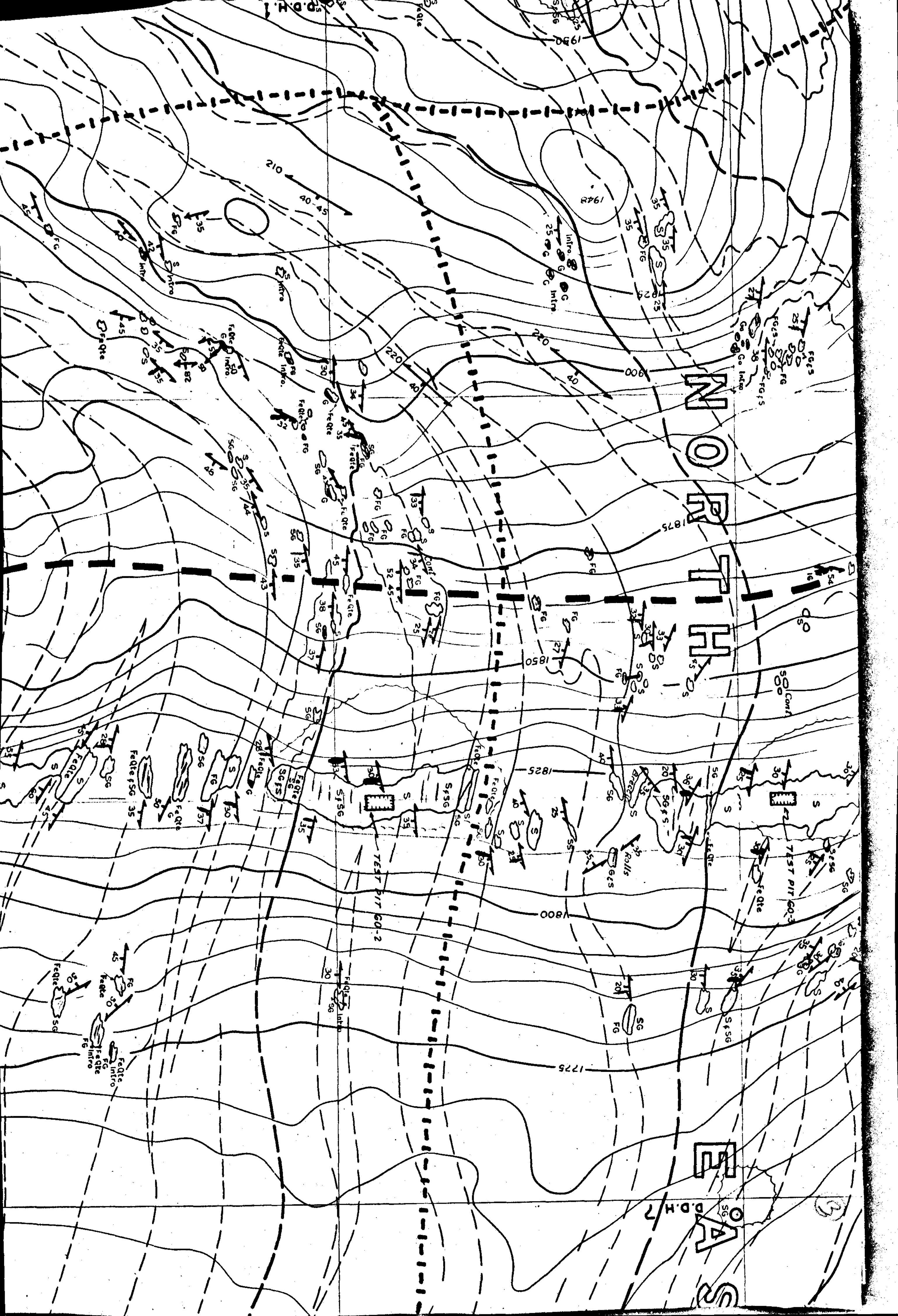
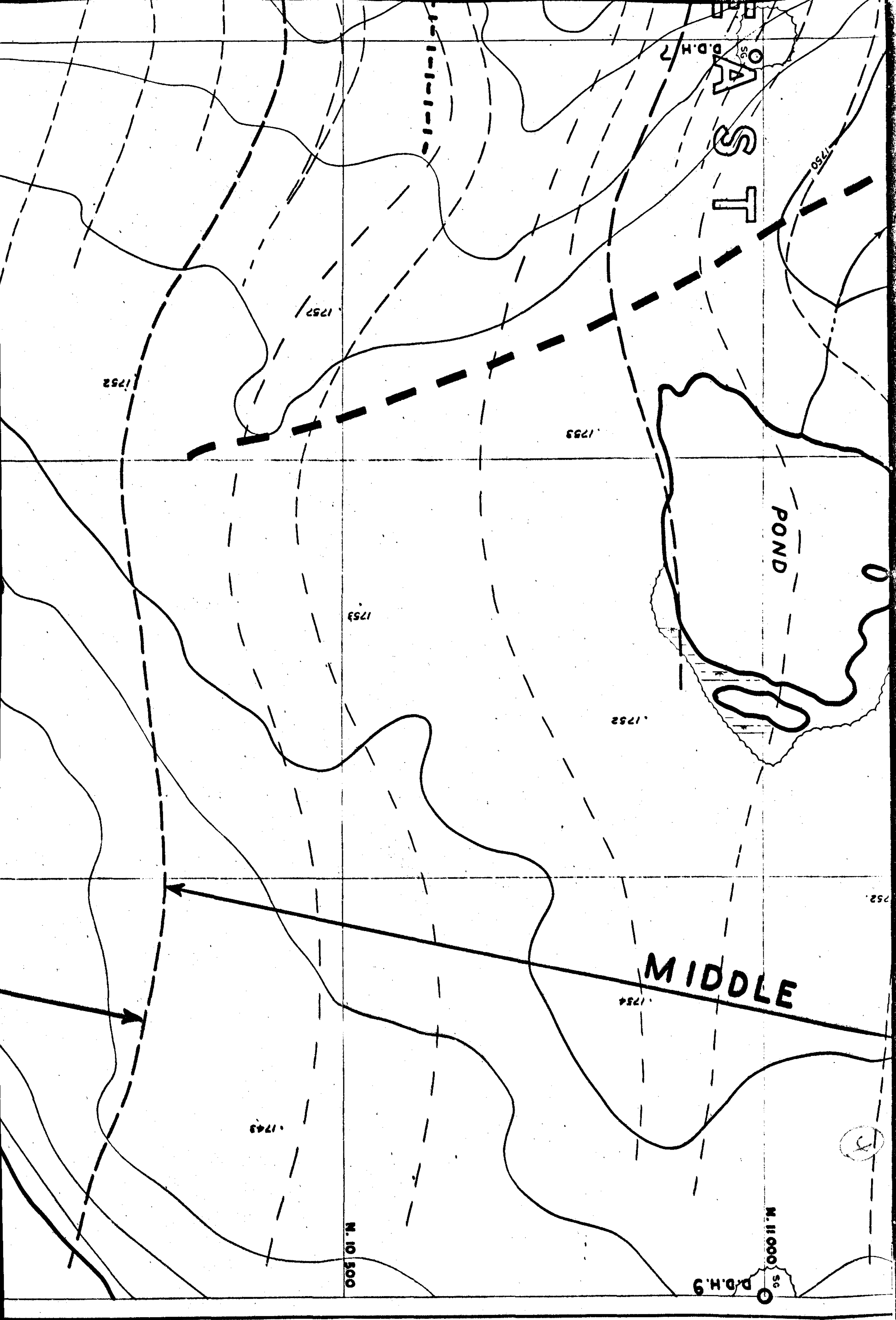
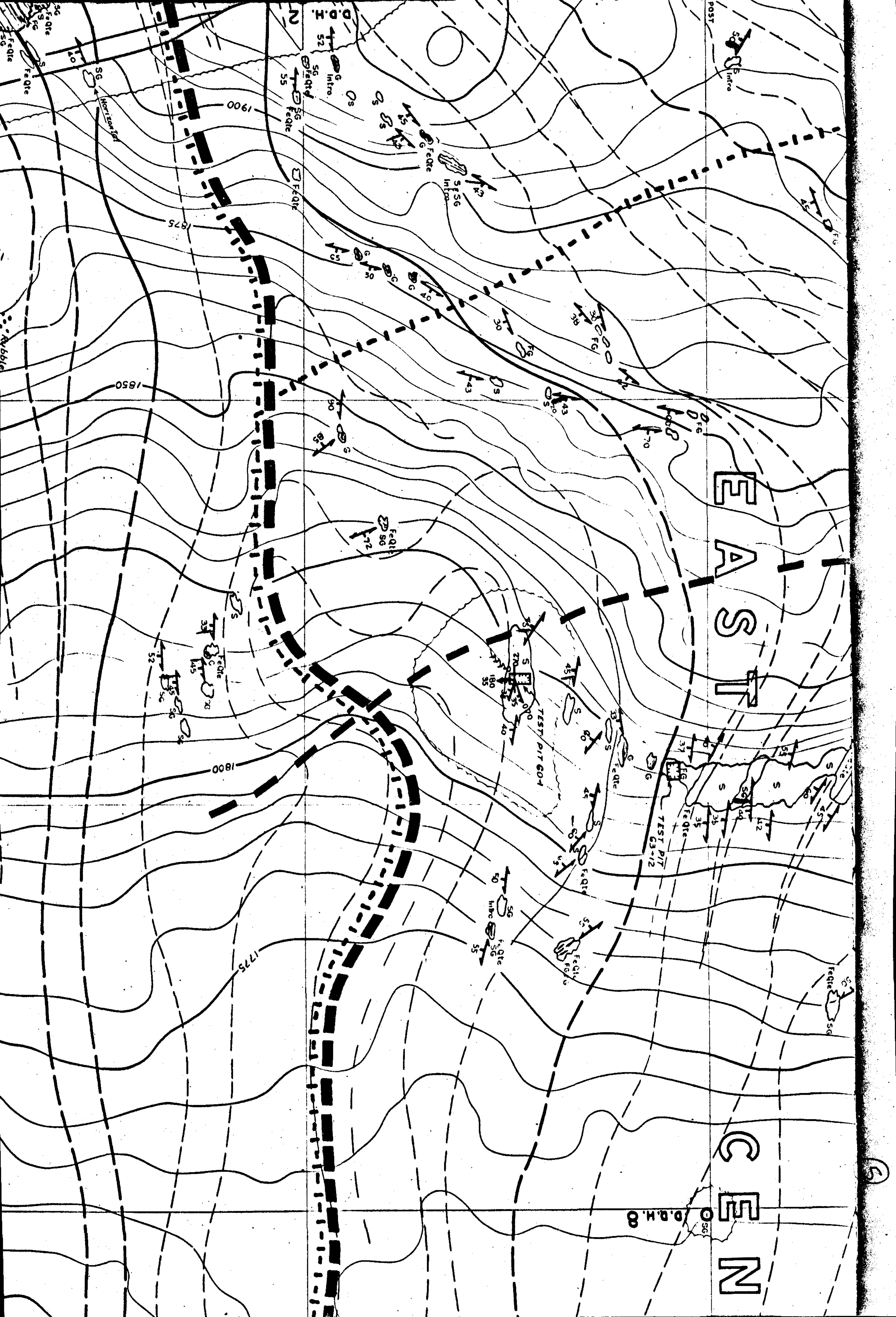
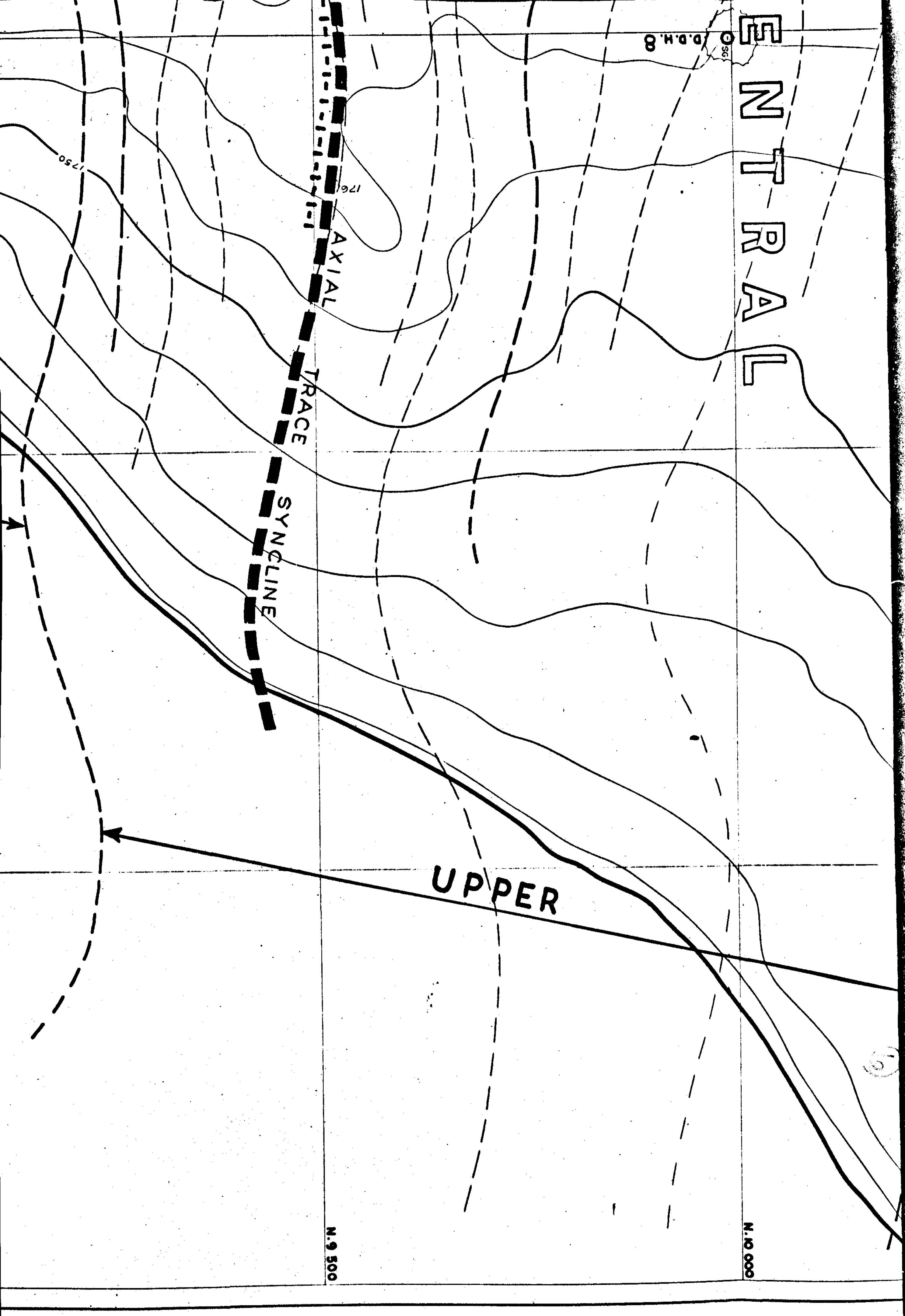
1747
1750
N.11 500
N.12 000


NORTH
EAS
TEST PIT GO-2
TEST PIT GO-3
D.D.H. 7
D.D.H.
1950
1948
1925
1900
1875
1850
1825
1800
1775
210
40-45
220
40
FG
SG
FeQte
S
G
Intro
S&SG
SG&S
FeQte&SG
Cont
Rolls
Breccia


A S T
D.D.H. 7
SG
1750
.1757
.1752
.1753
POND
.1753
.1752
752.
MIDDLE
.1754
.1743
N. 10 500
N. 11 000
D.D.H. 9
SG


EAST
CEN
TEST PIT G0-1
TEST PIT G3-12
D.D.H. 8
D.D.H.
POST
1900
1875
1850
1800
1775
Rubble
Horizontal
FeQte
SG
Intro
5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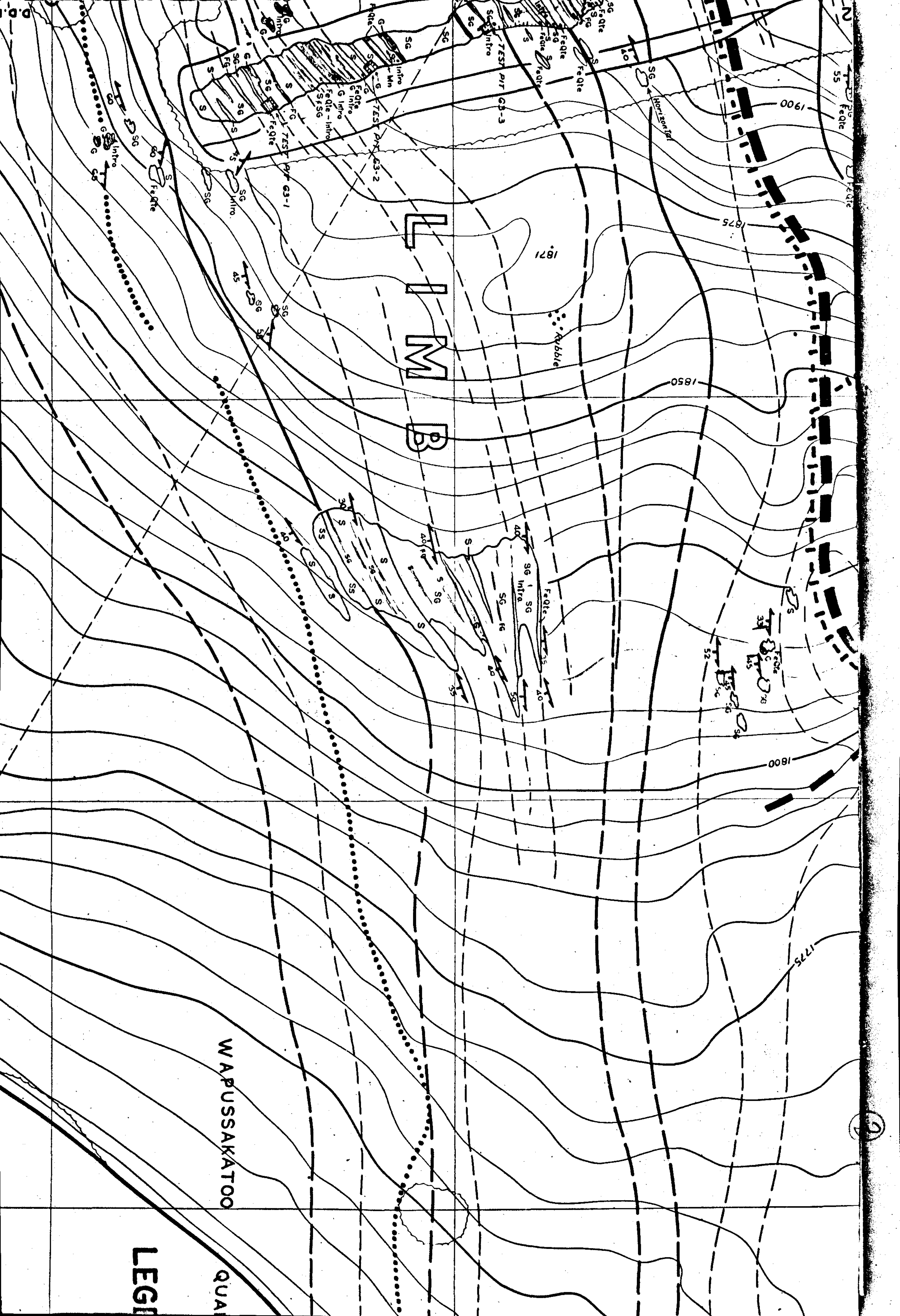
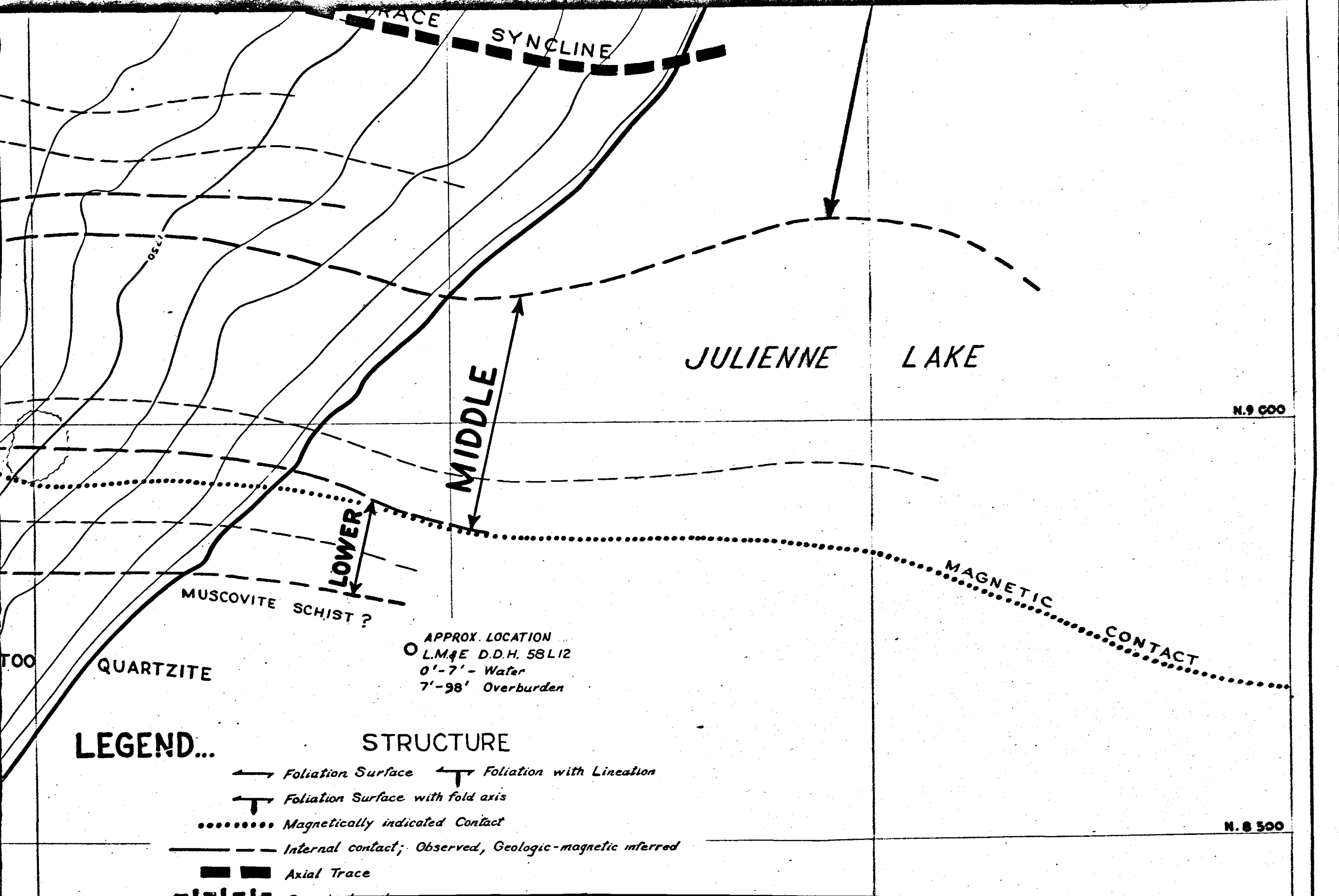
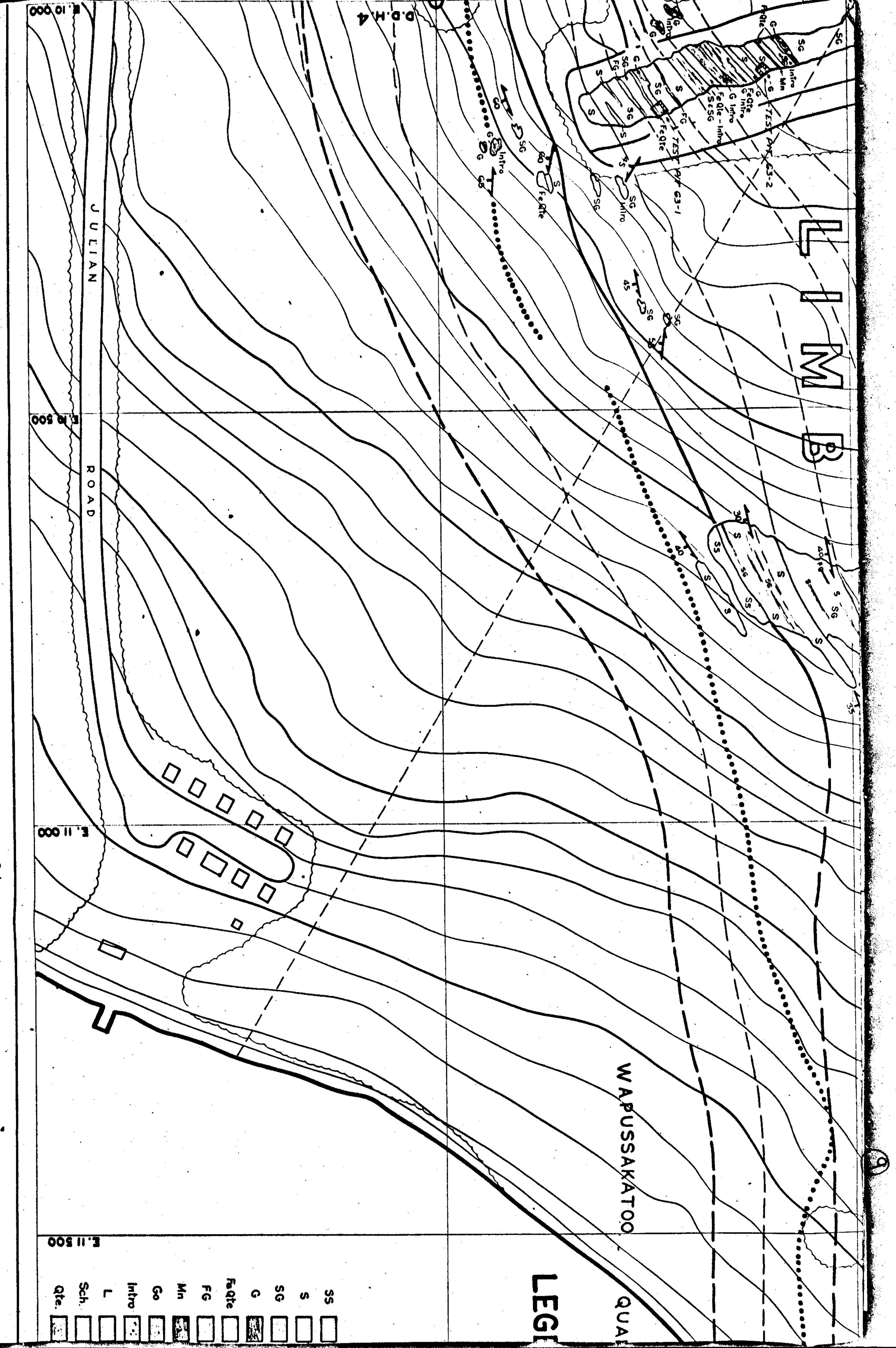
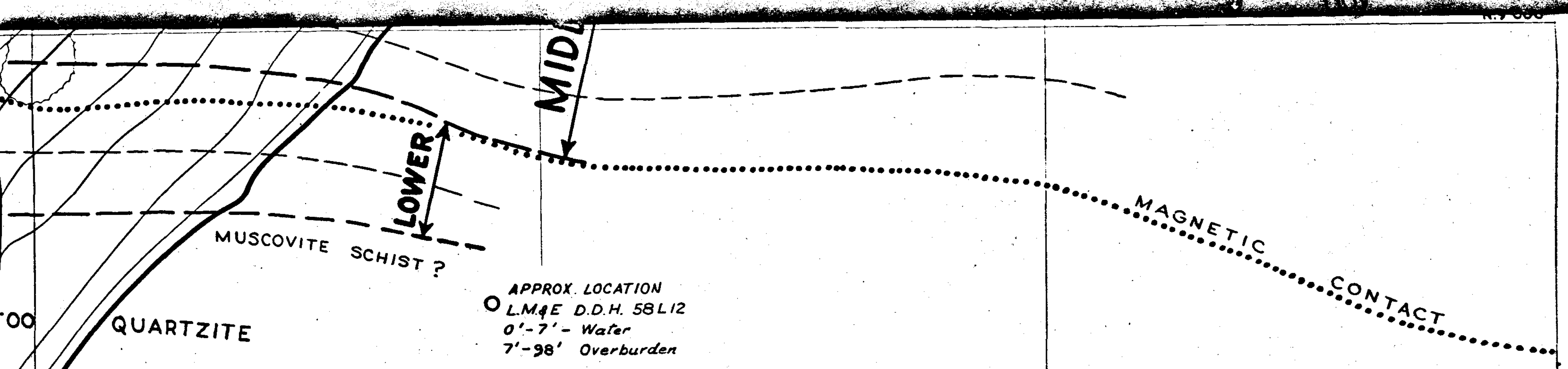
D.D.H. 8
SG
1750
176
AXIAL TRACE SYNCLINE
UPPER
N.9 500
N.10 000


L I M B
WAPUSSAKATOO
QUA
LEGE
1900
1875
1871
1850
1800
1775
Rubble
Horizontal
TEST PIT G3-1
TEST PIT G3-2
TEST PIT G3-3
SG
S
SS
G
FG
FeQte
Intro
Mn
C
N



TRACE
SYNCLINE
1750
JULIENNE LAKE
MIDDLE
LOWER
N.9 000
N.8 500
MUSCOVITE SCHIST ?
MAGNETIC CONTACT
TOO
QUARTZITE
APPROX. LOCATION
L.M.&E D.D.H. 58L12
0'-7' - Water
7'-98' Overburden
LEGEND...
STRUCTURE
Foliation Surface
Foliation with Lineation
Foliation Surface with fold axis
Magnetically indicated Contact
Internal contact; Observed, Geologic-magnetic inferred
Axial Trace


E.10 000
E.10 500
E.11 000
E.11 500
JULIAN ROAD
O.D.H. 4
LIMB
WAPUSSAKATOO
QUA
LEGE
TEST PIT G3-1
TEST PIT G3-2
SS
S
SG
G
FeQte
FG
Mn
Go
Intro
L
Sch.
Qte.
30
40
45
35



LEGEND...

STRUCTURE

- ⟷ Foliation Surface ⟷ Foliation with Lineation
- ⟷ Foliation Surface with fold axis
- ••••••••• Magnetically indicated Contact
- ——— — — Internal contact; Observed, Geologic-magnetic inferred
- ▬ ▬ Axial Trace
- -|-|-|- Domain boundary

MINERALOGY

SS	☐	*Qtz-Specular Hematite and leached Silicate*
S	☐	*Qtz.-Specular Hematite*
SG	☐	*Qtz.-Specular and Granular Hematite*
G	▨	*Qtz.-Granular Hematite*
FeQte	☐	*Ferruginous Quartzite - lean I.F.*
FG	☐	*Very fine grained, cherty, blue Hematite*
Mn	▨	*Manganiferous*
Go	▨	*Siliceous Goethite*
Intro	▨	*Introduced ferruginous material*
L	☐	*Limonitic*
Sch.	☐	*Muscovite Schist*
Qte.	▨	*White Quartzite*

STRATIGRAPHY

WABUSH IRON FORMATION	UPPER	*Iron Formation, largely Qtz. Spec.* *abundant Fe Qte*
	MIDDLE	*Iron Formation, Qtz., Spec. & Spec. Gran.* *largely Qtz. Spec.*
	LOWER	*Iron Formation, Qtz., Spec, Spec. Sil.* *siliceous Goethite*

MUSCOVITE SCHIST

WAPUSSAKATOO QUARTZITE

E.11 500

E.12 000

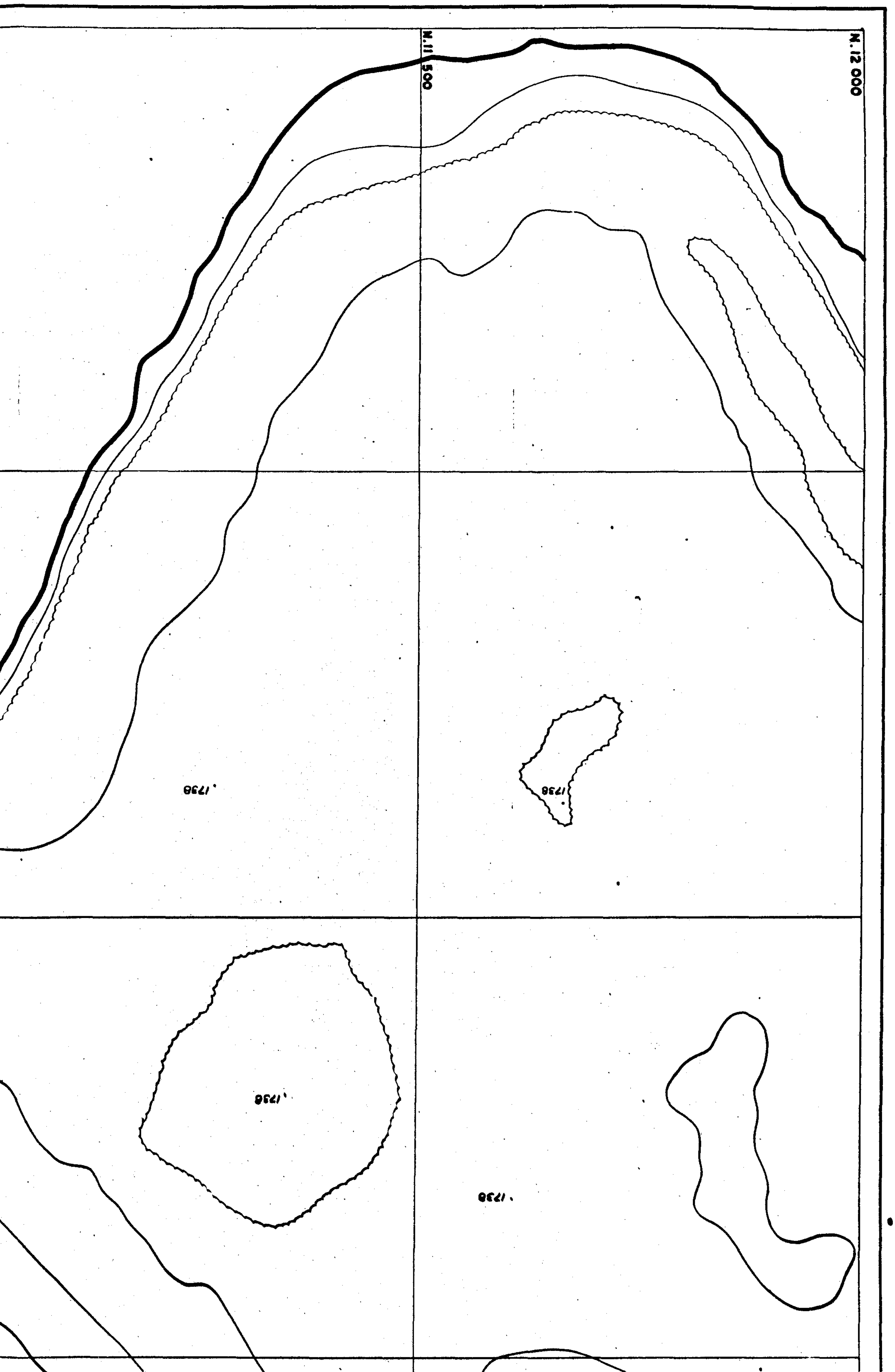
N.8 500

JULIENNE LAKE DEPOSIT

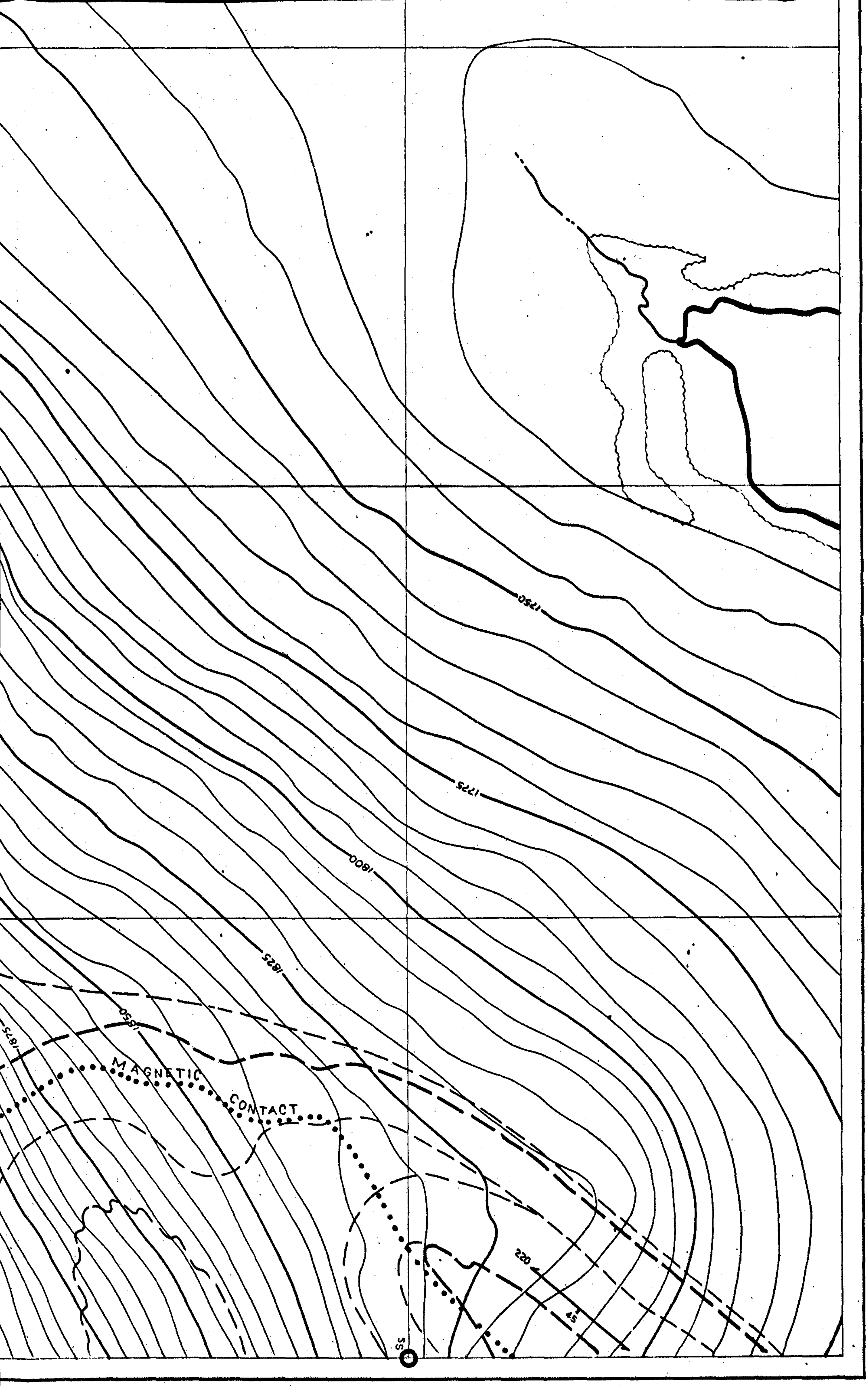
GEOLOGIC PLAN

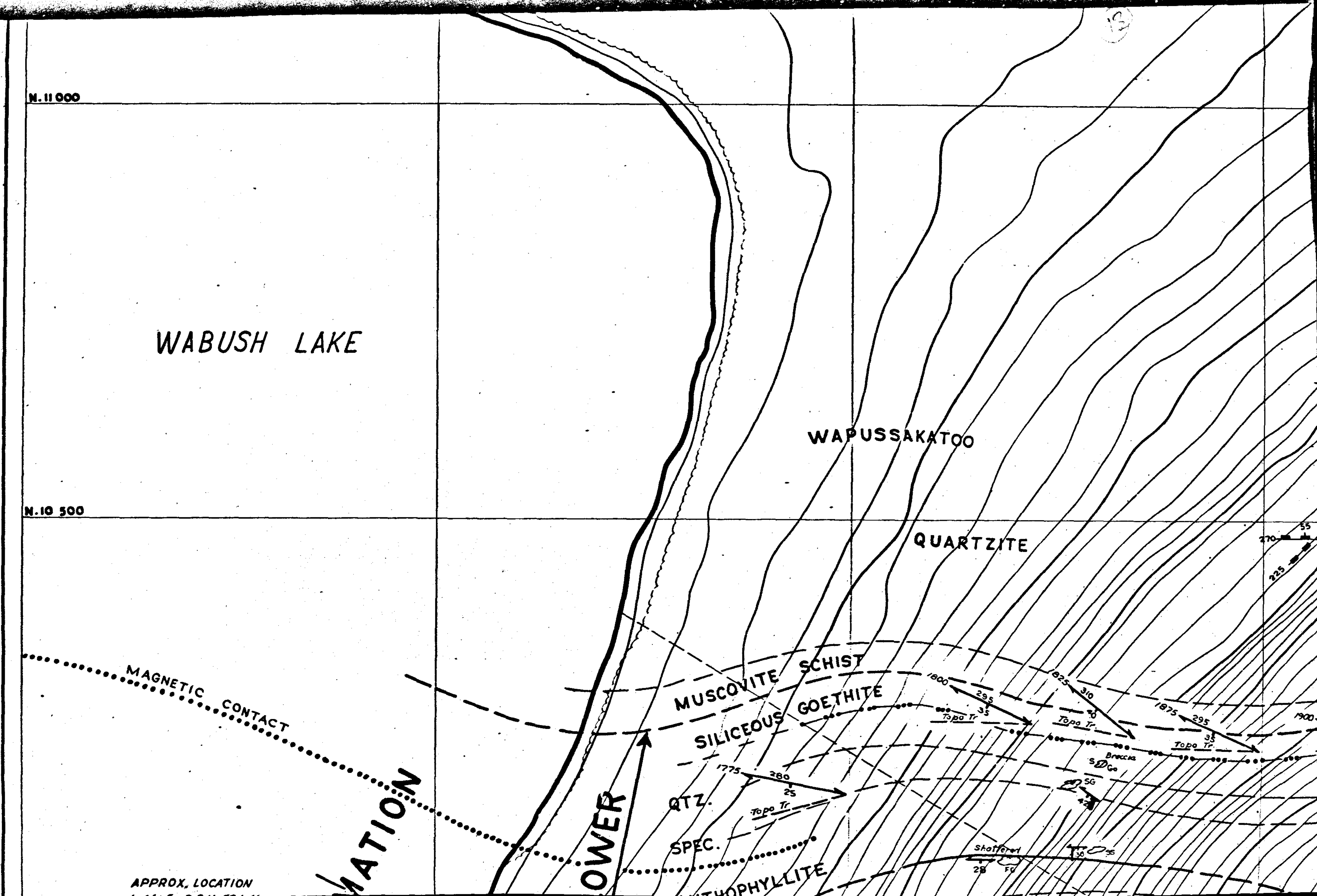
SCALE: 1"=100'

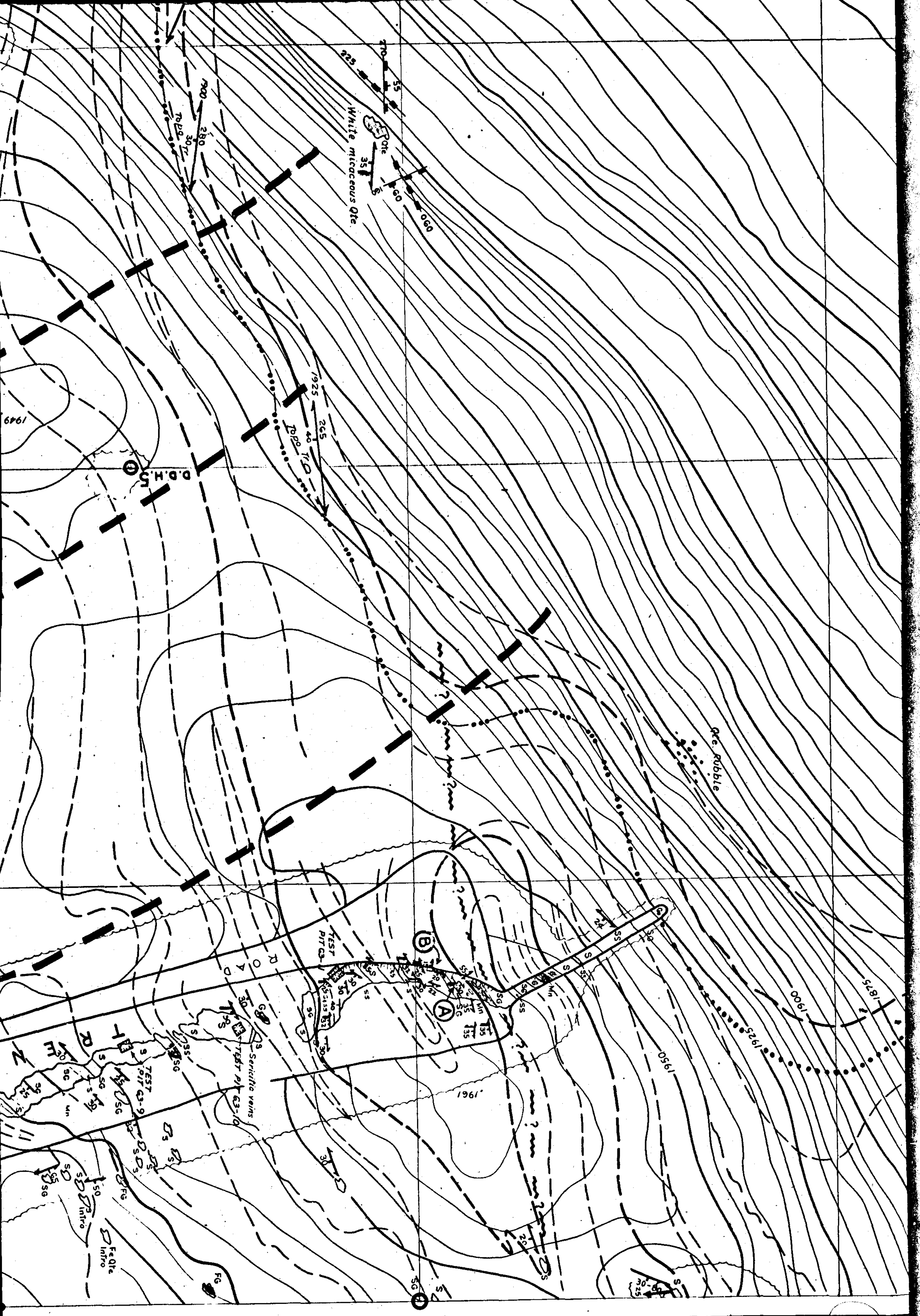
EAST SHEET



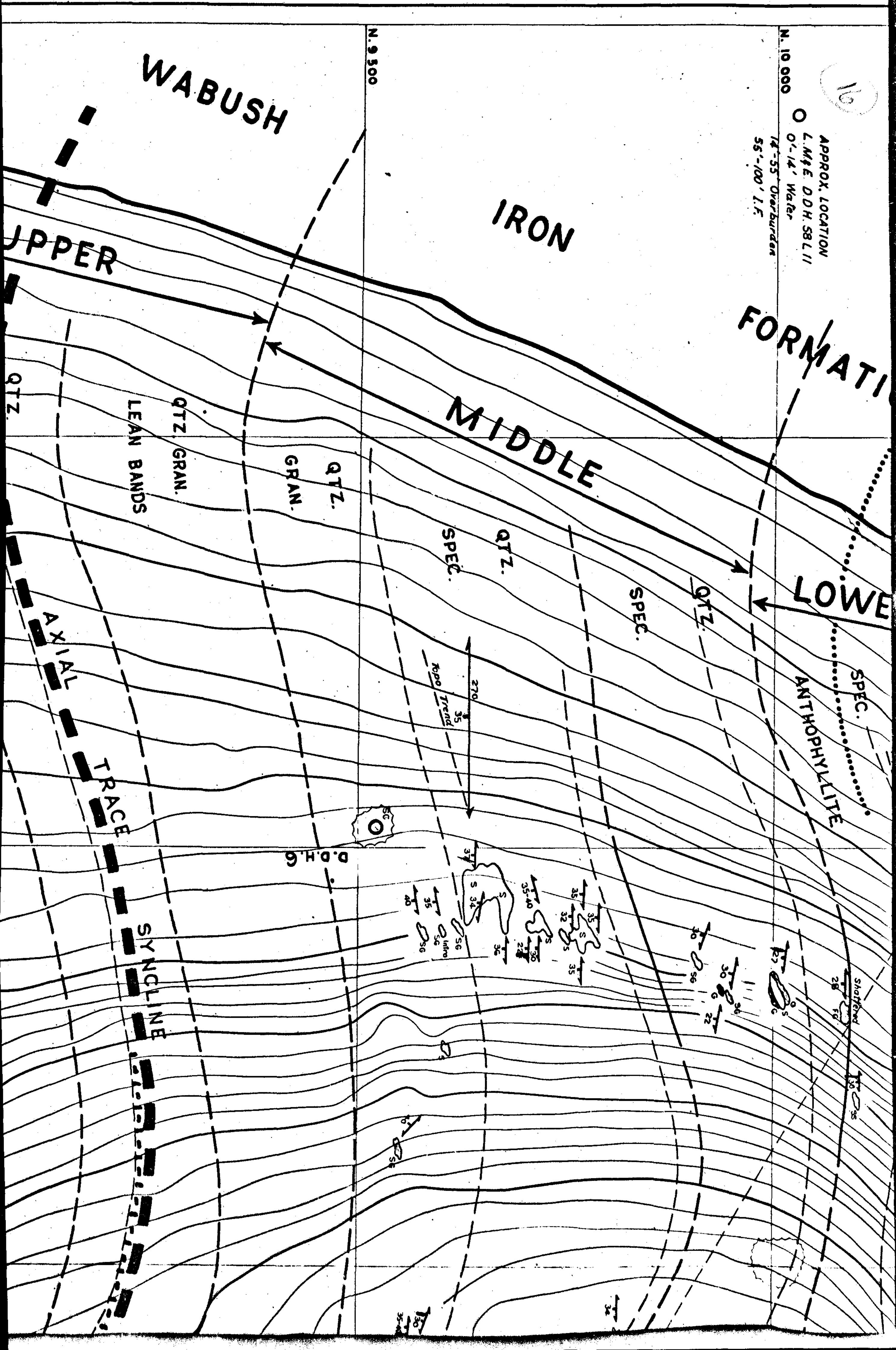
11

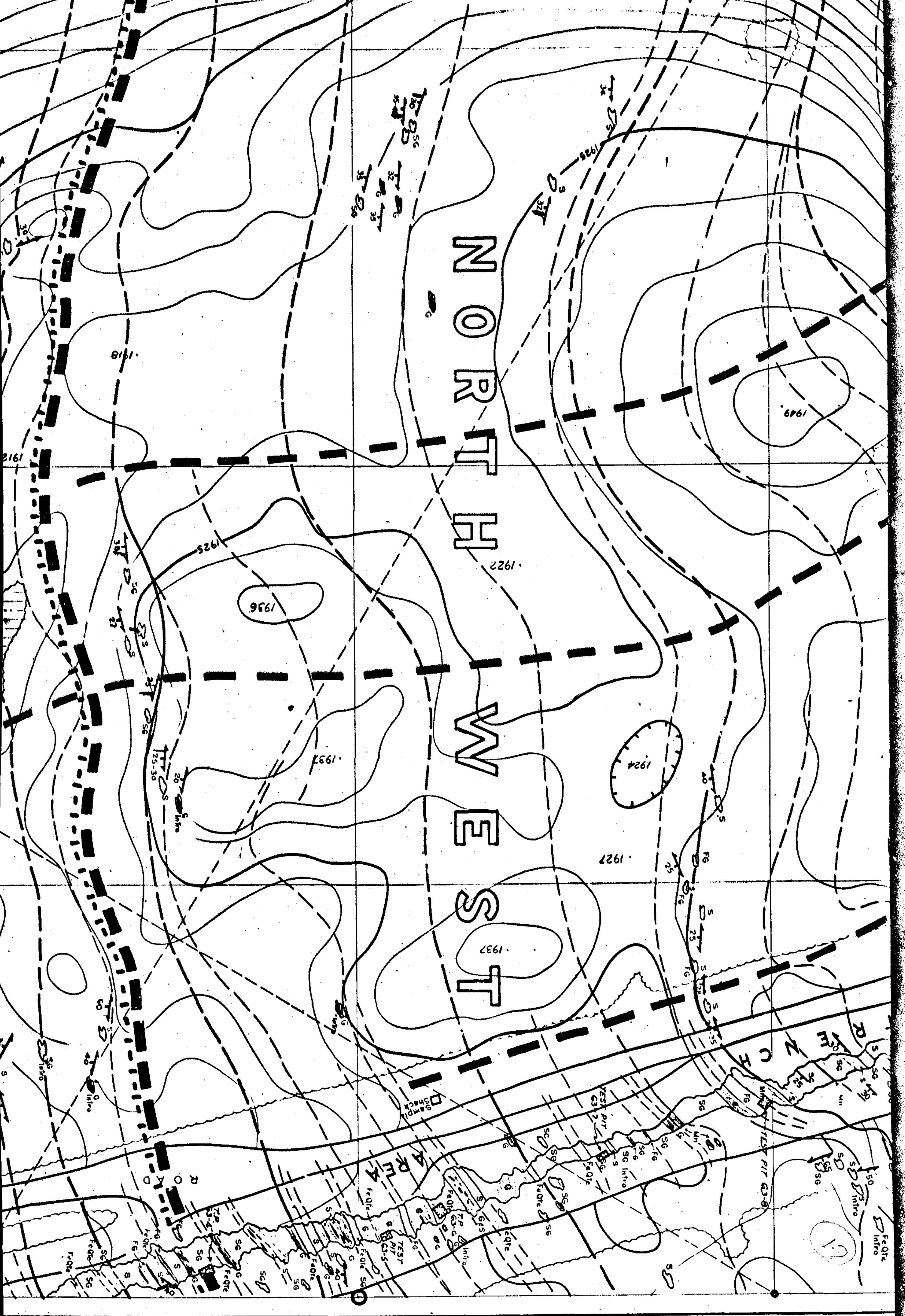

1750
1775
1800
1825
1850
1825
MAGNETIC CONTACT
220
45
SS

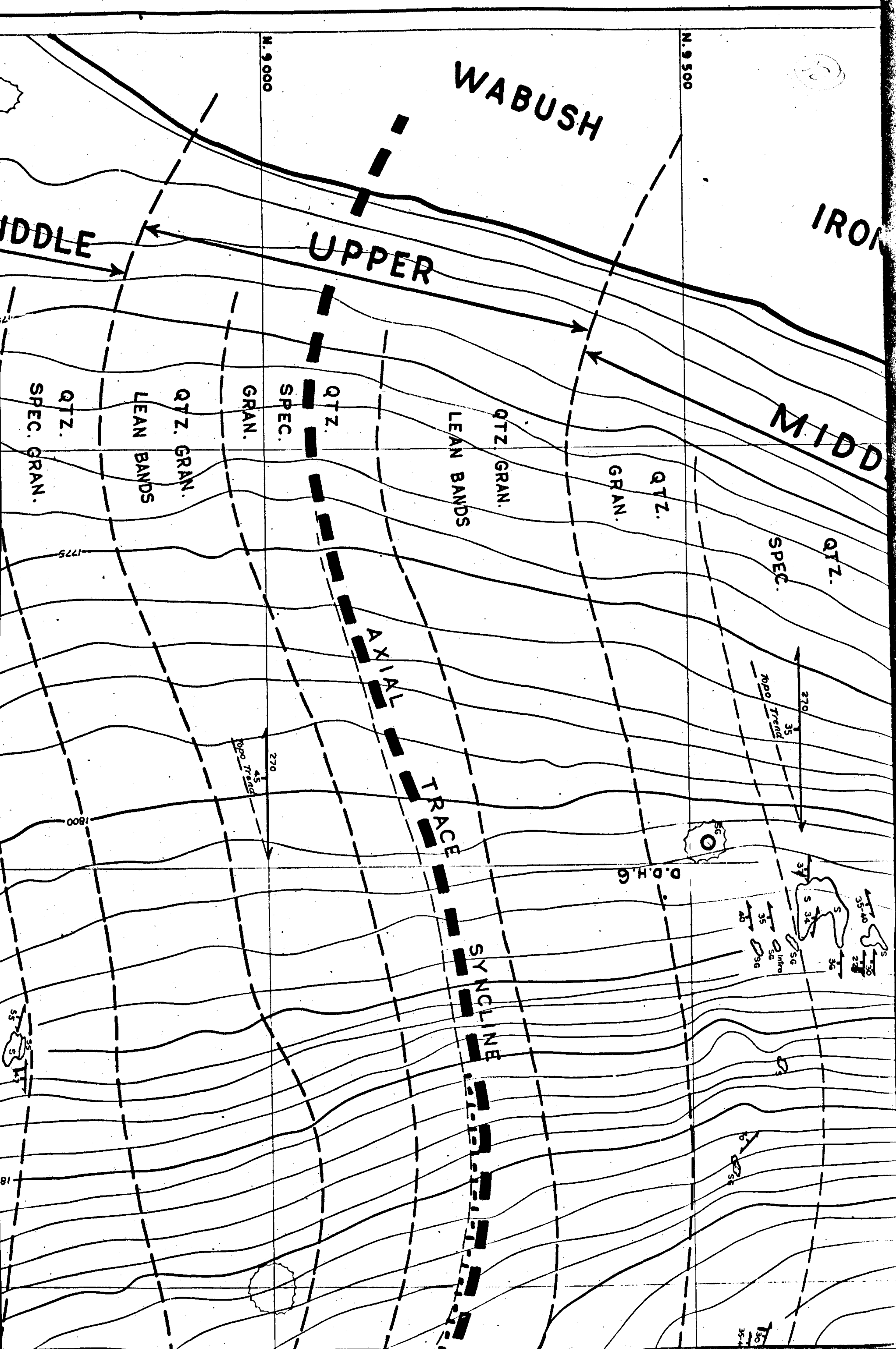

N. 11 000
N. 10 500
WABUSH LAKE
WAPUSSAKATOO
QUARTZITE
MAGNETIC CONTACT
MUSCOVITE SCHIST
SILICEOUS GOETHITE
QTZ.
SPEC.
ATION
OWER
APPROX. LOCATION
THOPHYLLITE
1775
280
25
Topo Tr.
1800
295
35
1825
310
40
1875
295
35
1900
Breccia
SG
Go
42
Shattered
28
FG
30
35
270
55
225


White micaceous Qte
Qte
Qte Rubble
Topo Tr.
D.D.H. 5
1949
1925
1900
1875
1950
1961
225
270
280
300
060
2C5
TEST PIT C3-
TEST PIT C3-9
TEST PIT C3-10
Sericite veins
R O A D
Z E T R
A
B
SG
SS
S
FG
Mn
Intro
Fe Qte Intro

16


WABUSH
IRON
FORMATI
UPPER
MIDDLE
LOWE
N. 9 500
N. 10 000
APPROX. LOCATION
L.M&E. D.D.H. 58L11
0'-14' Water
14'-55' Overburden
55'-100' I.F.
QTZ.
QTZ. GRAN.
LEAN BANDS
QTZ.
GRAN.
SPEC.
QTZ.
SPEC.
QTZ.
SPEC.
ANTHOPHYLLITE
AXIAL
TRACE
SYNCLINE
270
Topo Trend
35
D.D.H. 6
SG
S
37
34
35-40
35
32
35
35
40
35
36
24
30
SG
Infra
30
S6
30
G
36
22
27
G
S
28
FG
Shattered
30
S6
SG
35
34


NORTHWEST
TREND
ROAD
1918
1925
1928
1936
1937
1922
1949
1924
1927
1937
TEST PIT G3-5
TEST PIT G3-8
TEST PIT G3-7
Sample Shack
SG
FG
FeQte
Intro


N.9000
N.9500
WABUSH
IRO
IDDLE
UPPER
MIDD
QTZ.
SPEC. GRAN.
LEAN BANDS
QTZ. GRAN.
GRAN.
SPEC.
QTZ.
LEAN BANDS
QTZ. GRAN.
QTZ.
GRAN.
SPEC.
QTZ.
1775
AXIAL
TRACE
SYNCLINE
Topo Trend
270
45
Topo Trend
270
35
1800
D.D.H. 6
SG
S
Intra
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37
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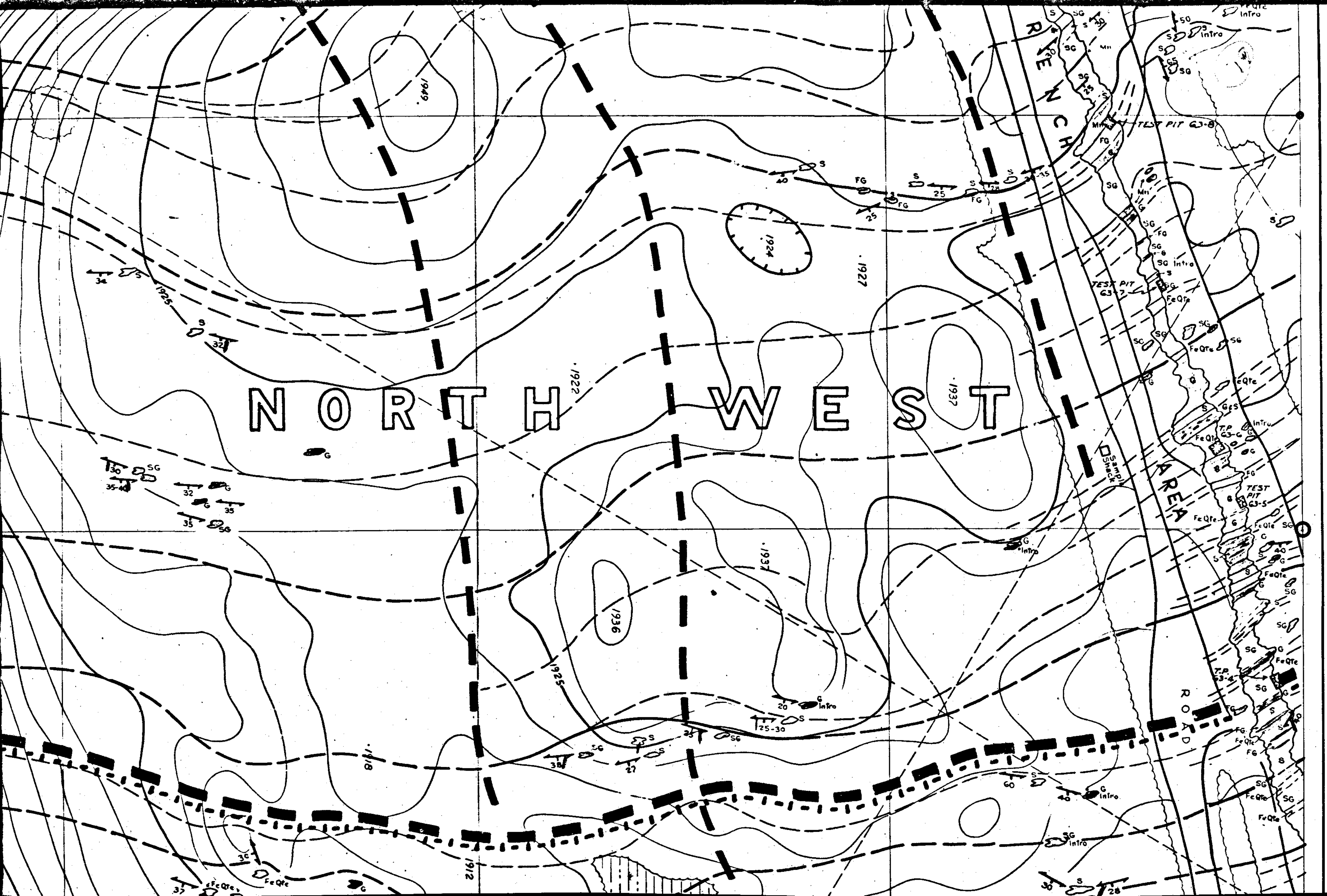
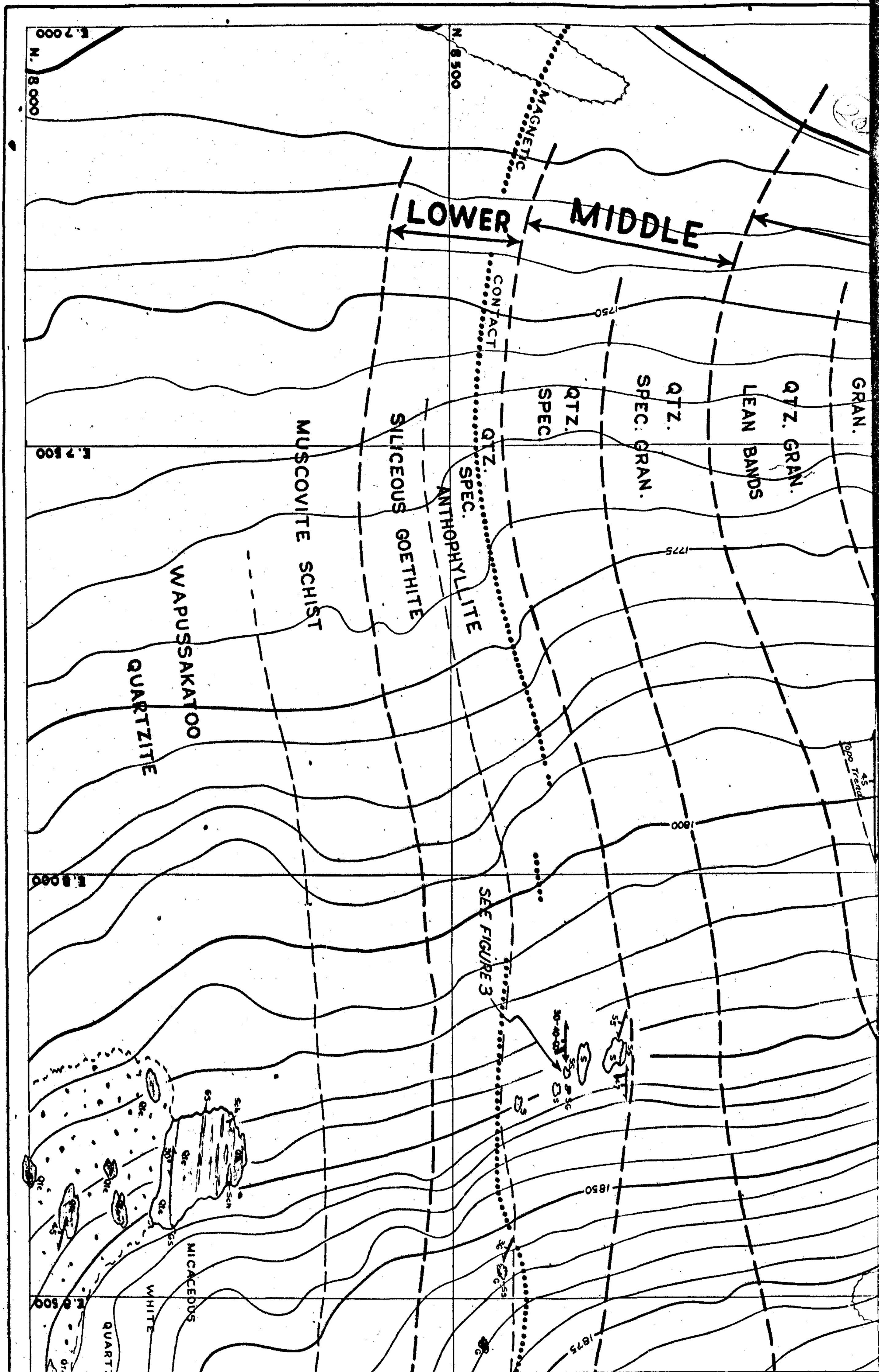
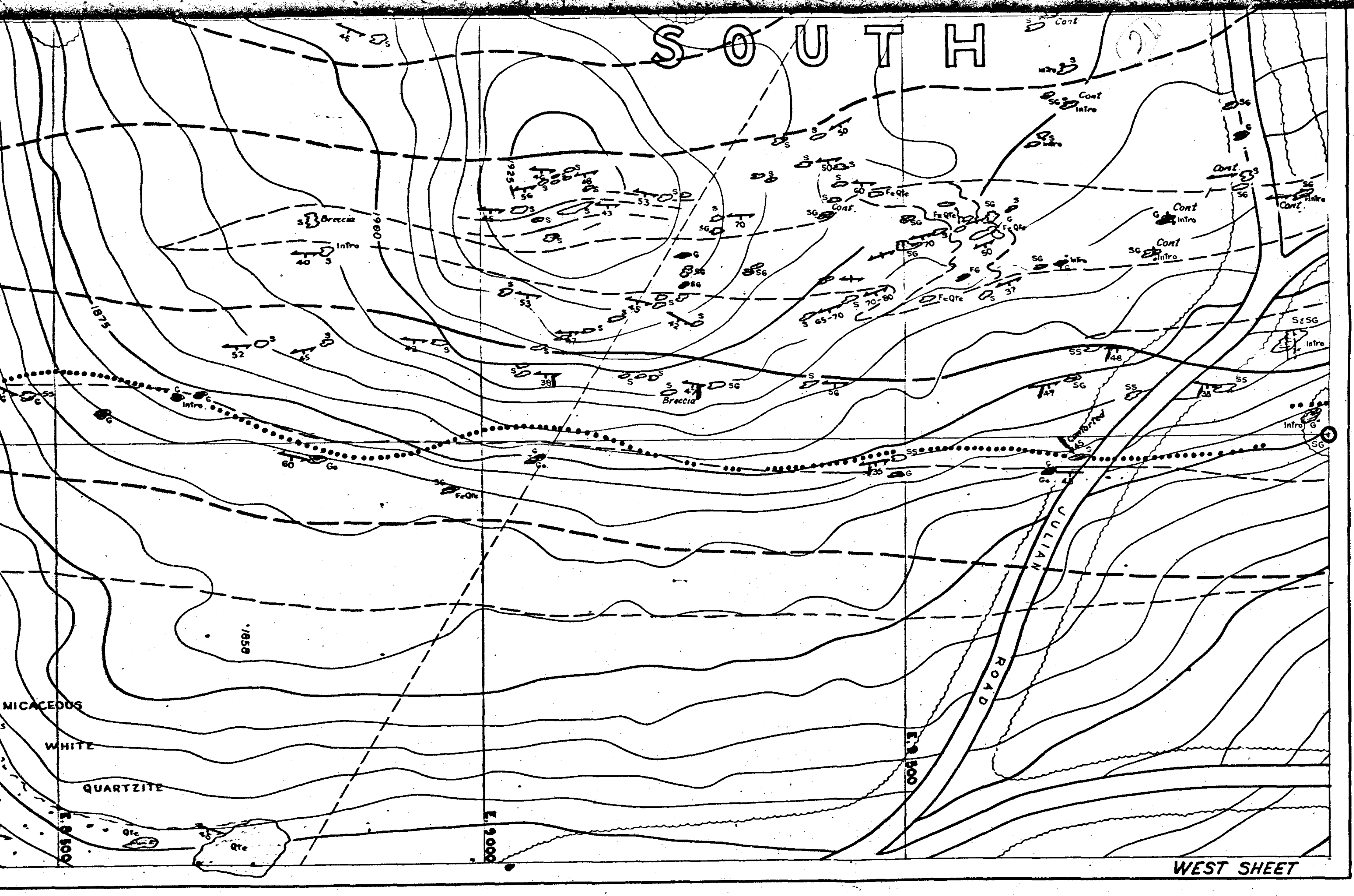
40
35-40
36
28
30
35

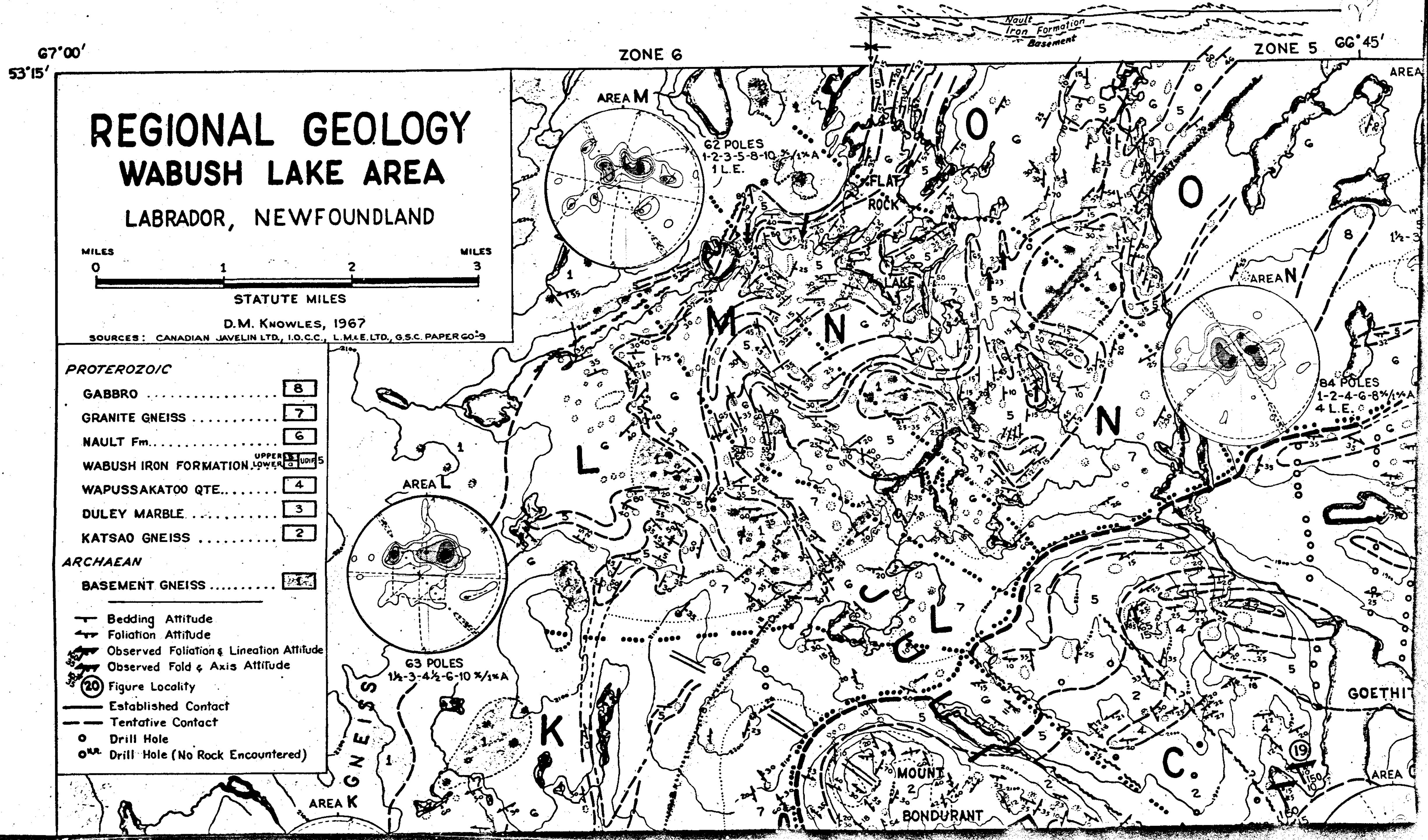


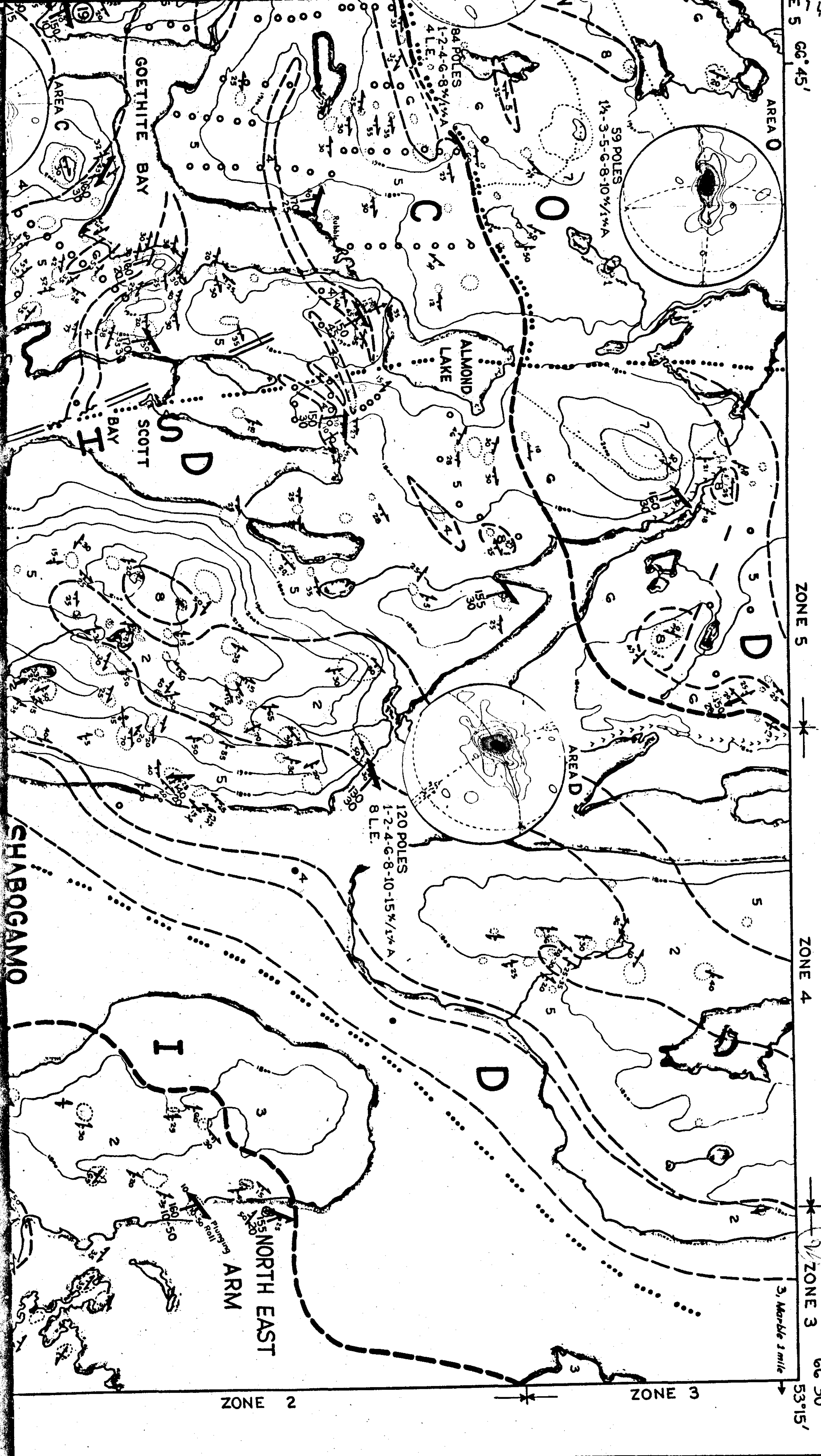
NORTH WEST
RENCH
AREA
ROAD
TEST PIT G3-8
TEST PIT G3-7
T.P. G3-6
TEST PIT G3-5
T.P. G3-4
Sample Shack
1949
1924
1927
1922
1937
1937
1936
1925
1925
1918
1912
S
SG
G
FG
FeQte
Intro
Mn

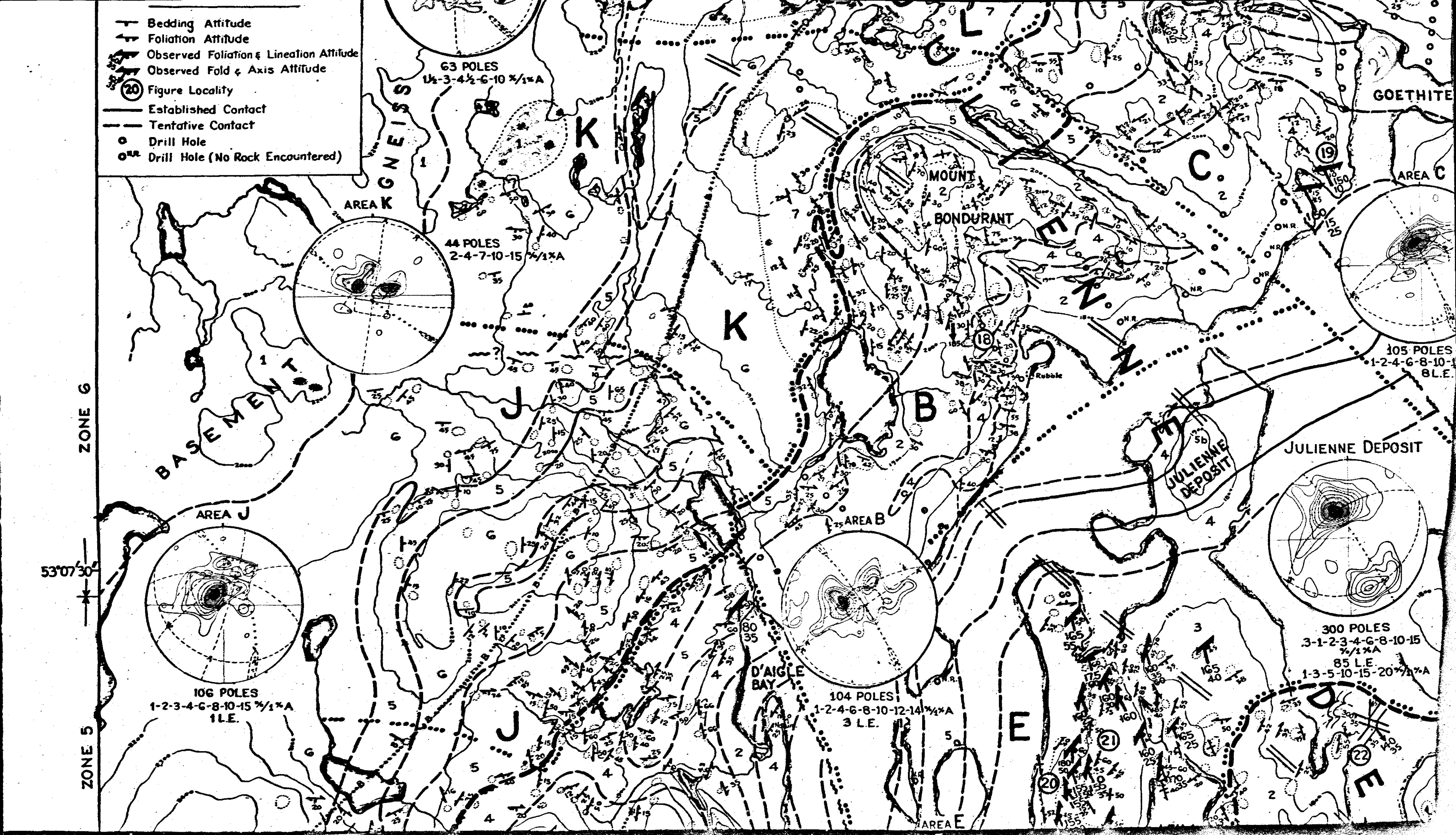


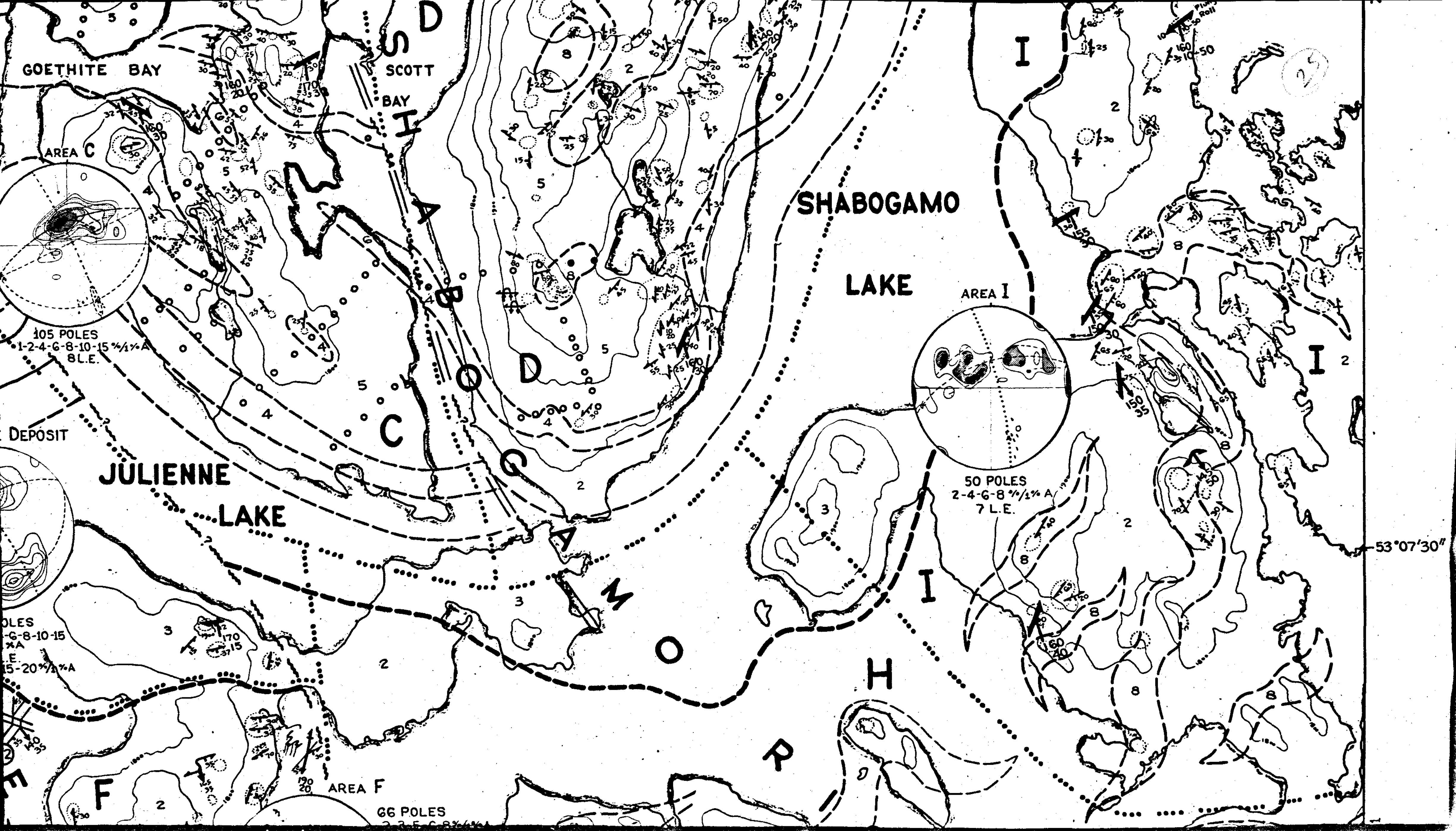
E. 7 000
N. 8 000
N. 8 500
MAGNETIC
CONTACT
LOWER
MIDDLE
1750
1775
1800
1850
1875
GRAN.
QTZ. GRAN.
LEAN BANDS
QTZ.
SPEC. GRAN.
QTZ.
SPEC.
QTZ.
SPEC.
ANTHOPHYLLITE
SILICEOUS GOETHITE
MUSCOVITE SCHIST
WAPUSSAKATOO
QUARTZITE
E. 7 500
E. 8 000
E. 8 500
SEE FIGURE 3
45
Topo Trend
Qtz
MICACEOUS
WHITE
QUART

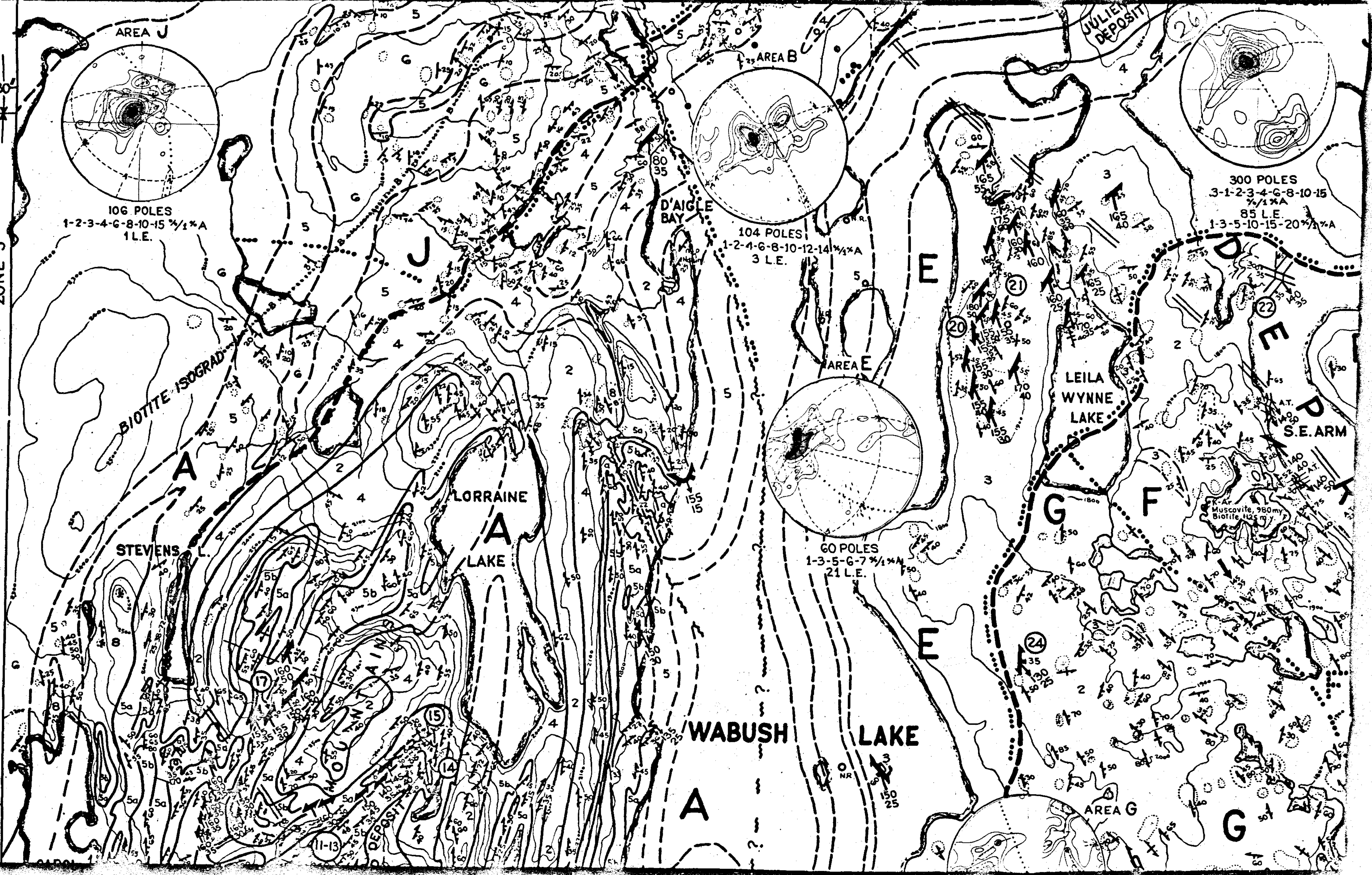

SOUTH
WEST SHEET
JULIAN ROAD
MICACEOUS
WHITE
QUARTZITE
E. 8500
E. 9000
E. 9500
1875
1900
1925
1858
Breccia
Intro
Cont
Contorted
Fe Qtz
Qtz
S
SG
SS
G
S & SG

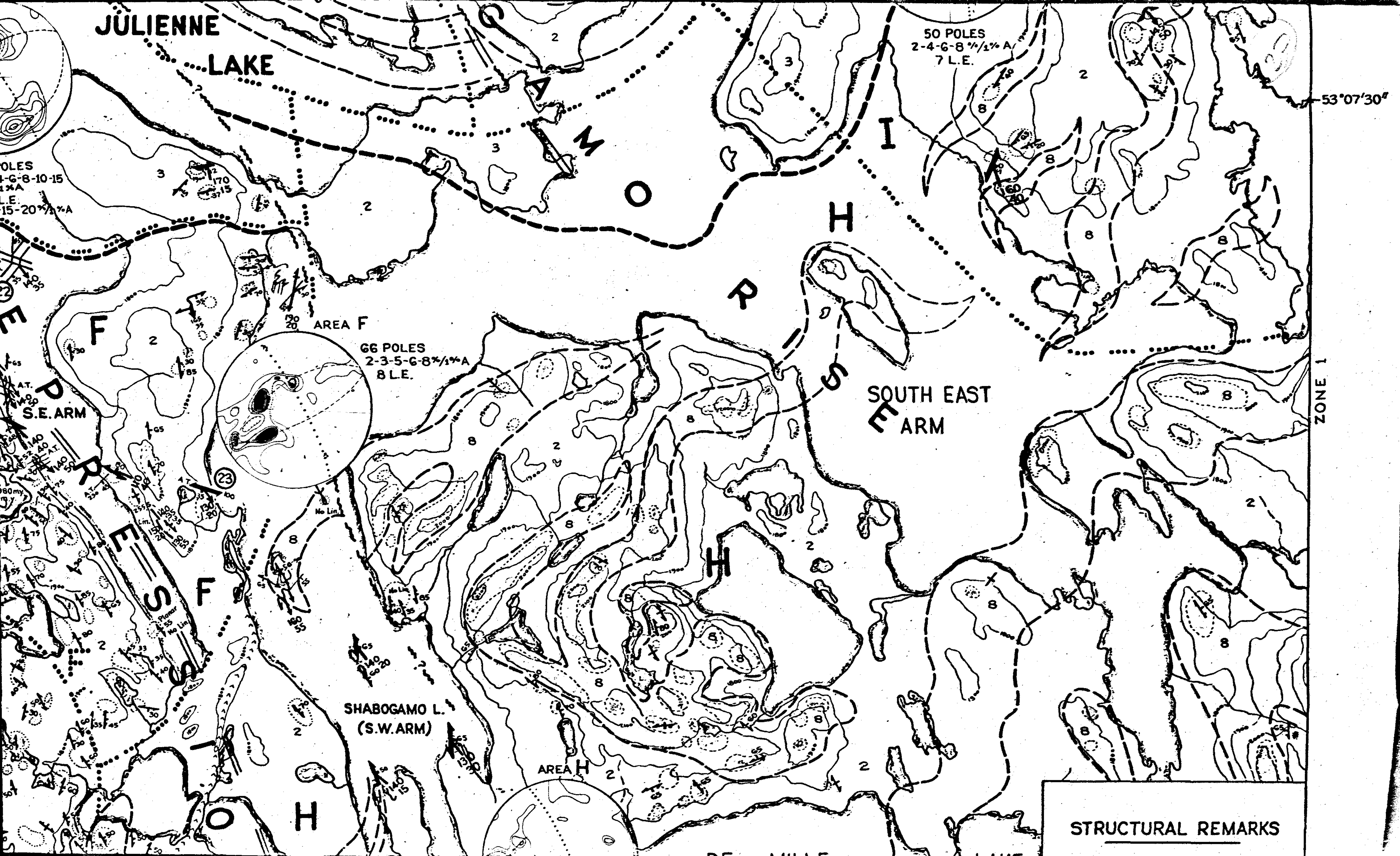
REGIONAL GEOLOGY
WABUSH LAKE AREA
LABRADOR, NEWFOUNDLAND
MILES 0 1 2 3 MILES
STATUTE MILES
D.M. Knowles, 1967
SOURCES: CANADIAN JAVELIN LTD., I.O.C.C., L.M.&E.LTD., G.S.C. PAPER 60-9
PROTEROZOIC
GABBRO 8
GRANITE GNEISS 7
NAULT Fm. 6
WABUSH IRON FORMATION UPPER LOWER 5
WAPUSSAKATOO QTE. 4
DULEY MARBLE 3
KATSAO GNEISS 2
ARCHAEAN
BASEMENT GNEISS 1
Bedding Attitude
Foliation Attitude
Observed Foliation & Lineation Attitude
Observed Fold & Axis Attitude
⑳ Figure Locality
Established Contact
Tentative Contact
Drill Hole
Drill Hole (No Rock Encountered)
67°00'
53°15'
ZONE 6
ZONE 5
66°45'
Nault
Iron Formation
Basement
AREA M
G2 POLES
1-2-3-5-8-10 %/1% A
1 L.E.
AREA L
G3 POLES
1½-3-4½-6-10 %/1% A
AREA N
84 POLES
1-2-4-6-8%/1% A
4 L.E.
AREA K
GNEISS
FLAT ROCK LAKE
MOUNT BONDURANT
GOETHIT
AREA
K
L
M
N
O
C
⑲

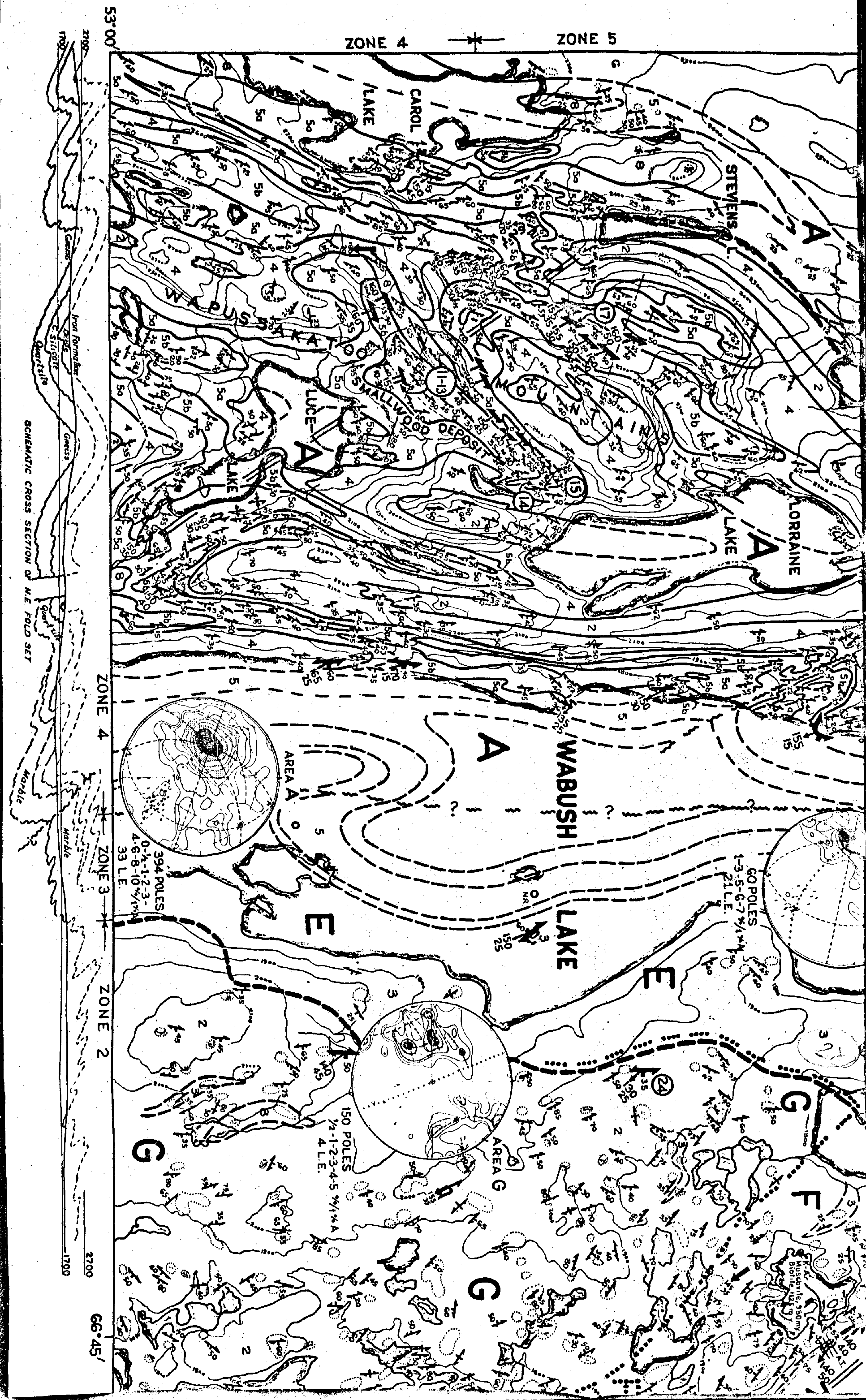

GOETHITE BAY
AREA C
84 POLES
1-2-4-6-8%/1% A
4 L.E.
59 POLES
1½-3-5-6-8-10%/1% A
AREA O
ALMOND LAKE
SCOTT BAY
AREA D
120 POLES
1-2-4-6-8-10-15%/1% A
8 L.E.
SHABOGAMO
NORTH EAST ARM
Plunging Roll
ZONE 5
ZONE 4
ZONE 3
ZONE 2
ZONE 3
GC°45'
GC°30'
53°15'
3, Marble 1 mile

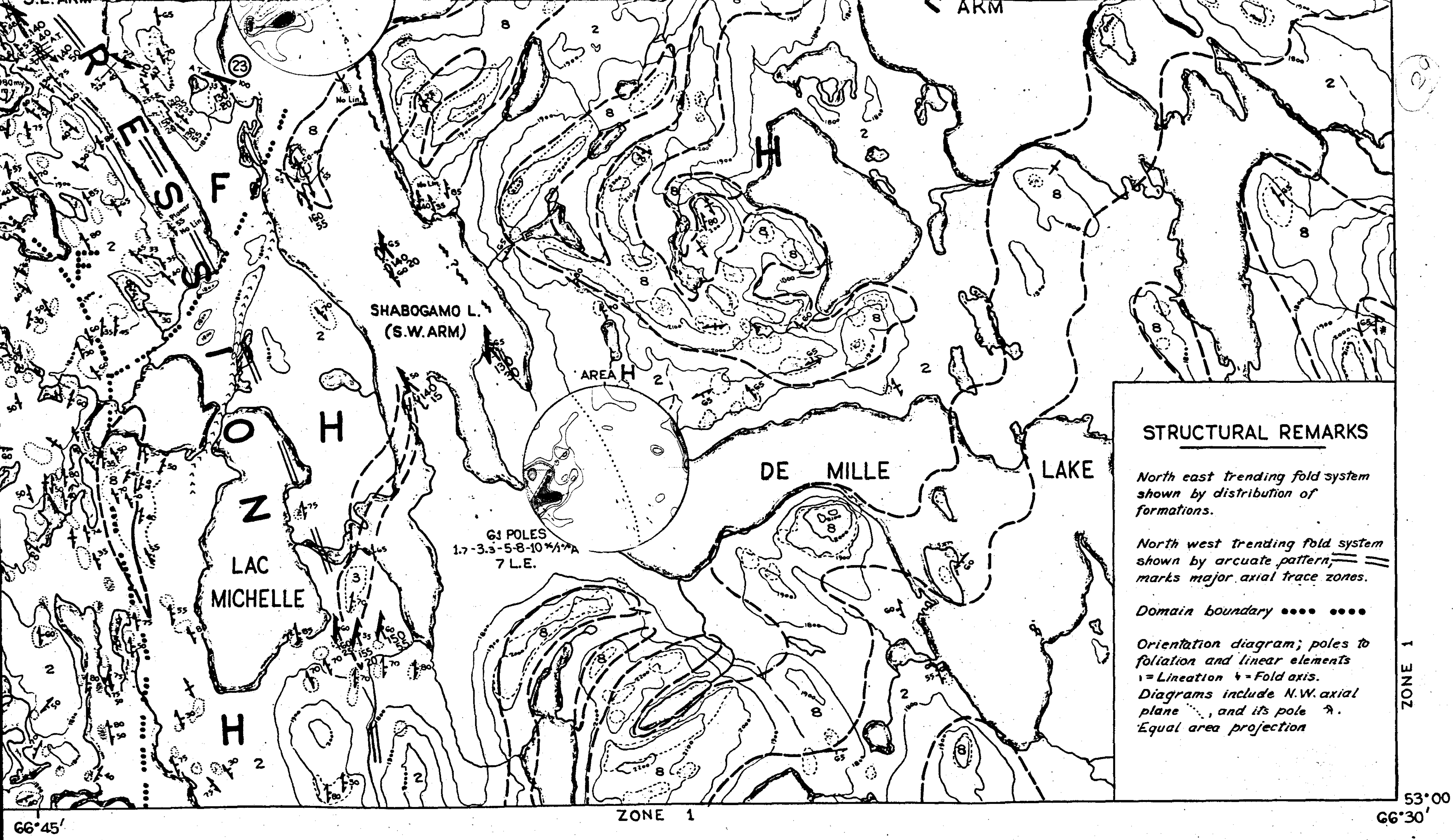

Bedding Attitude
Foliation Attitude
Observed Foliation & Lineation Attitude
Observed Fold & Axis Attitude
20 Figure Locality
Established Contact
Tentative Contact
Drill Hole
Drill Hole (No Rock Encountered)
ZONE 6
ZONE 5
53°07'30"
BASEMENT
GNEISS
AREA K
44 POLES
2-4-7-10-15 %/1%A
63 POLES
1½-3-4½-6-10 %/1%A
AREA J
106 POLES
1-2-3-4-6-8-10-15 %/1%A
1 L.E.
AREA B
104 POLES
1-2-4-6-8-10-12-14 %/1%A
3 L.E.
D'AIGLE BAY
MOUNT BONDURANT
AREA C
105 POLES
1-2-4-6-8-10-1
8 L.E.
GOETHITE
JULIENNE DEPOSIT
JULIENNE DEPOSIT
300 POLES
3-1-2-3-4-6-8-10-15
%/1%A
85 L.E.
1-3-5-10-15-20 %/1%A
AREA E
J
K
L
C
B
E
N
D
E
18
19
20
21
22
Rubble


GOETHITE BAY
SCOTT BAY
AREA C
105 POLES
1-2-4-6-8-10-15 %/1% A
8 L.E.
DEPOSIT
JULIENNE LAKE
SHABOGAMO LAKE
AREA I
50 POLES
2-4-6-8 %/1% A
7 L.E.
AREA F
66 POLES
S H A B O G A M O
D
C
H
I
F
OLES
-6-8-10-15
15-20 %/1% A
53°07'30"


ZONE 5
ZONE 5
53°07'30"
AREA J
106 POLES
1-2-3-4-6-8-10-15 %/1%A
1 L.E.
AREA B
104 POLES
1-2-4-6-8-10-12-14 %/1%A
3 L.E.
JULIENNE DEPOSIT
300 POLES
3-1-2-3-4-6-8-10-15 %/1%A
85 L.E.
1-3-5-10-15-20 %/1%A
D'AIGLE BAY
AREA E
60 POLES
1-3-5-6-7 %/1%A
21 L.E.
BIOTITE ISOGRAD
STEVENS L.
LORRAINE
LAKE
MOUNTAIN
DEPOSIT
WABUSH
LAKE
LEILA WYNNE LAKE
S.E. ARM
K-Ar
Muscovite, 980 my
Biotite, 1125 m.y.
AREA G
A
A
A
A
J
E
E
E
F
G
G
D
P


JULIENNE LAKE
50 POLES
2-4-6-8 %/1% A
7 L.E.
53°07'30"
ZONE 1
POLES
4-6-8-10-15
L.E.
15-20%/1%A
AREA F
66 POLES
2-3-5-6-8%/1%A
8 L.E.
S.E. ARM
SOUTH EAST ARM
SHABOGAMO L.
(S.W. ARM)
AREA H
STRUCTURAL REMARKS
22
23
F
H
E P R E S S I O N
H O R S E
C A M O
I


53°00'
ZONE 4
ZONE 5
CAROL LAKE
STEVENS L.
WAPUS SAKATOO MOUNTAIN
SMALLWOOD DEPOSIT
LUCE LAKE
LORRAINE LAKE
WABUSH LAKE
AREA A
394 POLES
0-½-1-2-3-4-6-8-10%/1%
33 L.E.
60 POLES
1-3-5-6-7%/1%A
21 L.E.
150 POLES
½-1-2-3-4-5%/1%A
4 L.E.
AREA G
ZONE 3
ZONE 2
A
E
F
G
SCHEMATIC CROSS SECTION OF N.E. FOLD SET
Iron Formation
Gneiss
Quartzite
C. Silicate
Marble
2700
1700
66°45'



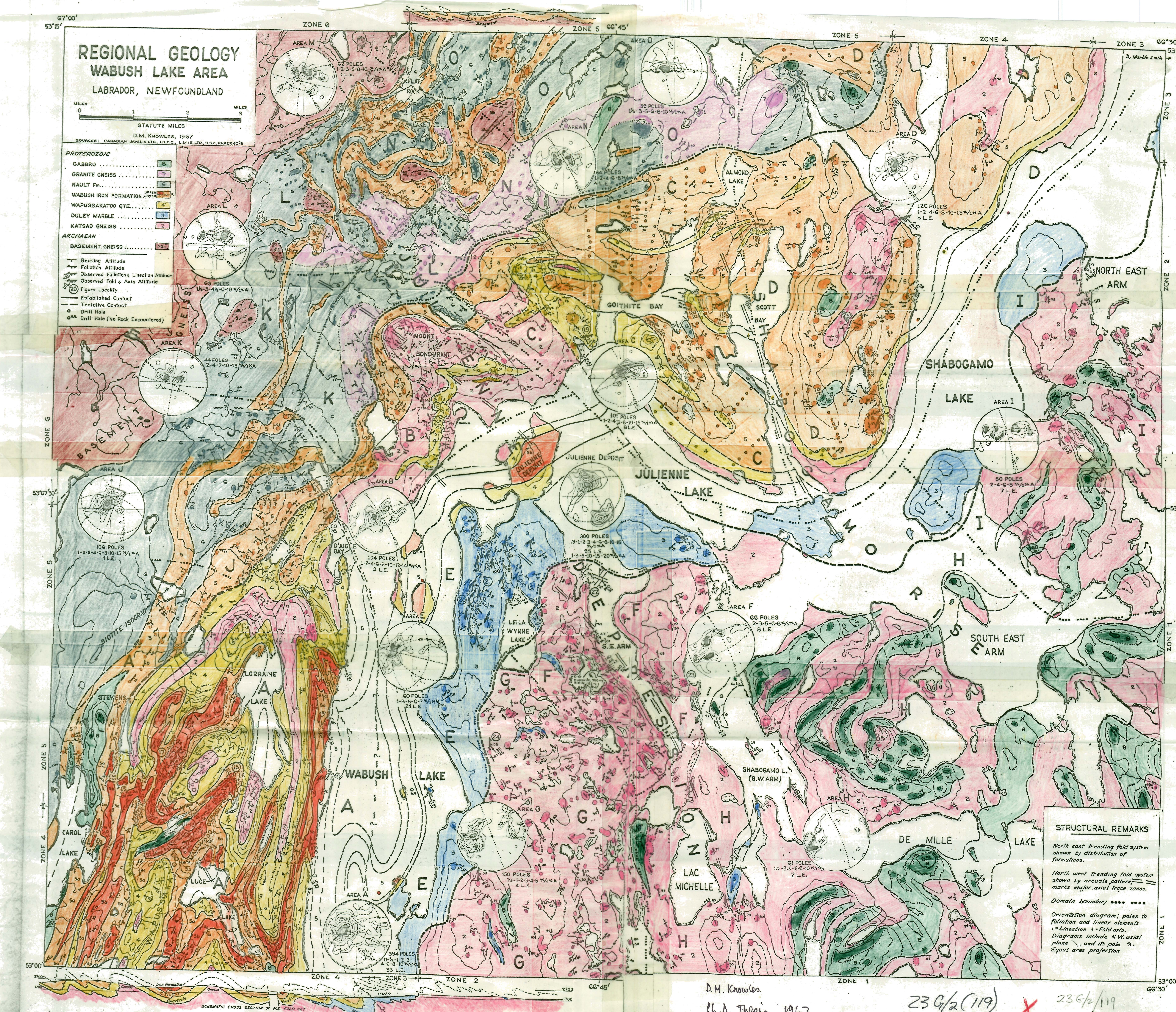
STRUCTURAL REMARKS

North east trending fold system shown by distribution of formations.

North west trending fold system shown by arcuate pattern, ══ marks major axial trace zones.

Domain boundary •••• ••••

Orientation diagram; poles to foliation and linear elements
ı = Lineation ⱡ = Fold axis.
Diagrams include N.W. axial plane ⋯, and its pole ⩚.
Equal area projection



D.M. Knowles.
Ph.D. Thesis 1967

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23G/2/119