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PALEOBASIN ANALYSIS AND STRUCTURE
OF THE ANGUILLE GROUP,
WEST-CENTRAL NEWFOUNDLAND

by

George H. P. Popper

A Dissertation
Presented to the Graduate Committee
of Lehigh University
in candidacy for the Degree of
Doctor of Philosophy
in
Geological Science

Lehigh University

1970

Approved and recommended for acceptance as a
dissertation in partial fulfillment of the requirements
for the degree of Doctor of Philosophy.

September 13, 1970
(Date)

J. Donald Rye
Professor in Charge

Accepted, September 13, 1970
(Date)

Special committee directing the doctoral
work of Mr. George H. P. Popper.

J. Donald Rye, Chairman

Paul B. Myers Jr.

B. W. Parker

James M. Park

Edwin S. Erickson Jr.

ACKNOWLEDGEMENTS

I am indebted to Dr. Ed Belt for introducing me to the intractable Lower Mississippian Strata of Western Newfoundland. Dr. J. Donald Ryan provided guidance in his role as Thesis Advisor "far above and beyond the call of duty." I am grateful both to him and to Dr. Paul B. Myers for overseeing the fieldwork and for giving direction and encouragement during the research. Dr. Ed Erickson gave graciously of his time and resources in help with photography and editing. I also wish to thank Dr. James Parks and Dr. Basil Parker for their advice and for serving on my thesis committee. Professor Sutton Monro helped resolve statistical interpretations.

Warmth, friendship and shelter was provided in Newfoundland by the Tom Gales of Cape Anguille, and the Len Swartzs and Doug Andrews of Deer Lake. Mr. Larry Woods of the Ernest Harmon Air Force Station arrived at the wilderness base camps with a smile and much-needed provisions on several occasions. The Bowaters Company granted me permission to travel on their woods roads and old logging trails.

I greatly appreciate the financial grants which made it possible for me to carry out this research. These were furnished by the Geological Society of America, 1965, 1966; The National Science Foundation, 1966; and the Lehigh University Research Center, 1967.

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ABSTRACT

Lower Mississippian sediments in the Grand Lake region of West-Central Newfoundland were deposited in a downfaulted, northeast trending, dominantly lacustrine paleobasin. Initial deposits consisted of volcanic rock debris derived from an igneous terrain to the east. Shortly thereafter a westerly derived dispersal system was initiated which contributed metamorphic detritus. Coarse material from each of these distinct provenances formed basin marginal deposits. Finer sands and silts were carried farther into the basin and then transported northeastward along the axis into deeper waters.

Sediments accumulated as three different lithologic associations (suites), each representing a successively shallower portion of the paleobasin. Intertonguing at suite boundaries indicates that, at least in part, they are time-equivalents of one another.

Primary structures are present in each of the suites but are disproportionately distributed. Deepest water deposits (siltstone-dolomite suite) are composed of laminated siltstones and ferroan dolomites, and graded graywacke beds which display tool markings and turbidite structures. Desiccation cracks and abundant ripple marks are also present. Crossbeds and parting lineations are most prevalent in the shallow lacustrine and fluvial arkoses, graywackes, and siltstones of the gray sandstone suite. The red arkose suite consists of interbedded alluvial fan (red arkoses), paludal, and shallow

lacustrine (non-graded graywackes and gray siltstones) deposits. The entire section represents a regressive pattern of sedimentation. Abundant red arkoses high in the sequence attest to the unroofing of a granite pluton to the south.

During and possibly subsequent to deposition of the overlying Deer Lake Group, wedge-shaped blocks of Anguille strata were folded and upfaulted through these younger units. Movements took place along high-angle, downward-converging reverse faults. Development of these piercement structures is probably related to strike-slip fault movements.

INTRODUCTION

Purpose and Scope

This study was undertaken in order to obtain a thorough understanding of the history of a sedimentary basin that existed in west-central Newfoundland (the present Grand Lake-Deer Lake area) during the Early Mississippian. The results are intended to provide some insight into the nature and pattern of the sedimentary fill, the interrelations between tectonic movements and resultant sedimentation, and the type of deformation to which the basin was subsequently subjected.

The techniques of basin analysis were applied in order to establish: provenance, current dispersal patterns, mode of transport, and environment of deposition of the sediments, as well as to obtain some knowledge of the configuration of the depositional basin. The basin lies in a critical position along a major regional lineament, the site of sporadic fault activity both during and subsequent to deposition of the Lower Mississippian sediments. As a result, stratigraphic interpretation has been complicated by structural effects and some understanding of the regional deformation is vital for proper interpretation of the

stratigraphy. A portion of this study was therefore devoted to mapping of the larger structural features of the area.

The rocks studied have been assigned to the Lower Mississippian by Baird (1959a) on the basis of plant remains. The designation is accepted for purposes of this study and no attempt was made to carry out detailed correlation of rocks in this region with those of similar age elsewhere in Newfoundland (Anguille Group at the type locality in southwest Newfoundland and the Spear Point Formation of White Bay).

Location

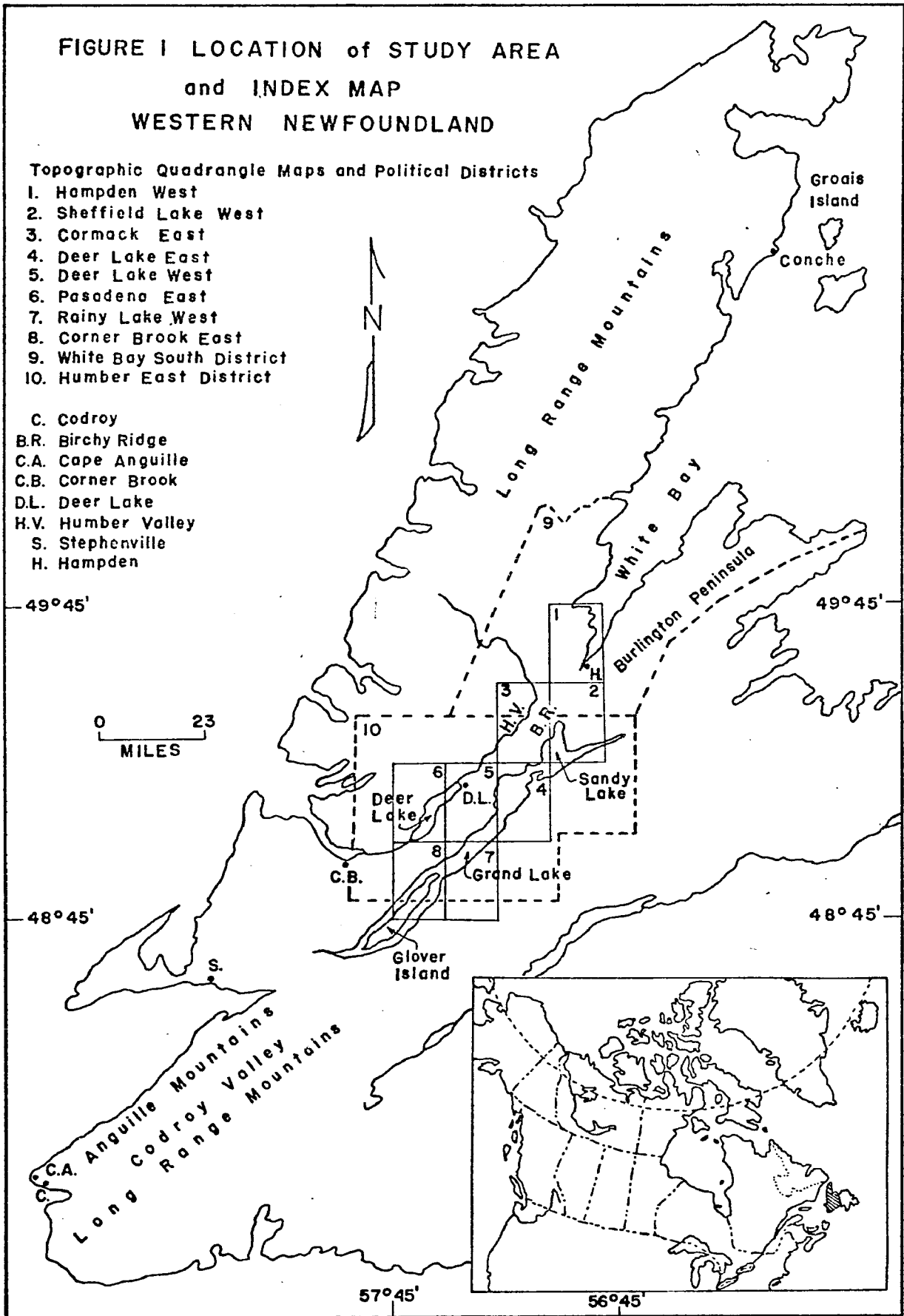
Field work was carried out in west-central Newfoundland during the summers of 1965 and 1966. The specific area of investigation (Figure 1) extends diagonally through a rectangle bounded by north latitudes $49^{\circ} 45'$ and $48^{\circ} 50'$ and west longitudes $56^{\circ} 45'$ and $57^{\circ} 45'$, and is located on portions of the following Canadian Department of Mines and Technical Surveys topographic map sheets (1:50,000 series): Hampden West, Sheffield Lake West, Cormack East, Deer Lake East, Deer Lake West, Pasadena East, Rainy Lake West, and Corner Brook East.

**FIGURE 1 LOCATION of STUDY AREA
and INDEX MAP
WESTERN NEWFOUNDLAND**

Topographic Quadrangle Maps and Political Districts

- 1. Hampden West
- 2. Sheffield Lake West
- 3. Cormack East
- 4. Deer Lake East
- 5. Deer Lake West
- 6. Pasadena East
- 7. Rainy Lake West
- 8. Corner Brook East
- 9. White Bay South District
- 10. Humber East District

- C. Codroy
- BR. Birchy Ridge
- C.A. Cape Anguille
- C.B. Corner Brook
- D.L. Deer Lake
- H.V. Humber Valley
- S. Stephenville
- H. Hampden



Previous Work

Although the existence of Carboniferous basins in western Newfoundland has been recognized since the pioneering field work of Jukes (1843), and Murray and Howley (1881, 1918), until recently little attention had been paid to these rocks. The present study is the only one devoted entirely to an investigation of the Lower Mississippian of the west-central region. Hatch (1919) filed a report with the Newfoundland government based on information gathered from four drill holes for coal prospects in the shales of the Grand Lake area. Schuchert and Dunbar's classic memoir (1934) on the Stratigraphy of Western Newfoundland includes only a brief section on Carboniferous stratigraphy.

More recently Riley (1957), Baird (1959), and Neale and Nash (1963) have published preliminary geological quadrangle maps, each of which covers a portion of the study area. These sheets encompass large regions, are reconnaissance in nature and give for the most part, brief and general accounts of rock types and structure. The report by Neale and Nash (1963) is the most detailed and provides, in addition to the map, a discussion on the structural geology and tectonic history.

Descriptions of the oil shales (Upper Mississippian) in the Deer Lake region are given by Landell-Mills (1922)

and Baird (1950). Snelgrove (1928) mentions the Upper Mississippian arkoses present on the eastern side of Grand Lake. The geology of much of the Humber Valley is summarized by Werner (1955) in a report to the Newkirk Mining Corporation. His report describes some aspects of Lower Mississippian regional geology but deals primarily with the potentially more petroliferous younger strata and contains the well logs of two prospects drilled into these Upper Mississippian rocks.

Elsewhere on the island work has been done in areas of Lower Mississippian outcrop. Geologic maps with accompanying reports were prepared by Heyl (1937a) and Betz (1948) for the region immediately north of the study area. Baird (1966) and Gillis (1966) studied the geology of Conche and Groais Island. In the region to the south, i.e., the greater Codroy Valley and Anguille Mountains, the following investigators have published papers dealing wholly or in part with the Lower Carboniferous geology: Hayes and Johnson (1937, 1938); Bell (1948); Phair (1948); Baird (1951); Riley (1962); Baird and Cote (1964); Utting (1965); Belt (1966, 1967a, 1967b); Gillis (1965); Mamet (1967); and Cumming (1967).

Methods of Investigation

Field Work

The field work was completed over a period of two summers, comprising some six months in total. During this time traverses were conducted along streams and shorelines in order to carry out:

1. Identification, description and study of distribution of lithologic types and primary features.
2. Collection of rock and fossil specimens for later laboratory examination.
3. Orientation measurements of directional features.
4. Measurement of bedding attitudes, fold geometries and the location and nature of faults.
5. Other standard field mapping procedures, including measurement and description of geologic sections and determination of formation contact relations.

All field-station locations were plotted on aerial photographs for later transference to base maps.

Laboratory Procedure

Field data were plotted in the laboratory on planimetric maps drafted from photostatic enlargements (twice original 1:50,000) of standard topographic maps. From this information structural and lithofacies maps, as well as stratigraphic and structural cross sections were prepared.

Construction of paleocurrent maps, using at first ungrouped and then grouped data, provided an areal perspective of dispersal patterns.

In order to obtain information about provenance and conditions of transport, rock samples were slabbed and inspected, using a binocular microscope. Over 100 thin sections were examined under the petrographic microscope. Modal analyses were performed on a select group of these in order to provide further information about provenance.

Identification of clay minerals was accomplished, using an X-ray diffractometer unit.

The colors given in the text to describe some lithologies are followed by symbols such as 10YR 6/6. These correspond to the color chips on the rock color chart issued by the National Research Council (1948).

Special Techniques and Procedure

Presentation of data. In spite of the disadvantages associated with summary graphical representations of paleocurrent data, the current rose diagram or polar histogram still remains one of the most effective means of portraying the orientations and variability of directional primary features. Such diagrams are presented in this study for the sole purpose of providing a visual representation of the data. The general method of illustration is the same as

that used by other investigators. Here, however, a degree of flexibility was introduced in the hopes of 1) representing the original distribution of data as accurately as possible, 2) overcoming some of the difficulties normally encountered when using this type of diagram with variable sized samples, and 3) simplifying comparisons between diagrams. Because this method departs somewhat from that which is usually employed, the procedure is discussed in some detail in Appendix 1.

Assigned names. Since much of the region under investigation is a wilderness area many of the topographic features have not been given formal map names. For convenience during field work it therefore became necessary to assign names to the various features. These have been maintained in the dissertation in order to facilitate the discussion and are indicated on the accompanying maps. A listing of these names follows: Allday Brook, Apologize Brook, Basement Brook, Delta Brook, Easy Plunkin' Creek, Glide Mountains, Glide Mountains Fault, Grand Lake Basin, Grand Lake Fault, Harbor Brook, Hopeless Creek, Larry Brook, Leo Brook, Minto Brook, Popcorn Brook, Seaplane Brook, Shiquee Brook, Way Out Brook, Woody Brook, and Wrong Brook.

Outcrop and sample indicators. Alphanumeric symbols (e.g., E71A, H15) used in the text refer to outcrop

localities indicated on the accompanying plates. Samples taken from any one locality are denoted by the same alphanumeric given that locality. For the locations of all figures and samples mentioned in the text, see Plate 1.

Physiography

Topography

The topography of the Grand Lake-(Deer Lake)-White Bay physiographic province (Twenhofel and MacClintock, 1940) possesses a northeasterly grain which has been accentuated by glacial affects but in the main reflects structural trends in the underlying bedrock. This irregular region, extending from the entrance of White Bay southwesterly to the northern portion of Glover Island on Grand Lake, is a composite of 1) hummocky, flat-topped, discontinuous uplands, underlain almost exclusively by the Lower Mississippian strata of this study and 2) lowlands underlain by younger rocks. A southern upland, here called the Glide Mountains, is divided into two parts separated by a major fault, an eastern block approximately 70 square miles in area and a western block of 75 square miles.

Although much of the land is mature and gently sloping in relief, the local topography in the environs of Glover Island is spectacular. The cliffs on the west side of the island rise extremely sharply from the lake (approximately

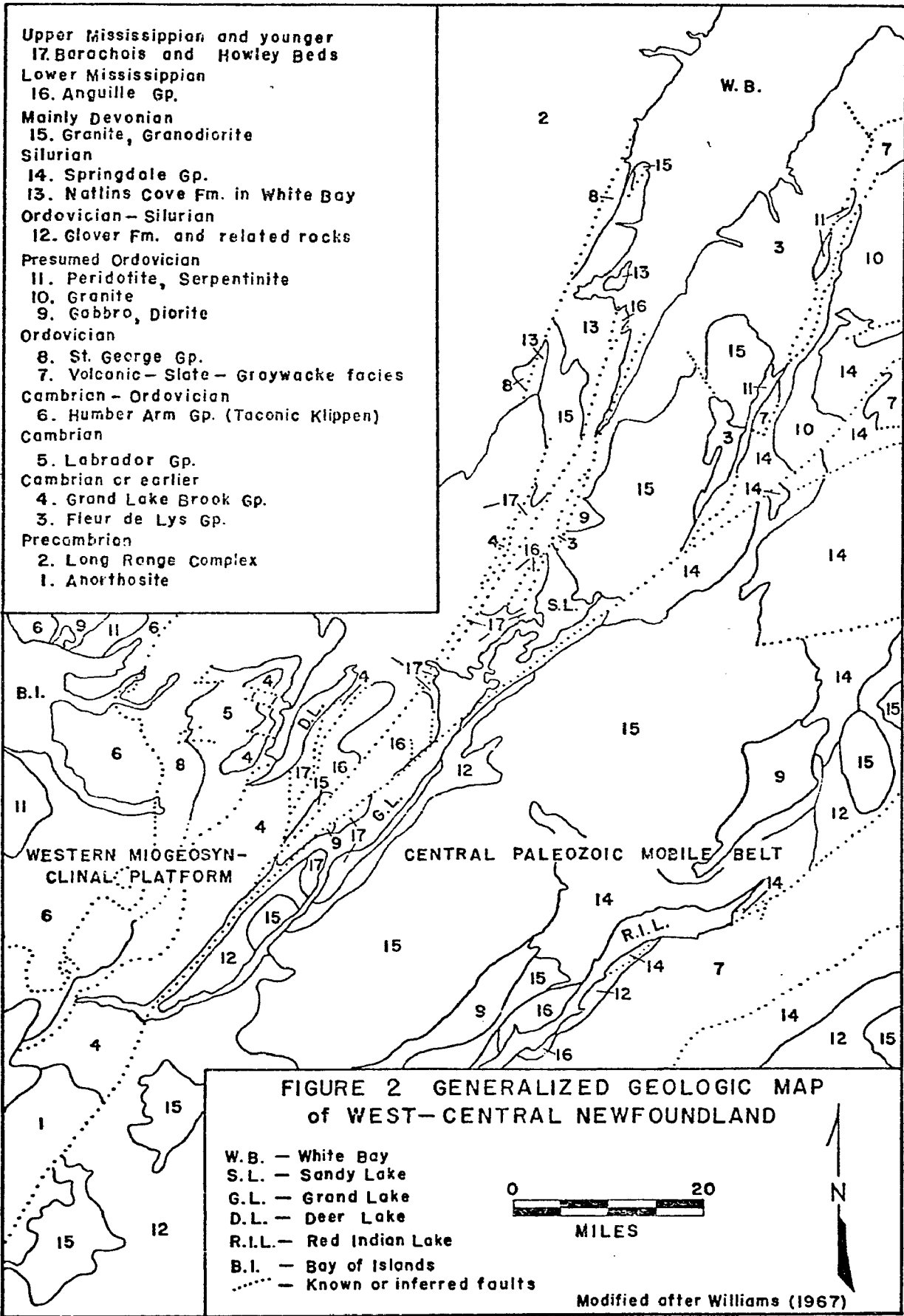
300 ft. above sea level) to 1900 feet. Just over a mile to the west, precipitous mountains rise steeply to similarly great heights. The lake bottom between these sheer cliffs is stated to be some 300 feet below sea level (Twenhofel and MacClintock, 1940) and may be considerably more. As such, the topographic profile is an impressive chasm in the earth's crust, a mile wide and at least 2200 feet deep. Some of this relief undoubtedly is the result of glacial overdeepening.

GENERAL GEOLOGY

Geologic Setting and Brief Geologic History

General Statement

Newfoundland, the northeasternmost exposed portion of the Appalachian geosyncline, can be subdivided into a symmetrical tripartite system consisting of a central Paleozoic mobile belt which is bounded both on the east and on the west by more stable Precambrian, crystalline-cored platforms (Williams, 1964). The western platform is separated from the central mobile belt to the east by a hinge line (Figure 2). This lineament, or trans-Newfoundland zone of weakness, can be recognized for at least 200 miles from the southwest tip of the island through Grand Lake and White Bay; throughout the length it maintains a relatively un-deviating northeasterly course (Murray and Howley, 1881). As a structural element it has a long and significant previous history intimately tied with sedimentation throughout the Lower and Middle Paleozoic. Thus, it represents a persistent and consequential feature of this part of the Appalachian geosyncline. In response to Early Mississippian tectonism, sedimentary basins were formed adjacent to the hinge line. Detritus was shed into these local basins from the surrounding pre-Carboniferous basement rocks. The basin in west-central Newfoundland (Grand Lake Basin) is the subject of this report.

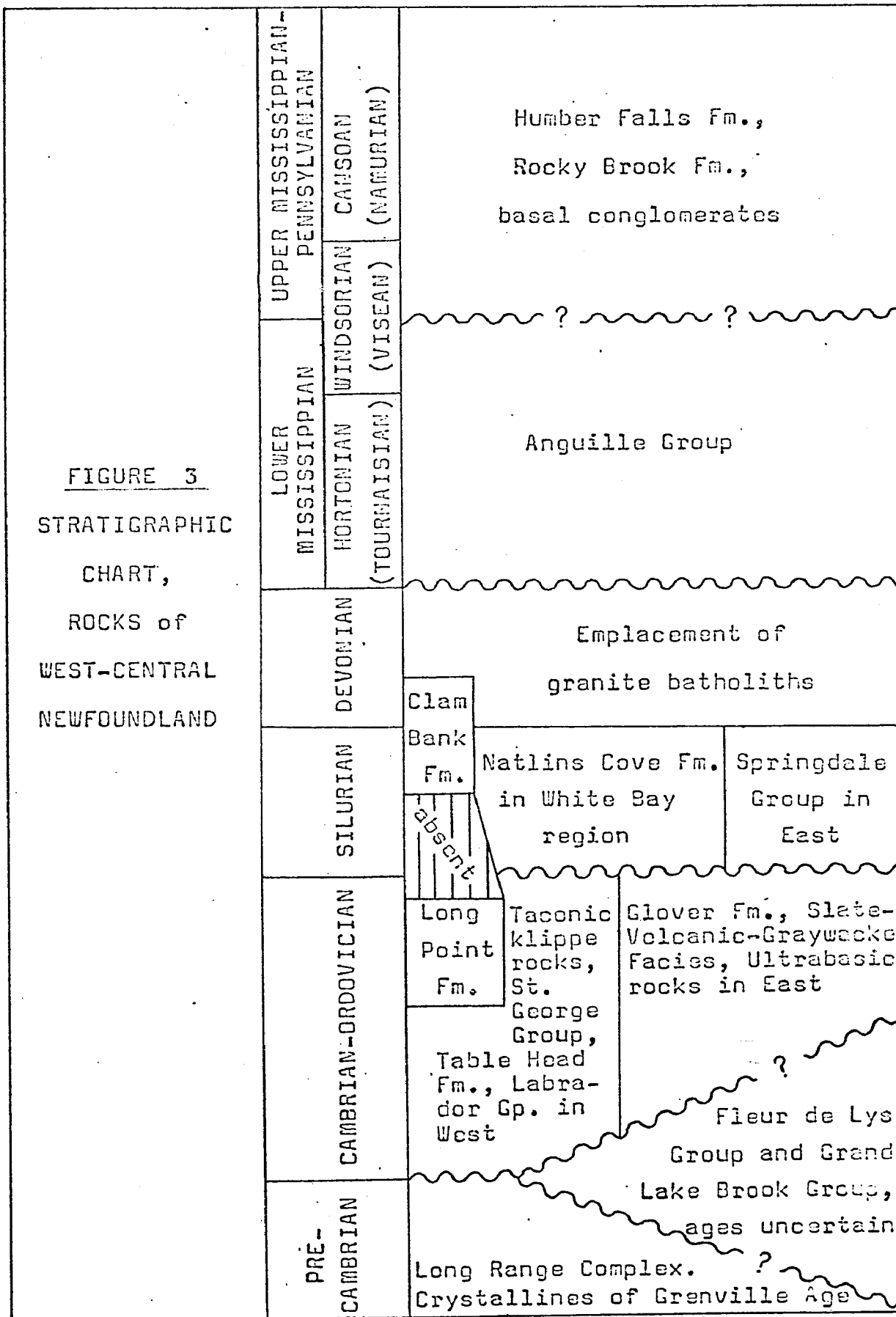


Geologic History of Western Newfoundland

The Precambrian history of the western part of the Appalachian geosyncline in Newfoundland is not well understood. The Paleozoic record, however, can be favorably compared in many respects with much of the geosyncline as it exists further to the south. (An excellent synthesis of the geologic evolution of the Appalachian geosyncline in the Maritimes is given by Poole, 1967.)

Throughout the Cambrian and Early Ordovician, thick sequences of carbonates and some sandstones were deposited on the crystalline basement (Long Range Complex, Grenville Age) of the western miogeosynclinal platform. In the eugeosyncline to the east lithologies were quite different, consisting of volcanic rocks, graywackes, shales, and ultramafic intrusions (Figure 3). The demarcation between these facies appears to have occurred at or very close to the trans-Newfoundland lineament (Riley, 1957; Williams, 1964; Kay and Colbert, 1965; Kay, 1967). During the Middle Ordovician Taconic orogeny the deep water clastics of the eugeosyncline (Humber Arm Group, allochthonous) were uplifted and thrust westward as gravity slides ("Taconic klippen") onto the platform carbonates (St. George and Table Head Groups, autochthonous) (Rodgers and Neale, 1963). The source rocks for the klippen probably originated in the western part of

FIGURE 3
 STRATIGRAPHIC
 CHART,
 ROCKS of
 WEST-CENTRAL
 NEWFOUNDLAND



the central Paleozoic mobile belt, i.e., the trans-Newfoundland lineament served as a zone of dislocation at the western margin of the root zone (Rodgers and Neale, 1963; Bruckner, 1966; Stevens, 1967; Tuke and Baird, 1967).

Although both the Ordovician and Silurian strata of the western part of the central mobile belt consist of assemblages of thick volcanic and sedimentary rocks, in detail they are quite different. The Ordovician sequences (Lush's Bight and Exploits Groups) are composed of pillow lavas, greenstones, volcanics, dark graywackes, siltstones and shales, (all marine in origin). Silurian lithologies (Springdale Group) are dominated by volcanics--only rarely pillowed, some containing fragments of red sandstone--and gray and red sandstone exhibiting cross bedding, ripple marks, and mud cracks (clearly suggestive of terrestrial origin).

Silurian rocks close to or on the western platform (Natlins Cove Formation, Heyl, 1937a, b, Lock, 1969) are composed of grayish clastics and volcanics, and apparently contain much smaller percentages of red sediments than do the equivalent units to the east. At the western edge of the platform, on the Port au Port Peninsula, a narrow belt of outcrop represents the stratigraphic record between the Taconic and Acadian orogenies (Rodgers, 1965). The unconformity at the base of the Middle Ordovician Long Point

Formation (dominantly greenish shales and sandstones) post dates the arrival of the "Taconic" klippen. Overlying these strata disconformably are red clastics of the Clam Bank Formation (probably Upper Silurian and Lower Devonian) the upper portion of which is possibly contemporaneous with the beginning of the main Acadian orogeny.

Sometime after the Early Devonian and prior to the Carboniferous, Newfoundland was affected by the Acadian orogeny. It has been dated in many places as Middle-to-Late Devonian (Lowdon, 1960, 1961, 1963; Neale and Nash, 1963; Poole, et. al., 1964; Rodgers, 1967). (Elsewhere in Newfoundland, however, stocks intrude even Upper Devonian sandstones and conglomerates (Ermanovics, et. al., 1967).) The orogeny was responsible for widespread folding of the earlier sedimentary and volcanic rocks of the eugeosyncline, metamorphism, and emplacement of granitic batholiths. This emplacement occurred almost entirely within the central Paleozoic mobile belt for virtually none exist outside the westernmost limit of the trans-Newfoundland fault zone (see map, Williams, 1967). By the end of the Devonian, much of the region had been raised to highlands and this portion of the geosyncline became a stable area and permanent feature of the continent.

At the beginning of the Carboniferous, the third and final phase of deformation in Newfoundland began--"Maritime Disturbance", (Poole, 1967). There developed on the western part of the island (as well as throughout the Maritimes and eastern Maine, Massachusetts, and Rhode Island), a series of fault-bounded basins. Vertical and horizontal displacements initiated a cycle of isostatic readjustments; uplifted highland blocks, composed of older Paleozoic rocks, were rapidly eroded into the contiguous basins and great thicknesses of detritus accumulated, dominantly as terrestrial deposits.

The initial accumulations on the pre-Carboniferous basement appear to have varied somewhat from place to place though all strata of Tournasian age (Fig. 3) are terrestrial in origin. The actual nonconformity at the base of these deposits has not been observed in Newfoundland proper because the contact invariably is marked by a fault, though Baird (1966) may have seen it in relatively mildly deformed rocks on Groais Island. For the most part, the basal deposits in the Maritimes consist of fluvial and shallow water, red sandstones, and conglomerates overlain by gray siltstone and shale containing limy interbeds. These darker units are interpreted by a number of authors (Bell, 1929; Greiner, 1962; and others) as being lacustrine in

origin. Some of these strata are petroliferous. Though not extensive, some local centers of volcanic activity did exist (Schiller, 1961; Kelly and Mackasay, 1965; van de Poll, 1967).

Throughout most of the Appalachians there has been recorded only one widespread marine invasion during the Carboniferous. The evidences for this major transgression in the Maritimes are the deposits left behind by the shallow Windsor seas (Meramec, mid-Visian, Upper Lower Mississippian in age). In southwest Newfoundland these consist of red and green shales, gypsum-anhydrite, fossiliferous limestone and evaporites. In contrast to the older Horton Group, which is the thickest of all Mississippian rock units, the Windsor marine strata are the thinnest but most widespread (Howie and Cumming, 1963). The seas, however, did not extend as far north as the study area, for there, no marine Windsor units have been recognized.

As the Windsor seas retreated, terrestrial sedimentation resumed and Upper Mississippian and Pennsylvanian fluviolacustrine dominantly red and gray clastics were deposited. With the exception of Pleistocene and Holocene sediments, these last-named strata represent the termination of the stratigraphic record in Newfoundland.

The Basement Complex

General Statement

The Carboniferous basin in west-central Newfoundland is surrounded on all sides by a variety of older crystalline rocks (Fig. 2). These units, which range in age from Precambrian to Devonian, constitute the provenance from which the Lower Mississippian sediments were derived. Some knowledge of these lithologies is therefore vital to this study and a considerable number of samples were collected for purposes of comparison and possible identification as source rocks.

In the Grand Lake region the basement rocks exhibit a distinct geographical division of contrasting lithologic types on either side of the trans-Newfoundland lineament. The terrain to the east of Grand Lake, including that of Glover Island, is underlain by igneous rocks (Fig. 2), while that to the west is formed entirely of low to high-grade metamorphics. Each of these areas can be further subdivided (on the basis of lithology) into two discrete subunits. The igneous terrain is composed of a western belt of volcanic rocks and an eastern plutonic region. The metamorphic rocks consist of eastern gneisses and schists, and western carbonates. This regional separation between areas of igneous and metamorphic rocks is most opportune for con-

siderations of provenance, since two quite different possible source areas are thereby represented.

Only a few summary statements and germane facts related to the various rock types are presented here; more detailed descriptions are given by the following authors: Baird, (1959), Betz, (1948); Church, (1967); Heyl, (1937a, b); Kalliokoski, (1953, 1955); Lilly, (1967); Lock, (1969); Lowdon, (1962); Lowdon et. al., (1963); Neale, (1959); Neale and Nash, (1963); Neale and Kennedy, (1967); Poole et. al., (1964); Riley, (1957); Walthier, (1949); Werner, (1955); Williams, (1964, 1967).

Basement Rocks of the Grand Lake-Deer Lake Region

Basement lithologies exposed immediately east of Grand Lake are predominantly volcanic. They include: acidic tuff and lava; dark gray and green andesitic volcanics; basic volcanics; agglomerate; red and purple lavas; and some minor sedimentary rocks. Glover Island is underlain predominantly by the Glover Formation (Ordovician), a unit of gray, basic and intermediate volcanic rocks.

The intrusive rocks located further to the east are areally far more important than the volcanics. An Early Ordovician pluton--the "Topsails Granite"--encompasses some 2400 square miles and has been described by Neale and Nash (1963, p. 25) as follows:

This complex consists chiefly of granite and quartz monzonite with lesser granodiorite. These rocks are mainly pale red to pale brown, less commonly shades of gray. Generally, they are equiangular (sic) and medium to fine-grained, although coarse-grained and porphyritic types are known. Partly chloritized hornblende is commonly the sole or dominant mafic mineral, but biotite-hornblende granite and biotite granite are known, particularly in the easternmost exposures (Kalliokoski, 1955). There are rare occurrences of muscovite-biotite granite in the northwesternmost exposures.

A stock on the southeast side of Glover Island consists of fine- to medium-grained red granite. In this section, the plagioclase is very pale orange and shows excellent zonation with alteration affecting crystal cores considerably more than margins.

The basement complex west of Grand Lake consists entirely of metamorphic rocks. The regional pattern is a two-fold division between eastern gneisses and schists, and western metamorphosed limestones and dolomites.

Mica and quartz-mica-feldspar schists occupy an elongate area west of Deer Lake (Baird, 1959). These rocks continue southwestward (Mount Musgrave Formation) along the western margin of a belt of gneisses and pelitic schists (Grand Lake Brook Group of Walthier, 1949), in which the intensity of metamorphism increases eastward (Lilly, 1967). The gneisses have been described as "granite-gneiss,

garnetiferous and micaceous granite gneisses, quartz-mica, mica-feldspar, and hornblende-feldspar gneisses" (Riley, 1957). Lilly (1967) refers to these rocks as phyllites, (meta) graywackes, (meta) arkoses and marbles. Where the rocks were observed along the margins of the outcrop belt, their outstanding characteristic was that of a well-developed schistosity. Generally, they are dark green, somewhat siliceous, muscovite-chlorite schists, locally containing pods of milky quartz and almandine garnets. In thin section, the plagioclase shows almost no twinning; notable accessory minerals include biotite and corundum. Williams (1967) suggests that these rocks may be related to the Fleur de Lys Group cropping out east of White Bay.

The St. George's Limestone (Ordovician) to the west, is one of the most extensive sedimentary units in western Newfoundland. In this area it consists of massive buff, white, pink, gray and blue-gray limestones and dolomites; shaly dolomites; and crystalline black limestones. It occurs in outcrop to the west and southwest of the study area, and data from drill holes show it to be present also in the subsurface beneath the Humber Valley (Werner, 1955).

Granites of the White Bay Area

For considerations of provenance, it is important to mention two granite bodies which crop out in the White Bay

area (Fig. 2, unit 15; see also Figures 29 and 31). The one situated east of White Bay (most likely Devonian; 358 m.y.; Lowden, et. al., 1963) has been described by Neale and Nash (1963) as a pinkish-gray porphyritic biotite granite, containing five to ten percent biotite and having potash feldspar phenocrysts more than one inch long. Near its contacts the granite grades into hybrid gneisses and schists that are characterized by large potash feldspar porphyroblasts. This batholith is separated from a similar body located west of White Bay by a thin strip of Lower Mississippian outcrop.

The western granite, according to Neale and Nash, (1963) "is pale to medium red, white weathered, very coarse grained and equiangular to sub-porphyritic. The most abundant mineral is microcline, in crystals up to two inches long." Along its western margin the granite has been described by Baird (1959) as red, heavily sheared, with coarse porphyritic facies.

Basement Rocks Within the Thesis Area

Basement rocks crop out at a number of localities within the Carboniferous basin itself. Their occurrence is commonly related to the appearance of faults at what would otherwise be the Lower Mississippian-Upper Mississippian contact. Examples are found along the central portion and eastern and western margins of the upland area, the Glide Mountains.

Basement Brook

A plug-like crystalline mass (Unit 9, Fig. 2) forms a prominent topographic rise along the Grand Lake shore approximately one mile northeast of the mouth of Porter's Brook. It is bounded by distinct faults and represents a horse or slice of the basement which has been brought up through the sedimentary cover by movement along the limiting faults.

Centrally, it is quite coarse grained but it becomes finer grained and mylonitized toward the east and west margins. It is a diorite, consisting of hornblende and large interlocking laths of a twinned and well-zoned andesine (An₄₆) having greatly altered cores. The feldspar presents idiomorphic outlines to the amphibole which occurs interstitially as crystals and fibrous crystalline clots. Chlorite is present with a similar appearance.

The mineralogy suggests that this rock is related to the Glover Formation for both contain intermediate feldspar (in the Glover Formation it has been almost entirely altered to clinozoisite), chlorite, and hornblende. However, differences exist, such as the much finer-grain size and lesser amounts of mafic minerals in the Glover Formation.

Northern Harbor and Northeastern Extension

A narrow, elongate, crystalline mass extends northeastward from the head of Northern Harbor on Grand Lake.

It is dominantly a red to pale orange, well-jointed granite containing very few mafic minerals; locally, it appears to have intruded a dark green mylonitized chlorite schist (Figure 25). In hand specimen the chlorite schist bears a distinct resemblance to portions of the marginal chlorite schists of the basement block to the south (discussed in the section on gneisses and schists west of Grand Lake).

The northeast extension of the same or a closely related body crops out along strike on Way Out Brook, situated to the north of Island Pond. Near the mouth of the brook occur schists and gneisses which are in fault contact with siliceous felsites of various pastel shades, dominantly pale orange, some pale yellow-green. Bedrock of the upper reaches of the stream is mostly a siliceous pale orange porphyry, containing almost no mafic minerals. Phenocrysts are predominantly twinned albite (An_{04}); a few are quartz. The presence of this crystalline mass from Northern Harbor to Way Out Brook is clearly demonstrated by a well-defined, northeast trending, elongate magnetic high of isomagnetic contour lines shown on the Geological Survey of Canada, Airborne Magnetic Survey Map, 272G.

The entire area described above is bounded to the east by the Glide Mountains fault.

Glide Brook

An isolated outcrop of gray, porphyritic, very slightly vesicular, volcanic rock (altered andesite?) occurs just south of the junction of Glide Brook and the north fork of Pynns Brook road (E71A). In thin section the phenocrysts can be identified as plagioclase but are considerably altered. Irregular masses of a pale green chlorite occur as a replacement mineral and, under crossed nicols, appear as a fine-grained mosaic of radial aggregates with anomalous blue birefringence. An amphibole and magnetite occur interstitially within the groundmass.

West Side of the Glide Mountains

As a result of fault movements, a linear band of Cambrian schists (Baird, 1959) has been interposed along much of the contact between the Lower and Upper Mississippian formations on the west side of the Glide Mountains.

The schists are light-to-dark green, micaceous (mostly muscovite, some chlorite), and many contain conspicuous granules of colorless, milky white, and rarely blue quartz. Degree of metamorphism of these rocks varies somewhat along strike but all are of a low grade. Evidences of cataclasis are visible both in hand specimen and thin section.

A solitary, large outcrop of serpentized ultrabasic rock occurs within the schists on Pynns Brook.

Regional Stratigraphy of the Anguille Group

Rocks of Early Mississippian age crop out in three distinct, aligned regions in western Newfoundland (Fig. 1): 1) the Anguille Mountains on the southwest side of the island (which give this group its name); 2) the Glide Mountains and Birchy Ridge area of west-central Newfoundland, and 3) the Conche-Cape Rouge Peninsulas and Groais Island, located some 100 miles northeast of the west-central area. Each of these regions has been shown to be equivalent or quasi-equivalent to the Early Mississippian (Tournaisian) Horton Group of Nova Scotia; correlation is based on plant fossils, spores and/or lithologic sequences (Heyl, 1937; Bell, 1948; Baird and Cote, 1964; Baird, 1966). Within the Anguille Group, however, stratigraphic relations are complex and less than clearly defined.

The Anguille Group was named, described and subdivided into two units in the type area by Hayes and Johnson (1937, 1938). A later three-fold division, also in the type area, was proposed by Baird (1951) and subsequently revised (Baird and Cote, 1964), for the "basal" sandstone member as originally defined by Baird, was found to overlies the middle shale unit. Unfortunately, even this newer three-fold subdivision cannot yet be used elsewhere in Newfoundland. On the Conche-Cape Rouge Peninsulas, for example,

Baird (1966) resorted to distinguishing two formations; in the west-central region a three-part differentiation is possible but the sequence of lithologies is not the same.

Such complexities are the result of a number of factors: paucity of invertebrate fossils (though plant remains are reasonably abundant); lack of good stratigraphic-marker horizons; local derivation of sediments, often in response to fault activity; rapid facies changes within units; and the time-transgressive nature of individual facies.

Recently, red sandstones on the west shore of Red Indian Lake (some 50 miles southeast of the Glide Mountains-- Fig. 2) have been dated as Early Mississippian on the basis of spores (H. Williams, personal communication). Although the lithology is unlike that of equivalent aged sandy units in the thesis area, the occurrence at Red Indian Lake signifies that Early Mississippian deposition was, in all likelihood, more extensive than that presently preserved in the outcrop belts.

Previously, the Anguille Group in west-central Newfoundland was undifferentiated. As a result of this investigation, it is now possible to subdivide the sequence into three major subunits.

Younger Carboniferous Strata

General Statement

Carboniferous strata younger than the Anguille Group crop out in the lowland areas of the Humber Valley, and the Codroy Valley (including a region westward to Stephenville and the Port au Port Peninsula). These units are predominantly terrigenous and, for the most part, terrestrial in origin. The exception is the dominantly marine Lower Codroy Group (upper portion of the L. Mississippian, Windsor equivalents) a transgressive sequence which was laid down in shallow epirogenic seas with fluctuating shorelines (Baird and Cote, 1964). Resultant deposits consist of alternating beds of marine limestones and terrestrial clastics; evaporitic conditions produced gypsum and anhydrite. Younger strata of the Upper Mississippian (Cansoan Age, Upper Codroy and Deer Lake Groups) and Pennsylvanian (Barachois Group) again are regressive in nature.

Younger Carboniferous Strata of West-Central Newfoundland

In the vicinity of the thesis area itself, Baird (1959) has described the Deer Lake Group (his Windsor Group) as a three-fold, red-gray-red sequence.

- (3) Humber Falls Formation: red, quartzose sandstone and conglomerate; minor shales and siltstones.

- (2) Rocky Brook Formation: red and gray shales and siltstones, thin gray and dark-gray limestone, commonly petroliferous, red siltstones with limy kunkers and much variegated; some red sandstones; dominantly gray.
- (1) Basal conglomerates of great variety with calcite and hematite cements, red siltstones and shales, red, gray and khaki sandstones; dominantly red except basal conglomerates and sandstones.

By and large, these units are readily distinguishable from rocks of the older Anguille Group on the basis of several criteria. The younger strata contain a large proportion of red beds, are generally poorly indurated, locally friable, and not severely deformed (except near some major faults). By contrast, the Anguille rocks are dominantly gray, quite well indurated with even, sharply defined bedding planes and commonly are intensely folded and fractured.

Although the Deer Lake Group is Carboniferous in age and definitely younger than the Anguille Group, unequivocal correlation with other units in the Maritimes has not been established. Baird (1959) mapped these formations as "probably correlative with the Windsor Group of Nova Scotia", stating only that they overlie the older rocks of the area. Belt (1967), on the other hand, considers them Cansoan.

GEOLOGY OF THE GRAND LAKE-DEER LAKE REGION

General Statement

Uplift and concomitant development of fault-bounded basins resulted in the accumulation of Lower Mississippian sediments as alluvial fan, fluviatile and lacustrine deposits in the Grand Lake-Paleobasin. Detritus was shed from peripheral areas into a northeast trending basin, the sediments being transported dominantly toward the north, northeast, and northwest. The resultant stratigraphic sequence represents three different environments of sedimentation. Each of these environments or regimes is characterized by a distinctive suite of sedimentary-rock types (facies units). The suites are, in part, time equivalents.

The term "suite" is used here intentionally, for these units are not considered formations in the strict sense of the word. They are not mappable lithologic units with lateral continuity clearly distinguishable from units above and below, for although some lithologies are restricted to a particular suite, others occur repeatedly through the section. Intertonguing is characteristic at all suite boundaries.

The sedimentary suites are:

1. The black siltstone-orange dolomite suite, (that in which occur gray-to-black siltstones and orange dolomites).

2. The gray-sandstone suite, (that dominated by gray sandstones, arkosic and graywacke sandstones, and gray siltstones).

3. The red-arkose suite, (that containing red arkoses).

The names applied to the first and third suites are not meant to indicate that they are dominated by that lithology, but rather that such strata are unique to the particular suite and serve to identify it, even if in places they are only sparsely present. Mapped and differentiated on the basis of stratigraphic first and last appearances, the distinctive lithology gives the suite its name.

In addition to the three major suites, there exists a mylonitized, volcanic and plutonic pebble conglomerate which is of very limited surface extent. It probably represents the basal unit to the sequence.

The eventual filling of the basin and lithification of the Anguille sediments was succeeded by folding and fault activity; with this, the Lower Mississippian-Grand Lake Basin was converted into the existing upland area. The folds which were produced are of the flexural-slip type. Large-scale regional folds and many of the smaller variety are very low-to-moderately steep (less than 40°) in plunge. Locally, some smaller folds have very steep axes.

Faults, both dip and strike-slip, exhibit a full range of offsets, from small ones measurable in inches to regional dislocations along which miles of movement have probably taken place.

Facies Descriptions

Basal Conglomerate

The nonconformity at the base of the Anguille section is not exposed within the thesis area, since the contact with the basement rocks is marked invariably by a fault. The lowest unit observed is a dark greenish-gray conglomerate (Plate 1, F88, E64) which very likely represents the basal unit in the sequence. This pebble conglomerate is unlike any other in the area and is thought to represent the initial accumulation in topographic depressions of the basement prior to the inception of later black siltstone-dolomite sedimentation.

One outcrop (F88) occurs on the drainage divide 0.6 miles north of Island Pond. It is only in slabbed or thin section that its true nature as a deformed small pebble conglomerate is revealed. Dark green volcanic (?) clasts have a maximum length of 3 cm., and most are attenuated as a result of shearing. The matrix as well as the great majority of clasts show evidences of mylonitization. Some fragments, however, are unaltered or only slightly so, which permits identification as volcanic porphyries, fine-grained anortho-

sites and quartz grains which exhibit sharp extinctions. The fact that some grains are not sheared whereas others are, suggests that at least some of the mylonite clasts are original and not the result of deformation which post-dates sedimentation. If true, then these fragments were, perhaps, derived from faults which initiated basin formation.

These rocks lie stratigraphically above pale-orange felsite porphyry on Way Out Brook. Since no clasts of this latter lithology are present in the basal conglomerate, it is concluded that the acidic basement was not locally exposed during the Early Mississippian and that it did not contribute detritus as an active source. The presence of the anorthosite clasts is intriguing since bedrock outcrops of anorthosite have not been recognized in the Grand Lake-Deer Lake area. The nearest known occurrence is located 40 miles to the southwest.

An outcrop (E64) of similar appearing greenish-gray, rudely foliated conglomerate is located along strike 3.7 miles to the northeast on Easy Plunkin' Creek. The pebbles consist of fine- to very fine-grained, dark green, gray, and maroon-brown volcanic and hypabyssal (?) rocks. It is not mylonitized and clasts are rhyolitic porphyry, dark-red syenite, and fine-grained sodic anorthosite.

The conglomerates undoubtedly were derived from east of the Grand Lake Fault; that region is the only one which could have supplied shallow intrusive and volcanic debris in any abundance.

Black Siltstone-Orange Dolomite Suite

General Statement

Rock types and associations in this suite include: gray, fine- to medium-grained micaceous sandstone (arkose, lithic and feldspathic graywacke) and black-and-gray micaceous siltstone (all containing abundant plant fragments and carbonaceous material); white coarse arkose and sandy polymictic conglomerate; dolomite and sandy dolomite; and interlaminated gray or black siltstone and orange dolomite. In spite of the fact that a range of lithologies is thus represented, all possess common bedding characteristics. Almost without exception they are evenly bedded, laterally persistent through the length of the outcrop and have very sharply defined upper and lower contacts (even where thick sequences consist of a single rock type). These three features (evenness, persistence, and sharp contacts) are independent of bed thickness or surrounding lithologies and are characteristic not only of this facies unit but of the entire Anguille Group.

The siltstone-dolomite suite has been delineated on the basis of the highest stratigraphic appearance of interbedded black siltstones and orange dolomites. In the well-exposed section along the western shore of Grand Lake, this limit is established 0.6 miles south of Woody Brook harbor; it coincides with the southernmost occurrence of true black shales. Interbedded siltstones and dolomites, along with other lithologies, crop out at intervals throughout the area to the east of a line originating at the point mentioned and trending in an arcuate northerly direction to Allday Brook (see Plate 2). The contact with the adjoining gray-sandstone suite to the south is not sharply defined but rather is marked by a gradual increase in the number of sandstone beds and decrease and eventual absence of orange dolomites.

Although rocks of this suite crop out dominantly in the northeastern portion of the Glide Mountains, their occurrence in the subsurface probably is considerably more extensive. Block-fragments of interbedded siltstone and dolomite are found in the fault zone near Basement Brook, possibly having been brought up from depth. A carbonate-cobble conglomerate located along the western limit of the Glide Mountains lies in a similar stratigraphic position to rocks of the siltstone-dolomite suite; it may therefore represent

the basin margin coarse equivalent of this facies. If this is the case, then these units underlie the entire region.

Siltstone, Sandstone, and Conglomerate - Lithologic Description and Provenance

By far, the most abundant rock types present in the siltstone-dolomite suite--and the total Lower Mississippian section for that matter--are the fine- to medium-grained gray micaceous sandstones (arkose and graywacke), and gray-and-black micaceous siltstones. Gray or black on fresh surfaces, they weather to shades of gray, less commonly tan, and rarely olive. Locally, the black siltstones are spotted and stained rusty brown by small iron sulfide nodules.

Beds of siltstone and gray sandstone vary in thickness from less than one inch to several feet, with thicker layers generally of coarser grain size. The ubiquitous, sharply defined, even and continuous bedding mentioned previously is disrupted only by post-depositional effects such as: loading; faulting (both pre- and post-lithification); and tectonic flowage of siltstones around more competent fine sandstones, resulting in the formation of sandstone boudins.

In texture and composition, the sandstones are categorized as graywackes and arkoses according to Pettijohn's (1957) classification. The graywackes, perhaps three times more abundant than the arkoses, in many cases show evidences

which suggest rapid and turbulent deposition. This includes their uniformly poor degree of sorting, marked angularity of coarser grains, and graded bedding with basal flute casts and tool markings, e.g., groove casts.

Almost without exception, the dark siltstones and sandstones are abundantly micaceous with increasing amounts of white mica present in the finer sizes. As Pettijohn (1957, p. 565) has pointed out, the excellent cleavage of the micas accentuates the effects of sorting and sedimentary bypassing, thereby tending to concentrate micas in the fine sands and silts. Nevertheless, the presence of small amounts of mica, hydrodynamically mobile, in the coarser fraction indicates a certain lack of winnowing and further attests to reasonably rapid deposition of these sediments.

The omnipresence of white mica has a further and, perhaps, greater significance, because, of the various basement lithologies in this region from which it might have been derived, only the schists to the southwest could have provided this mineral in sufficiently abundant quantities (see p. 23). The orientations of sole marks tend to confirm such an origin for they indicate that the currents which deposited the gray sands and silts moved toward the northeast (see Plate 3).

All clastic material was not derived from the metamorphic terrain to the southwest. Hand-specimen identification of clasts and thin-section modal analysis of pebbly sandstones (see Table 1, D92, E21, H15) from within the siltstone-dolomite suite suggests that the plutonic-volcanic basement east of Grand Lake contributed significantly to these deposits. (This is confirmed by directional feature orientations discussed later.) The results of the analyses, based on 200 counts per slide, show that a reasonable minimum of 15.5-28.5% of the fragments were derived from an igneous terrain. Included in this category are grains of: 1) volcanic, granitic and other plutonic rocks, and 2) twinned varieties of plagioclase, microcline, and perthite. A percentage of some other types of grains (e.g., varieties of quartz) should be added to these figures, but as they stand, they provide at least a minimum value.

Sample H15 taken from Wrong Brook (see Plate 1) is a feldspathic graywacke containing a slight amount of metamorphic fragments; D92, from Woody Brook Harbor is a lithic graywacke with high feldspar content (Fig.); E21, taken from a point 0.3 miles to the south of D92, is an arkose. All contain large amounts of quartz (21-37.5%). Commonly, these have abundant bubble trains and dust inclusions which are characteristic of hydrothermal vein quartz (Krynine, 1940).

TABLE 1 - ESTIMATED MODES IN VOLUME PERCENT

Clast Type	Sample	D47	D87A	D92	E1	E12	E21	E63
Quartz		33.5	13.0	28.0	15.5	27.0	37.5	25.0
Composite Quartz					10.5	15.5	7.0	
Sutured Quartz		9.0	9.5	8.0	3.5	3.0	2.0	
Other Quartz		3.0						
Polycrystalline Sylica		.5		4.5			1.5	
Chert		.5						
Twinned Plagioclase	{	9.0	{	11.0	2.5	8.0	.5	2.0
Untwinned Plagioclase							2.5	5.0
Altered Plagioclase				5.5	5.0	6.5	5.0	23.0
Granitic Rock Fragments		6.5	8.5	2.5	4.0	8.0	5.5	
Perthite		9.5	35.0	1.0	{	39.5	{	8.5
Potash Feldspar		6.0	.5	1.0			{	7.0
Volcanic Rock Fragments			11.5	7.5	3.5	20.0	12.5	8.5
Plutonic Rock Fragments (other than Granite)		3.0	2.5	1.0		.5	.5	
Sedimentary Rock Fragments				4.5				
Metamorphic Rock Fragments		5.0	.5	1.0		1.0	1.0	1.0
Metaquartzite-Elong. Sutured Quartz								
Marble Clasts								
Marble Clasts cont. Quartz Grains								
Quartzo-Feldspathic Muscovite Schist								
Muscovite-Epidote- Garnet Schist								
Chlorite Schist								
Muscovite		2.0						3.5
Dark Mica-Phlogopite, Biotite-Chlorite			.5					6.5
Matrix		6.0	7.0	25.5	10.0	7.5	13.0	18.0
Cement				3.5				7.5
Opaque & Heavy Minerals							2.0	1.5
Other		6.5		4.0	.5	2.0	1.0	
TOTALS		100.0	100.0	100.0	100.0	100.0	100.0	100.0
% Q		53.8	24.7	56.4	32.4	50.3	55.6	34.2
% I For Definitions		39.8	74.2	42.1	67.6	48.6	43.2	50.7
% M see p. 82		6.4	1.1	1.5		1.1	1.2	15.1

PERCENT FOR PEBBLY SANDSTONES OF THE ANGUILLE GROUP

E63	E70	E77A	E84	E87	F60	F85	F94	G75A	H15
25.0	29.0	6.0	21.5	26.5	3.0	3.5	11.5	24.0	21.0
		12.0			5.5			11.5	
	9.0	2.5	8.5	11.5	.5		5.5	.5	5.0
			2.0						
	2.0		4.0	2.0			1.5	.5	
			.5						
5.5	8.0		{17.5	{6.5				2.5	5.5
				{15.0					6.5
23.0	9.0						4.5	10.5	2.0
	10.5	5.0	9.5	12.0			6.0	15.0	7.0
	5.0		11.0	2.5	{1.5		35.0	{13.0	{8.5
8.5	3.0		4.0	2.5			2.0		
	{8.0		{6.0				4.0	14.0	7.0
				.5					.5
	.5							.5	
1.0	8.5	2.0		1.5			2.5	1.0	5.5
		16.0			2.5	36.5			
		10.0			14.0	16.0			
		8.5			29.5	7.5			
		23.5			3.0	18.5	3.5		
		2.5							
						.5			
3.5			.5	1.5		1.0			
6.5									
18.0	4.5	5.0	11.0	7.0	40.0	13.5	23.5	6.0	28.0
7.5	2.0	7.0	1.0						.5
1.5			.5	4.0	.5	.5			
	1.0		2.5	7.0		2.5	.5	1.0	3.0
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
34.2	41.9	23.3	36.8	47.9	15.0	47.6	22.9	39.0	37.7
50.7	48.4	5.7	59.8	48.5	2.5	.6	68.6	59.9	53.6
15.1	9.7	71.0	3.4	3.6	82.5	51.8	8.5	1.1	8.7

The medium- to coarse-grained sandstones and conglomerates are white or buff. Pebbles scattered throughout the quartzo-feldspathic matrix of the conglomerates are predominantly angular and subangular. The most conspicuous clasts are milky and clear quartz, and red, green, and bright turquoise-colored jasper. Prevalent rock types include felsite porphyries of pale shades, and light and dark green, very fine-grained volcanic rock fragments. Present in small amounts are pale-pink granite, greenstone, and possibly black siltstone. Clearly, many of these fragments are distinctly similar to rocks which crop out east of the Grand Lake Fault (see p. 22).

In summary then, it appears that dual sources created the interbedded polymictic conglomerates, pebbly sandstones, and gray micaceous sandstones and siltstones. Abundant mica and other associated fine-terrigenous material were almost surely derived from the metamorphic area to the southwest while the plutonic and volcanic pebbles of the coarser sandstones and conglomerates reflect an obvious similarity to the igneous rocks east of Grand Lake.

Primary Features Associated With the Sandstones and Siltstones

A more precise picture of the dispersal pattern operating in the paleobasin is indicated by the primary features associated with the sandstones and siltstones. Many of

these features have often been reported from turbidite and flysch sequences; others, however, are not common to such horizons. Representative of the former are repeatedly graded graywacke beds which contain a variety of sole markings. Without exception, this characteristic bedding is restricted to strata of the siltstone-dolomite suite.

Graded beds, tool marks, and flute casts. Graded beds occur at a number of localities. Those best developed are exposed at Woody Brook harbor where the largest are two-foot thick and contain medium-sized pebbles at their base (see Fig. 4). The soles of many of these beds are covered with tool markings. Shorter varieties include skip, bounce, and brush casts, while longer uninterrupted types (up to three feet) are groove casts and striated-groove casts which extend the length of exposed surfaces. The depth and width of these longer groove casts (Fig. 5) is approximately one-quarter to one-half of an inch, though many are thinner and more delicate in appearance.

The tools which created the furrows were nowhere observed at the ends of the casts. However, the graded beds which exhibit these casts quite regularly contain abundant plant fragments, less commonly pebbles, and in some instances, chips of siltstone presumably derived from the underlying silty bed. It seems reasonable to conclude that these objects served as the tools with which the grooves were initially carved.



Fig. 4

Graded beds at Woody Brook harbor, siltstone-dolomite suite. Ruler = six inches.

Fig. 5

Groove casts on sole of graded graywacke bed, Woody Brook harbor, siltstone-dolomite suite.



Groove-cast orientations (after rotation correcting for bedding inclination) exhibit an impressive consistency; 49 readings on separate beds throughout this section have a standard deviation of 33° from the vector mean sense of 31° - 211° (Plate 3). Such regularity instills confidence in the reliability of these features as paleocurrent indicators. Also associated with the graded bedded sequences are: 1) micro cross-laminations (less than three-quarters of an inch in height), 2) ball and pillow, and flame structures, 3) load casts of various shapes, and 4) flute casts. Load casts of elongated shape have a mean sense of 44° - 224° with a standard deviation of 30° for 11 readings (Plate 3); thus, they are roughly parallel to the groove casts. Flute casts (Crowell, 1955), although sparse, are very well defined where encountered (see Figure 6). They are closely grouped or nested on any one bedding surface and therefore differ from the isolated flutes in the gray-sandstone suite. The largest are 4 x 13 inches (Figure 7). These were observed along the Grand Lake shoreline near the suite's southern limit. Flute casts are extremely useful, for they indicate the direction of transport of depositing currents rather than only the line or sense of movement as shown by tool markings. All flute casts denote a northward direction of transport (toward vector mean azimuth of



Fig. 6

Nested flute casts, siltstone-dolomite suite.
Chisel points downcurrent.

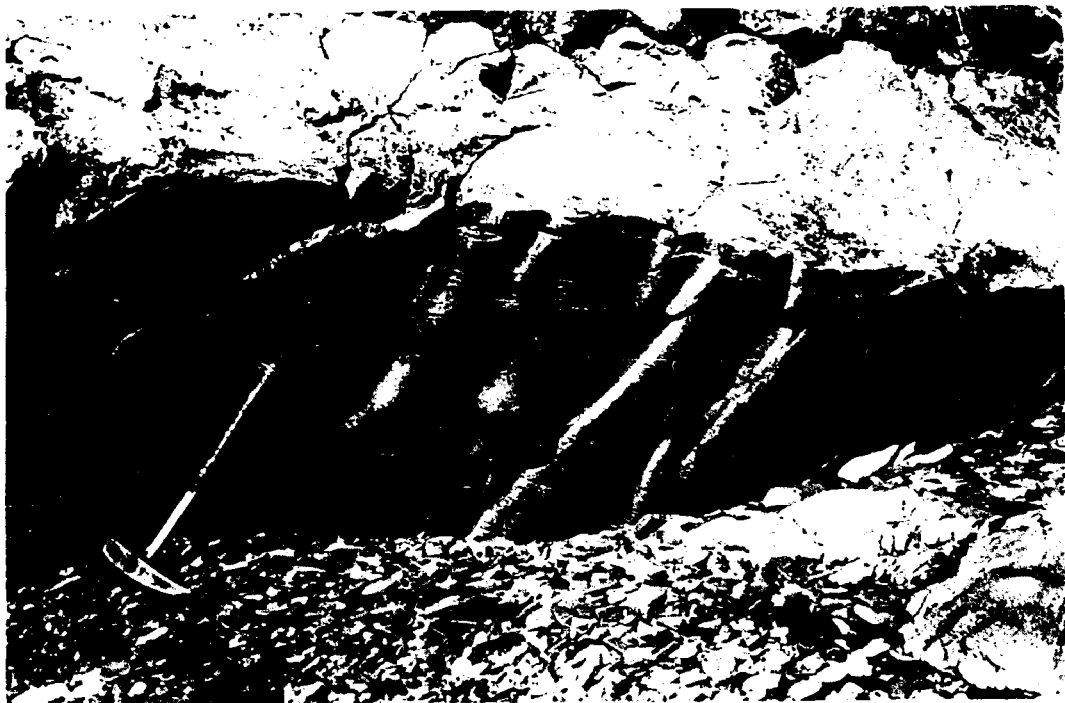


Fig. 7

Large flute casts, siltstone-dolomite suite.
Hammer handle points downcurrent.

17° for five readings (Plate 3). Since they occur interbedded with groove cast-bearing strata, it seems reasonable to conclude that these latter features also have a northern polarity.

The overall character of the sandy and silty beds described above suggests that they were deposited from turbidity flows which moved downslope northeastward into the relatively deeper portions of the basin. However, not all primary features associated with these beds are especially characteristic of turbidite sequences. In addition to those already reported, are parting lineations, few cross-beds, abundant ripple marks, and, surprisingly enough, desiccation cracks.

Cross-beds. In the siltstone-dolomite suite, well-developed cross-beds are minor in number and, where present, occur only in units of sand-sized (very fine to medium) grains. Nevertheless, those observed give relatively consistent readings and display a somewhat more northerly, overall transport direction than that indicated by the flute, groove, and elongate load casts (Plate 4). In the northern shore section, four readings yield a mean azimuth of 38° and standard deviation of 7°. A single cross-bed on Allday Brook also suggests a northeasterly direction of transport (azimuth, 52°). Near the southern limit of the suite, from Woody Brook harbor southwestward, seven cross-beds indicate a northwesterly direction of transport of 341° (standard deviation of 23°).

The information obtained from cross-beds, sparse though it may be, suggests therefore that south of Woody Brook harbor sand-depositing currents entered the basin somewhat tangentially, trending north-northwest. Presumably these veered slightly clockwise as they continued deeper into the basin so that ultimately, near the northern limit of the outcrop belt, they were aligned with the northeasterly groove-cast direction. Thus, both north and northeasterly directed current systems appear to have been active. Other directional features substantiate this conclusion.

Parting lineations. Although parting lineations (primary current lineation of Stokes, 1947) occur in sandy beds throughout the siltstone-dolomite suite, as with the other primary features so far discussed, they are most abundant and best developed along the Grand Lake shoreline southwest of Woody Brook harbor. Their form is typical of parting lineation surfaces as described by Potter and Pettijohn (1963, pp. 137-138):

A thin veneer, but a millimeter or two thick, is seen to cling in irregular elongate patches to the bedding surface-- the residue of a once continuous layer now largely removed but having plaster-like remnants adhering to the bedding plane. These patchy, irregular areas are elongated in the direction of the parting lineation.....

The mean sense of 34 parting lineations is 63° - 243° (see Plate 5). This orientation is at a considerable angle to that of the cross-beds and agrees much more closely with the

groove-cast direction. The association of groove casts and parting lineations is unusual, for groove casts are generally thought to form in relatively deeper waters (in association with rhythmically graded beds and flute casts), whereas parting lineations are usually cited as occurring in shallower regimes of sedimentation (in association with cross beds). The northeasterly parting lineation trend is, however, in no way anomalous, for it is prevalent not only in this suite but also in the red arkose suite and gray sandstone suite as far south as Island Pond Brook and the upper reaches of Porters Brook. The similarity in orientations between the groove casts and parting lineations may be a result of the fact that both are thought to form under flow conditions of relatively high intensity. Allen (1964) has reported on the hydrodynamics of parting lineation formation and suggests that parting lineations may be formed on submerged sand bars in fresh-water river channels or tidal ebb-flood channels where rapid flow is persistently unidirectional. Stokes (1947) also emphasizes their shallow-water origin.

The variability of the parting lineations in the siltstone-dolomite suite (standard deviation of 49°) is in distinct contrast to their overall consistency in the two other suites.

Ripple marks. Ripple marks are by far the most abundant primary feature in the Lower Mississippian section. They are particularly common in the siltstone-dolomite suite

but are present also on gray fine sandstones of the other two suites. Almost without exception, ripples are of the oscillation type (symmetrical in cross section) and very uniform in size; wave lengths vary from two to four inches, with the great majority of crests three inches apart.

Oscillation ripple marks have been reported from modern and ancient lacustrine environments (Davis, 1965; Greiner, 1962; and Picard, 1967) as well as modern and ancient marine shelves (Vause, 1959; King, 1948; and Picard and High, 1968). There are differences of opinion, however, in the interpretation of their environmental significance. Pettijohn (1957, p. 186) considers them wave-generated and therefore related to prevailing wind direction and topography (shore line). Presumably they are indicative of a standing body of water, forming only in depths affected by wave motion. "As wave-generated movement dies out rapidly with depth, oscillation ripples are indicative of shallow waters, generally waters but a few tens of feet deep." Although symmetrical ripples have been reported from waters as deep as 4500 feet (Menard, 1952), it is considered doubtful that profusely ripple-marked sands could form at such great depths. These conclusions are largely supported by Davis' study (1965) of oscillation ripples in Lake Michigan. He ascribes their origin to prevailing wind-generated wave action with ripple crests forming normal to the wave direction. Their maximum observed depth was 36 feet, though they may

have extended into deeper waters. Where winds struck perpendicular to the shoreline, the resultant ripples paralleled the strand; where the winds were oblique, ripples near the strand were oriented as much as 65 degrees from the shoreline. For this reason caution must be used in establishing ancient shoreline directions from ripple data.

A different point of view, based on the study of ripple marks on an ancient shallow marine shelf, is presented by Picard and High (1968). They propose that

"...symmetric" and "asymmetric" ripple marks are not wave- and current-formed respectively. Rather, most ripple marks possess some degree of asymmetry, either in shape or internal structure, and are formed by currents (including most waves in shallow water). Truly symmetric ripple marks formed by standing oscillatory waves are probably rare.

Since oscillation ripple marks are affected by slight topographic variations as well as by the above-mentioned shorelines, currents, and variable wind-driven wave systems, a wide range in their orientations is to be expected. Ripple marks of the siltstone-dolomite suite display such a dispersion. Nevertheless, there is a general tendency in all three depositional regimes for the more easterly ripple marks, those near the present Grand Lake shoreline, to be oriented in the northwest-southeast quadrants while those further inland occur more commonly with northeast-southwest trends. This is well illustrated in the siltstone-dolomite suite. Inland, on Allday Brook, 11 ripple marks all with northeast-

southwest orientations, have a mean sense of 58° - 238° and a standard deviation of 37.5° (Plate 6); by contrast, near the Grand Lake shore-ripple azimuths exhibit a moderately well-defined northwest-southeast preferred orientation. Eighty measurements on separate beds give a standard deviation of 58° from the vector mean sense of 135° - 315° . This direction is very nearly perpendicular to the mean sense of the groove casts (mean sense = 31° - 211°) and parting lineations (mean sense = 63° - 243°). (Picard and High, 1968, p. 413 also report ripple crests normal to parting lineations.) Thus, the ripple marks are orthogonally related to the groove casts and parting lineations, perhaps through the influence of the original basin topography. If paleowinds are accepted as ultimately responsible for the ripple-mark orientation, then they and the resultant waves may have been directed along the length of a northeast trending elongate basin; this condition of elongation and prevailing wind direction exists in Grand Lake today. Northeastward deepening of the basin would have controlled the orientation of turbidity currents (and the formation of groove casts) so that sediment transport occurred in the same direction as elongation and dominant wind direction. An alternative explanation is that the ripple marks are more directly related to currents (perhaps slight) generated by northeasterly moving turbidity flows. If true, then the ripple marks would be parallel to, and define, the depositional strike. McIver (1961, loc. cit. Potter and

Pettijohn, 1963, p. 97) noted ripple marks at right angles to flute and groove casts in Upper Devonian flysch deposits of the Central Appalachians and considered them as having been formed parallel to the depositional strike. Greiner (1962) found that orientations of oscillation ripple marks in the known lacustrine Albert Formation (Lower Mississippian, Horton equivalent in age) of New Brunswick, Canada, coincided with the strand line rimming the depositional basin. Therefore they also were formed parallel to the depositional strike. Parallelism of ripple marks to modern lakeshore lines has been reported by Wulf (1963) and Davis (1965). The modal orientation of ripple marks in the siltstone-dolomite suite closely parallels the southern contact with the gray sandstone suite. Their orientation thus coincides with the depositional strike and supports the statement by Potter and Pettijohn (1963, p. 98), "In flysch deposits, ripple marks, where they have been measured, tend to parallel the depositional strike." In conclusion, the orientation of the ripple marks used in conjunction with other primary structures indicates a northward or northeastward deepening of the basin.

Plant fragments. In spite of the fact that plant fragments are quite abundant throughout much of the Anguille Group, their general random orientation on bedding planes severely reduces their effectiveness as paleocurrent indicators. A poor correlation between plant debris and current direction has been reported by others (Gradazinski et. al.,

1959, loc. cit. Potter and Pettijohn, 1963, p. 39, p. 175; and Sullwold, 1960). Conversely, Hopkins et. al., (1966) noted a fair correlation between oriented plant fragments and cross-beds. As it has been suggested by Potter and Pettijohn (1963, p. 39), size variation may influence the hydrodynamic properties of the fragments thus reflecting their ability to become oriented. Plant fragments have been reported both perpendicular and parallel to paleocurrent directions as inferred from other sedimentary features.

At the few places in the siltstone-dolomite suite where plant debris are distinctly aligned, the long axes of the fragments tend to lie in the northeast-southwest quadrants (vector mean sense of 43° - 223° --see Plate 7). Yet even in these cases, grouped data does not exhibit a strongly preferred orientation; the standard deviation for only six readings is 50° . The wide range of these few measurements restricts their value as paleocurrent indicators.

Very poorly preserved plant remains are present at one locale on Allday Brook. Their rude parallelism (sense = 55° - 235°) is similar to the average ripple-mark orientation on this stream (sense = 58° - 238°).

The abundance of plant fragments and carbonaceous remains does have, however, another and perhaps greater significance. Throughout the entire Lower Mississippian section in west-central Newfoundland, no faunal fossils were uncovered. By contrast, floral remains and macerated car-

bonaceous debris are present in almost all horizons and locally are very plentiful. This abundance suggests that deposition took place proximal to a source area profuse in terrestrial vegetation and thus it appears quite likely to have been a continental basin.

Desiccation cracks. The most unexpected primary features in the siltstone-dolomite suite are desiccation cracks. They were observed at several localities along the Grand Lake shoreline in a somewhat sandier section of the northern portion of the regime. They occur as polygonal-shaped sandstone fillings in green and gray fine siltstones and black shales. At one locality the fillings are dolomitic sandstone. Desiccation cracks are unexpected because further to the south this same suite contains graded graywacke beds displaying sole markings, a phenomenon considered to be the result of turbidity current deposition. Sedimentation of this type is generally thought to require at least moderate depths of water for formation and is therefore incompatible with the subaerial drying conditions necessary for the formation of desiccation cracks.

The existence of the cracks may be explained in either of two ways.

1. They are not desiccation cracks and have originated by some other mechanism. Dzulynski and Walton (1967, p. 167) have described sand polygons or pseudo-mud cracks which they suggest are the result of sand-like injection in a poly-

gonal pattern. In plain view, therefore, they resemble the desiccation features. The sand polygons are thought to be created through earthquake shock and consequent liquification and differential horizontal expansion of interbedded, sand-shale sequences. The greater increase in the horizontal extent of the sands would cause hexagonal tension cracks in the shales into which sand could be injected. Such an origin for the features described from the siltstone-dolomite suite seems improbable, for no clastic dikes were observed in these strata. Others who have mentioned the formation of polygonal cracks probably not due to subaerial drying conditions include Moore (1914), Twenhofel (1923, 1926), and Daley (1968). Their explanations, however, are not applicable here.

2. They are true desiccation cracks and have been formed in shallow water. An origin such as this seems more likely, since oscillation ripple marks--interpreted as relatively shallow water in origin--abound in the same general region as that in which cracks occur. The sediment-water interface is therefore considered to have been no deeper than that which could have been affected by surface-generated waves. The association of shallow-water desiccation cracks and turbidite sequences in the same sedimentary regime may be explained in either of two ways.

(a) The strata of the sandy section in the northern portion of the siltstone-dolomite suite represent a somewhat

later (possibly correlative with the upper portion of the gray sandstone suite) and downfaulted sequence which represents a shallow phase of deposition during which sedimentary fill and/or tectonism reduced the water depths in the basin.

(b) The strata containing desiccation cracks are approximately correlative with those of the turbidite sequences but were deposited in a locally shallower portion of the basin. This interpretation would imply that either the basin was very steep-walled, having some shallower portions, or that turbidity deposits were formed in relatively shallow waters. There are precedents for both these models in the geologic literature. Crevasse deposits have been cited by Prentice (1962) from the continental Weald Clay Sandstone of Sussex, England. Alternatively, DeRaaf (1964) has reported turbidite-type deposits in a relatively shallow-water basin. He describes Oligocene strata of the southern Pyrenees as containing rhythmically graded sandstone beds with flute and groove casts; these are interpreted as having originated from turbidity currents. In the same horizons, however, occur: abundant oscillation-ripple marks with quite variable orientations; pseudomorphs after salt crystals and gypsum deposits, both indicative of evaporitic and shallow-water conditions. Mangin (1962) has reported the association of flute casts and bird tracks from these same strata.

It may be safely assumed, therefore, that either the basin described was very shallow or that Oligocene birds had very long legs.

Dolomite, Sandy Dolomite and Interlaminated Orange Dolomite and Black Siltstone

In addition to the psammitic strata described above, the black siltstone-orange dolomite suite contains carbonate rocks; these include for the most part orange-weathering dolomites and, in lesser amounts, some few gray limestones. The orange dolomites are unique to this depositional regime and so have been used to delimit its boundaries as well as to provide the facies unit name. Throughout, they occur interbedded with the other sedimentary rock types already described. Quantitatively, the carbonates are much less abundant than the sandy units but are otherwise very important for they provide significant clues to the environment of deposition.

Lithologic description and environment of deposition - dolomites and sandy dolomites. The dolomite

beds are conspicuous, for they weather to bright or dull orange and so stand out in sharp contrast to the darker gray, black and brown sandstones and siltstones. Also, weathered surfaces invariably are slightly undulatory and uneven in appearance. The distinctive orange color of the weathered dolomite (due to the presence of iron) and the fact that both its indices of refraction are above that of Canada balsam indicate that it is a ferroan or ankeritic dolomite.

Where pure, the ferroan dolomites weather to bright orange (dark yellowish orange, 10YR 6/6 to light brown, 5YR 5/6) and are creamy white (pinkish gray, 5YR 8/1) on fresh surfaces. However, more commonly the dolomitic beds contain sandy and carbonaceous material and as a result, weather to duller shades of tan-orange (moderate yellowish brown, 10YR 5/4) and are dark gray or black on fresh surfaces. In thin section, the sandy dolomite appears as a crystalline-carbonate mass throughout which are scattered: ragged, elongate, opaque fragments of carbonaceous material; equant, angular, clear quartz grains; and acicular muscovite and biotite.

The black color of dolomites, siltstones, and shales, the abundant unoxidized carbonaceous debris, and the presence of ankerite and iron sulfides (presumably primary) indicate that deposition took place almost certainly under euxinic conditions. Such conditions are characterized by quiet water and a reducing environment (Krumbein and Sloss, 1963, p. 565). Pettijohn (1957, pp. 305, 314, 594) mentions that ankerite is often associated with graywackes and that its existence is suggestive of deposition in stagnant, anaerobic waters where wave and current action is negligible.

Lithologic description and environment of deposition - laminites. Orange dolomites are also found in a distinctive interlaminated association with black, carbonaceous-rich siltstones and shales (Fig. 8). The lamina-

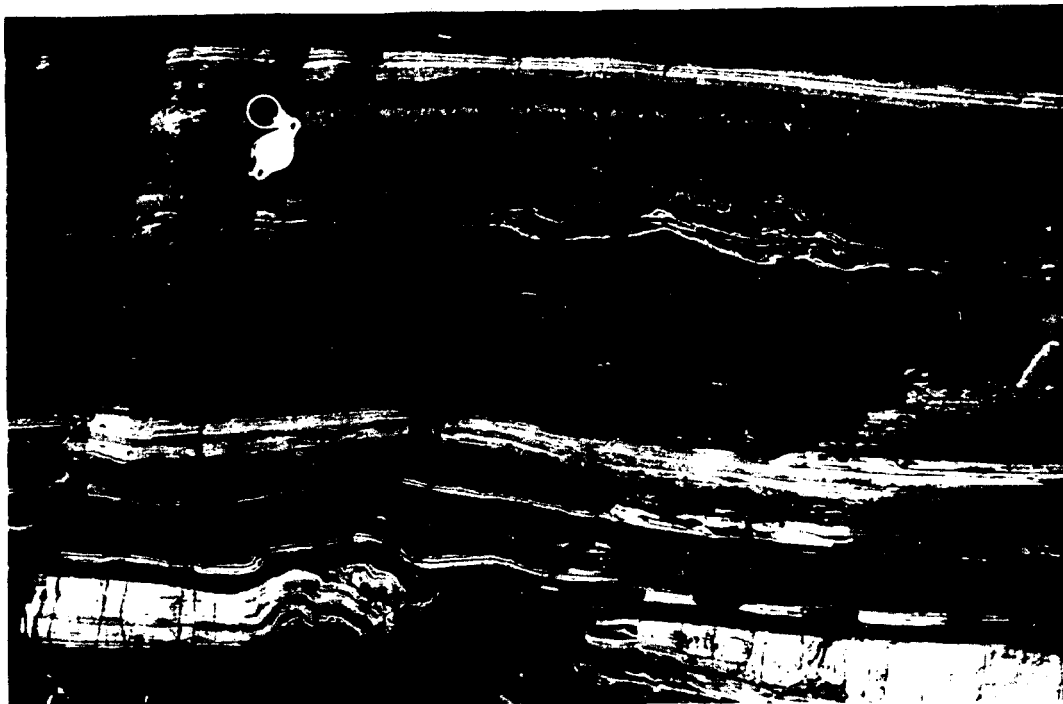


Fig. 8

Laminated siltstones and dolomites, Woody Brook harbor, siltstone-dolomite suite.

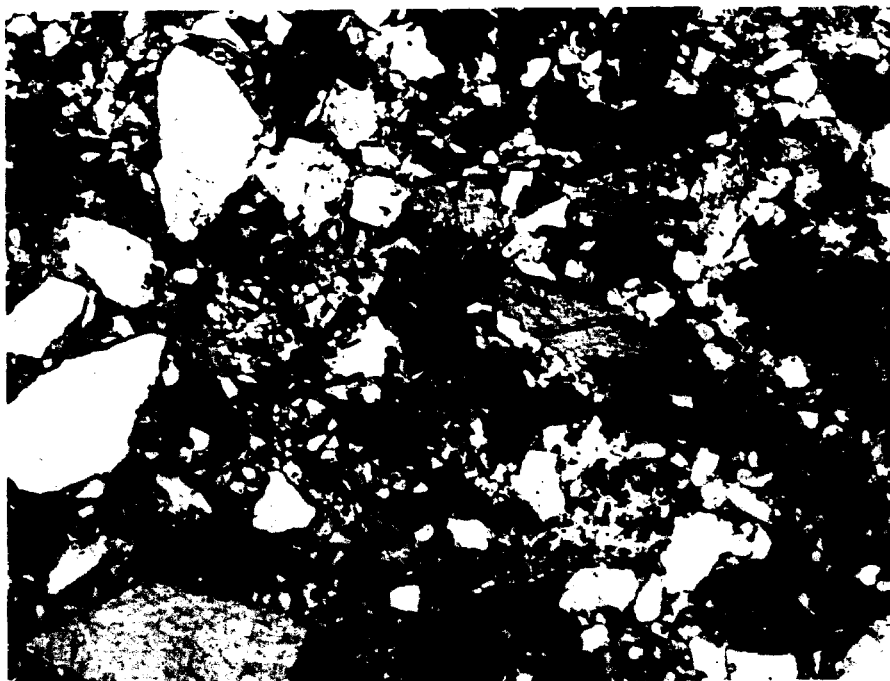


Fig. 9

Photomicrograph of fine-grained portion of carbonate cobble conglomerate. Clear grains mostly quartz; carbonates exhibit twinning. (F60, plane light, approx. 20X.)

tions are extremely fine, many less than .3 mm. thick, remarkably continuous, and have sharp upper and lower contacts. Preservation of this type of layering is critical to paleoenvironmental interpretations, for associated with it are several important implications.

1. Benthic organisms, other than, perhaps, anaerobic bacteria were absent; burrowing creatures unquestionably would have destroyed the delicate laminations. This conclusion coincides with the lack of any other evidences for the existence of fauna.

2. Deposition took place below wave base in still, undisturbed water, and in the absence of any bottom currents which likewise would have disturbed the laminations. As Pettijohn (1957, p. 163) has pointed out,

"The distinctness and degree of preservation of the laminations is in part a rough measure of the quietness of the waters in which the sediments accumulated. Even slight bottom currents would destroy any previously formed laminations. Hence laminations record deposition below wave base."

Stagnation of the water and resultant oxygen deficiency in this portion of the basin would explain why the strata are devoid of any signs of benthic life; again, deposition under euxinic conditions is suggested.

3. Deposition was rhythmic or cyclic in nature. The general appearance of the laminations is strikingly similar to varves commonly associated with glaciolacustrine deposits. No evidences of glaciation were uncovered,

however. On the other hand, varved deposits have been described from non-glacial sequences by Nipkow (1928), Bradley (1929, 1948), Muir and Walton (1957), Anderson and Kirkland (1960), Van Houten (1962, 1965), and Rayner (1963); the majority of examples are from lacustrine basins. Pettijohn (1957, p. 163) mentions that the most perfectly laminated shales are those purported to be lacustrine in origin.

After a review of the literature, Duff et. al. (1967, pp. 62-63) describe the characteristics of varved lake sediments from areas not affected by glaciation. The following passage points out the remarkable similarity of such units to the laminated strata of the siltstone-dolomite suite; again it is concluded that deposition took place in a lacustrine basin.

The smallest rhythmic unit is bipartite like the glacial varves but the couplets are made up of an organic (carbonaceous)-rich layer and an organic-poor layer. The latter often consists of carbonates though sometimes mineral material comprising quartz, feldspar and clay minerals assumes greater importance. The carbonates are commonly calcite or dolomite, occasionally ferroan dolomite... The thickness of the individual varve is almost invariably a fraction of a millimeter. The lateral extent of each couplet is difficult to judge but the thickness of each lamina seems to be fairly constant. Current bedding even on a small scale is noticeably absent, as are erosional features...there is no disturbance of bedding due to...burrowing organisms (benthonic life must have been at a minimum).

The contacts of the individual layers are usually sharp both top and bottom except in those couplets where clastic debris instead of carbonate is predominant.

Origin of the laminites. Several theories have been proposed to explain the origin of non-glacial varves. It has been suggested that they may be the result of: biochemical reactions; spasmodic storms; differential settling; or periodic supply. Duff et. al. (1967, p. 64) have discounted each of the above as unlikely causes except for periodic supply which they deem a necessity and point to seasonal control as the most plausible explanation. Other authors in accord with this view are Nipkow (1928), Bradley (1929), Rubey (1930), Seibold (1955), Pettijohn (1957, p. 353), Kaplan and Rittenberg (1963), and Reineck (1967).

Compelling evidence for the seasonal periodic supply of detritus in Recent lake deposits has been provided by Nipkow (1928, loc. cit. Bradley, 1948, and Duff et. al., 1967). In his extended study of the sediments of Lake Zurich and Lake Baldegg, Switzerland, Nipkow found that each year a deep-water (greater than 90m) varve was formed consisting of a light-colored, microgranular carbonate, summer layer and a darker, thinner, winter-layer composed of organic matter. He was able to determine that they were annual because 1) each summer his diatom plankton nets clogged with calcium carbonate that had precipitated out of the surface waters and 2) it was possible to date pre-

cisely the individual varves due to the presence of thick, muddy layers in the sequence which corresponded to years of accurately known lakeshore cave-ins; at those times large sections of the shore slid into the lake. Another such event, which took place in Lake Zug, Switzerland, 1887, is described by Heim (1908, loc. cit. Hills, 1967, pp. 59-60). These lakeshore landslides and their subaqueous counterparts interrupted seasonal laminite deposition. There is thus a striking resemblance of sediment types and associations of the Swiss Lakes with strata of the siltstone-dolomite suite. In both cases the turbidites account for the presence of the coarser, graded sandstones interbedded with the laminites.

One portion of the siltstone-dolomite depositional regime consists solely of laminated strata to the exclusion of any other type of bedding. This subdivision is a narrow band of outcrop (0.3 miles wide) extending from the lake at the head of Allday Brook directly southward to Wrong Brook. The region is characterized by: finely laminated orange dolomites and/or black siltstones and shales; an absence of microscopic plant fragments; and an utter lack of primary features. It seems likely that this was the site of deepest-water deposition. Primary directional features indicate that paleocurrents were moving downslope into this region. Furthermore, in order to produce and preserve the laminations, sedimentation must have taken place below wave

base, exclusively by the undisturbed, slow settling of fine particles beyond the limits of the peripheral supply of coarse detritus. Just such origins and spatial relationships between turbidites and laminites (deposited on and beyond the distal margins of the turbidites) is reported by Lombard (1963). Nipkow's study of Recent lake sediments also provides confirmation for relatively deep-water laminite origin (loc cit. Bradley, 1948); he found varved sediments only in the deepest portions of Lake Zurich (below 90 meters) where dissolved oxygen was absent and where no bottom fauna could spoil the laminations. Kaplan and Rittenberg (1963, p. 589) similarly favor stagnant-bottom conditions as the most likely location for the preservation of laminations.

Laminated deposits (dolomites) are thought, in some instances, to be formed in tidal areas. Such an origin is clearly not the case here; this conclusion is based on the other characteristics associated with these laminites.

Source of the carbonates and the carbonate-cobble conglomerates. As it has already been mentioned, the laminated strata in the siltstone-dolomite suite are composed of interlayered, dark, carbonaceous siltstones and lighter-colored, ferroan dolomites. It seems most likely that the organic matter in the silty layers was derived from nearby terrestrial vegetation and that the ankeritic layers are the result of carbonate precipitation from surface waters. Zoogenic origins might also be considered for the

carbonate, but in light of the foregoing conclusions indicating a total lack of fauna, such a contention is untenable. The presence of ankerite is prima facie evidence that carbonates must have been supplied to the basin at the time of deposition; corroborating evidence is provided by strata exposed along the west flank of the Glide Mountains. There, a carbonate cobble conglomerate occupies a similar stratigraphic position to that of the siltstones-dolomites; i.e., at least in part, the conglomerates are located below the white weathering sandstones and conglomerates of the gray sandstone suite (see Plate 2). Since the carbonate conglomerates and siltstones-dolomites occur in similar positions, they are considered likely to be time-equivalent facies of one another, with the carbonate conglomerates representing the coarse basin margin units. Bradley (1929) has envisioned the same depositional pattern for eocene lacustrine deposits.

The carbonate conglomerate (Fig. 9) consists of cobbles and pebbles of: sub-rounded, tan, buff, and pale orange, fractured and marmorized dolomite; white, gray, and grayish-white limestones, some containing white calcite veins; few pink limestones; and sub-angular, milky-white quartz. All clasts are set in a poorly sorted, coarse sandy, calcareous matrix. The dolomite clasts are yellowish gray (5YR 7/2) on fresh surfaces and weather to grayish orange (10YR 7/4) or dark yellowish orange (10YR 6/6). The similarity in

color to the laminated ferroan dolomites again suggests that the two are genetically related. The conglomerate is also exposed at the southern limit of Lower Mississippian outcrop on Grand Lake (see Plate 2). There it consists of clasts much like those just described but additionally contains considerable amounts of green, chloritic, schistose fragments, some jasper, and a few green and gray, possibly volcanic (?) clasts. Locally the conglomerates are interbedded with red and green coarse siltstones and in places contain large chunks of red siltstone two to three feet in width. Thin section modal analyses for three samples from the carbonate conglomerate horizon show them to be closely alike in composition (see Table 1, samples E77A, F60, F85, and Fig. 13).

Although no directional features are associated with the conglomerates and in most places even distinct bedding is lacking, the source and approximate transport direction can be deduced from stratigraphic scalars and attributes. The conglomerates constitute the overall coarsest lithology in the area, with maximum clast size decreasing in a northeasterly direction from 30 cm. on Salmon Creek and Eastern Brook in the south to 3 cm. on Lanes Brook in the north. The cobbles must therefore have been brought into the basin from the south and/or west. (Maximum clast size also decreases from older to younger strata in these units.) The coarseness and abundance of clasts further dictates that

they must have been derived from a relatively nearby carbonate source. The only group of rocks satisfying these qualifications is the St. George's Limestone. Since all carbonate lithologies described as clasts within the conglomerate are also present in the St. George's Limestone (see description, p. 24) and no carbonate deposit exists proximally east of the trans-Newfoundland lineament, the St. George's Limestone is taken as the source rock for the carbonate clasts. The chlorite schist fragments in the conglomerate on Grand Lake quite probably were derived from rocks of the Grand Lake Brook Group (see description, p. 23).

These carbonate cobble conglomerates most likely accumulated as a result of fault movements. As Pettijohn (1957, p. 257) has pointed out, carbonate conglomerates are exceptional in character for they

"...record unusual conditions which permitted the erosion of limestone as gravel rather than the usual removal by solution ...This implies sharp uplift and locally high relief--best achieved along a fault scarp..."

A model proposed by Bradley (1948) for the origin of the carbonates in the lacustrine Green River Formation (Eocene) is well suited for application here.

...streams that drained into the lake crossed upturned limestones or limy formations in the neighboring mountains. We have deduced that the climate of the area was warm and relatively moist. In such regions the streams are characterized by carbonates in solution...The lake therefore had an abundance of carbonates

brought to it. Now the lake occupied so large a portion of its hydrographic basin and the temperature was such that each year most of the accession of water was lost by evaporation rather than by overflow. Indeed, for long intervals the lake had no outlet. This means that most of the dissolved carbonates were caught and held in the lake basin. Within the lake two factors tended to precipitate the calcium and magnesium carbonates: 1) the summer warming of the water, which decreases the solubility of these carbonates, and 2) the photosynthesis of the algae which takes carbon dioxide out of the system and thereby raises the pH values, which increases the concentration of normal carbonates until the solubility product is exceeded and the calcium and magnesium carbonates are thrown down.

It has already been pointed out that stagnant-water conditions existed in this part of the basin. The abundance of organic matter indicates that here the Early Mississippian lake must have been stratified, that is, seasonally separated by a thermocline into an upper epilimnion and a deeper hypolimnion. The thermocline acted as a seal separating oxygenated warm waters of the epilimnion from mixing with deeper, cooler waters of the hypolimnion where decay of organic matter continued to use up the dissolved oxygen and increase the quantity of dissolved carbon dioxide. Stagnation ensued and the water became charged with hydrogen sulfide. Dissipation of the thermocline in the fall and resumption of full circulation resulted in overturn, mixing of the deeper water with the more alkaline surface waters, a raising of pH values, precipitation of the carbonates, and the resumption of a new cycle.

Correlation. The distinctive association of interbedded black siltstones and orange dolomites was observed in two other formations in western Newfoundland:

1. The Snakes Bight Formation (Baird and Cote, 1964), exposed in cliffs along the southwest shore of the island, northeast of the village of Codroy.

2) The Spear Point Formation (Heyl, 1937), exposed in cliffs along the western shore of White Bay, south of Upper Head.

Both formations belong to the Anguille Group and on the basis of plant remains, have been reported to be approximately equivalent in age (Lower Mississippian, see Betz, 1948 and Baird, 1959).

Gray Sandstone Suite

General Statement

The following section discusses the gray sandstone suite, the medial unit in the tripartite division of the Anguille Group. Lithologies present in this suite include white and gray weathering arkosic conglomerates; gray arkosic sandstones, micaceous sandstones, and graywackes; even-bedded, gray, black, and brown weathering siltstones; a few black silty shales. Psammitic strata are in far greater abundance than carbonates, which are sparsely represented by few gray limestones.

Rocks of the gray sandstone depositional regime are the most widespread in surface outcrop of any of the three suites

and extend from the environs of Leo Brook in the south, northeasterly to Lanes Brook and Allday Brook (see Plate 2). In the intervening area, the existence of gray sandstone suite strata is attested to by outcroppings along brooks and by "float" on trails in the more heavily wooded sections. No high gradient streams cross the region immediately east of the headwaters of Lanes Brook, an area undoubtedly supporting thick glacial cover. As a result, no evidence of bedrock-type was obtained and the underlying lithology remains indeterminate. However, since gray sandstone suite strata are exposed on Lanes Brook, it seems likely that these units also occur in the region to the east.

The name applied to this suite is derived from its abundance of gray sandstones and sandy conglomerates. These lithologies, however, are not restricted to this suite and in fact are present in each of the other two suites.

Nature of the Contacts With Other Suites

As it was mentioned at the outset of the section on siltstones and dolomites, contacts with adjacent suites are set by the first or last appearance of a particular lithology. This technique has also been applied to the gray sandstone suite. Here too, lithologic change at the suite boundaries is characterized by a gradual change of the dominant lithology and interfingering of distinctive units. Along the west shore of Grand Lake southwestward from Woody Brook harbor, there is a gradual decrease and eventual absence of orange

dolomites and black shales; this is accompanied by an increase in the number of gray sandstone beds. The last southerly occurrence of orange dolomites (also that stratigraphically highest) is taken to indicate the beginning and lower limit of the gray sandstone suite.

A gradual transition of lithologies similar to that just described is displayed in the section from the headwaters westward to the base of Allday Brook. There, a change from dominantly silty to sandy beds is coupled with a decrease and ultimate absence of orange dolomites. The change again takes place through generally younger strata and again the last occurrence of orange dolomites is taken as an indication of the onset of the gray sandstone depositional regime.

The pattern of gradual transition is maintained within the suite itself, for along the west shore of Grand Lake, brown weathering siltstone beds become progressively more scarce in a southwesterly direction. The last appearance of black, even-bedded siltstones associated with gray fine sandstones occurs just north of the mouth of Harbor Brook. This is close to the first appearance of red arkose which marks the upper limit of the gray sandstone suite.

The nature of the boundaries between regimes--one of interfingering units rather than abrupt change--indicates that portions of the gray sandstone suite must be, at least in part, time-equivalent to rocks in the other suites.

Sandstone and Conglomerate - Lithologic Description and Provenance

Sandstones and sandy conglomerates of the gray sandstone suite are generally immature, ranging in composition from arkose to graywacke. The arkosic units contain angular to sub-rounded fragments of milky white or colorless quartz, white feldspars and perthite. Present in lesser amounts in the matrix and as rounded pebbles in the conglomeratic strata are granitic, igneous and metamorphic rock fragments. A few of the sandstones contain irregular pyrite nodules. Gray siltstone is present in some conglomerates as intraformational clasts (Fig. 10) or in greater or lesser amounts as part of the matrix. In cases where the silt fraction exceeds 15 percent as matrix, the rock is classified as a feldspathic graywacke (Pettijohn, 1957). Arkoses and graywackes are interbedded and present in approximately equal amounts, but the relative proportion of arkoses to graywacke increases toward the southwest.

All units are well indurated and evenly bedded. Most sandy strata range in thickness from two inches to two and one-half feet (though some are as thick as 20 feet); conglomeratic beds range from one and one-half feet to 15 feet (though some are as much as 50 feet thick). Where weathered to completion, the arkoses have a distinctive stark-white appearance (Fig. 11), a result of kaolinitization of the feldspars. Other arkoses are buff or pale gray, depending upon: 1) the degree of weathering, 2) the silt content, and

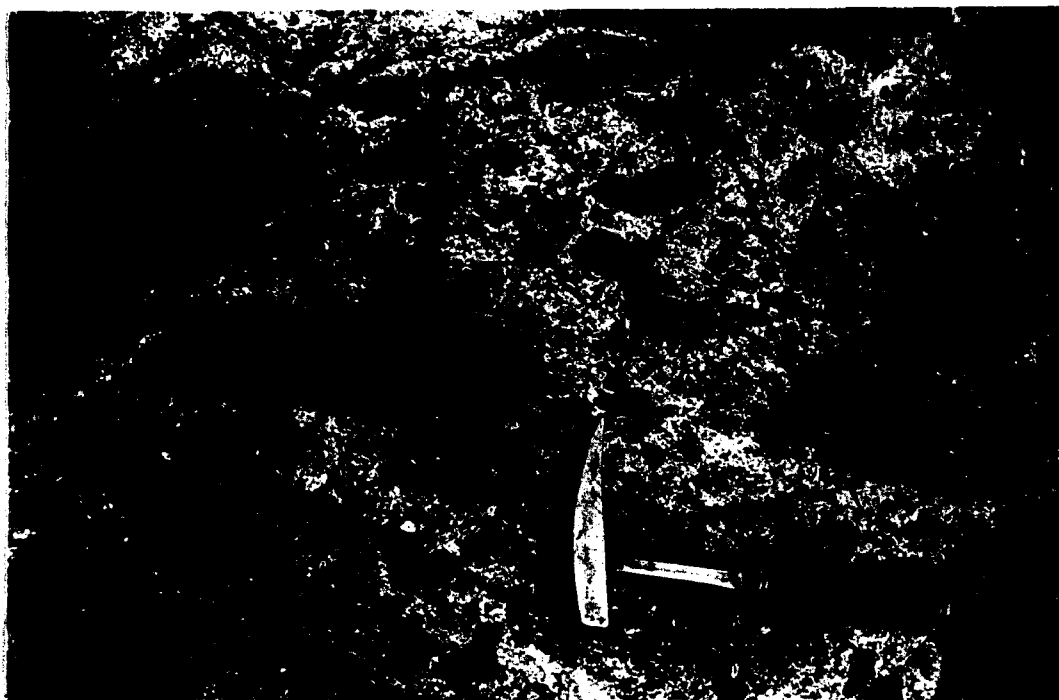


Fig. 10

Intraformational siltstone clasts in arkosic conglomerate, gray sandstone suite.

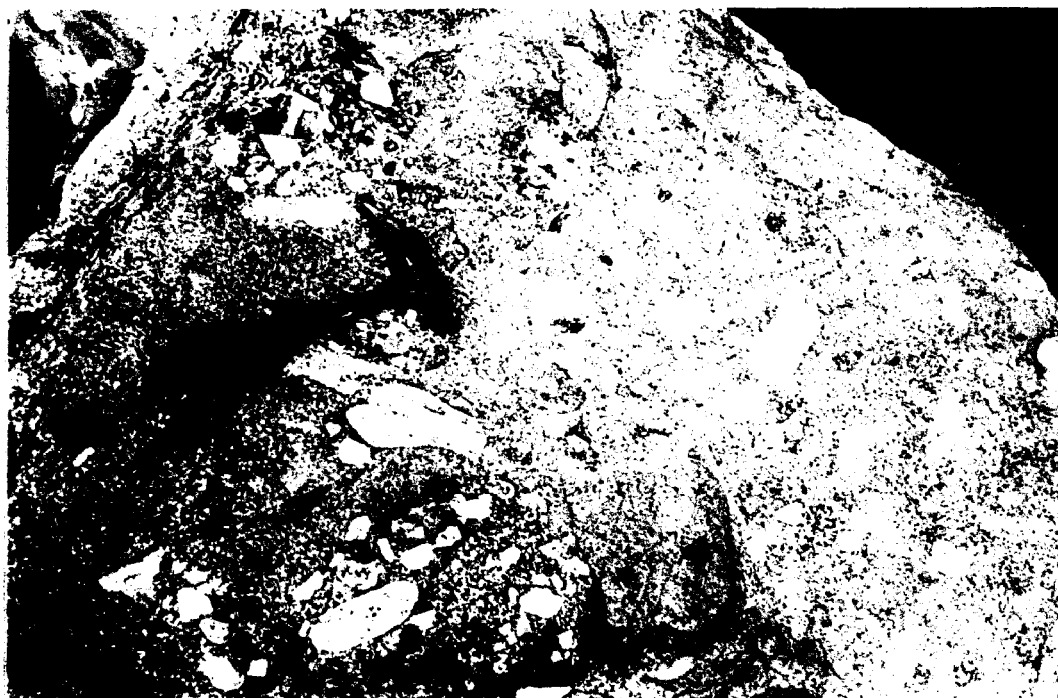


Fig. 11

White weathering arkosic conglomerate, gray sandstone suite.

3) the amount of included dark clasts such as chlorite and rock fragments. Arkoses are buff or gray on fresh surfaces. Weathered and fresh surfaces of graywackes are dark or light gray. Sole markings and turbidite structures are much less common in graywacke beds of this suite than those of the siltstone-dolomite suite.

In the conglomeratic sandstones, large, rounded clasts are enclosed in a more angular, quartzo-feldspathic matrix. The maximum exposed diameter of most of these clasts is three to eight cm.; a few are as large as 15 to 21 cm. The types of pebbles in the conglomerates vary somewhat according to location. Along Grand Lake, on the eastern side of the Glide Mountains, pebbles in the sandstones are predominantly quartz, white granite and some feldspars. Clasts present in lesser amounts but invariably larger in size are of volcanic origin. Pastel shades, especially pale yellow, are most common. The concentration of volcanic clasts increases in a northeasterly direction (see Table 1, D47--G75A--E12) as does red jasper and prase (green jasper). These last are very conspicuous in the white arkosic matrix.

An unusual constituent present in some of the arkoses are clasts which most likely are amorphous hydrous aluminum silicates. Their occurrence is unexpected because they are extremely soft (hardness, approximately one) and possess excellent sectility. Fragments are composed of flakelike, olive green aggregates which stand out in contrast to the

lighter shades of the surrounding matrix. Although almost entirely amorphous, they do display some crystallinity. In thin section, scattered, microcrystalline, acicular and platy grains exhibit a low birefringence; additionally, the X-ray diffractogram shows a broad curvature but lack of any truly prominent peaks, except for those of weak intensity for chlorite, biotite and quartz. Undoubtedly these clasts are related to the clay minerals, for each of the major clay mineral peaks ($7\overset{\circ}{\text{A}}$, $10\overset{\circ}{\text{A}}$, $14\overset{\circ}{\text{A}}$) can be distinguished. Because of their softness and lack of cohesiveness, these grains are testimony to the rapid accumulation of the enclosing deposits. Even slight distances of transport would have abraded these soft fragments. Alternatively, they may represent volcanic clasts which have been altered subsequent to deposition. In this case, no significance could be attached to their physical characteristics.

The pebble association in gray sandstone suite units on the east side of the Glide Mountains (quartz-feldspar-granite-volcanics-few metamorphics) contrasts with that of similar strata on the western side, where in addition to quartz (milky white, colorless, blue), feldspar, and some white granite, there are carbonates (orange dolomite, pink and white marble) and schists. Volcanic pebbles are absent. The regional differentiation of pebble types is further accentuated by the fact that on the western side of the uplift, some of the sandy matrix is quite micaceous and in places

calcareous; on the eastern side, carbonate is not present as clasts or rock matrix.

In the central part of the Glide Mountains, rock outcroppings are limited. Where bedrock is exposed, fine sandstones and siltstones predominate, coarse or pebbly sandstones are generally lacking, and conglomerates are absent. Presumably, the coarser sediments only rarely were transported to the central portions of the basin.

Modal analyses of sandstones from the gray sandstone suite are given in Table 1. Analyses of those rocks taken from along the Grand Lake shore (D47, E12, G75A) show them to be arkoses; however, graywackes are also present. Samples from the more central portion of the Glide Mountains are graywackes (E63, F94) and an arkose (E70). Thin sections of the arkoses, especially the lake shore samples, show limpid quartz containing abundant dust inclusions and bubble trains. Genetically this has been referred to as hydrothermal vein quartz (Krynine, 1940). Much of the quartz also has a composite appearance, a result of rectilinear suturing most likely related to incipient fractures. The plagioclase grains which exhibit twinning indicate that all are soda rich, ranging in composition from oligoclase to andesine. In spite of the angularity of most clasts, all of the gray sandstone suite arkoses along Grand Lake contain very little matrix or pore space. In some cases the size of much of the

original pore space appears to have been reduced as a result of brecciation. Fractures pass through the grains and into the matrix.

Sample E70, located inland on the Glide Mountains, is also an arkose but clearly has a greater percentage of metamorphic rock fragments than that in the lake shore samples. This is also true for the graywacke (E63) which contains metamorphic rock fragments and a considerable amount of minerals derived from the local metamorphic terrain. These include garnet and large flakes of muscovite, chlorite, and biotite.

An analysis of sample F94, a graywacke from atop the Glide Mountains, proved to be particularly enlightening, for in it there is a distinct compositional contrast between the larger clasts and the matrix. Framework clasts are subangular to subrounded and consist primarily of strikingly distinctive perthite grains (35%). These are white, twinned perthites within which occur large patches of twinned and somewhat altered plagioclase (Fig. 12). Most of these plagioclase patches have clear, unaltered, more sodic rims. Quartz, which is present in moderate amounts (17%), contains abundant dust and bubble inclusions; microcline clasts (2%) are elegantly twinned; metamorphic rock fragments are few (2.5%). The nature and abundance of the perthites, the excellent preservation of plagioclase twin lamellae and the lack of any large metamorphic minerals suggest that almost



Fig. 12

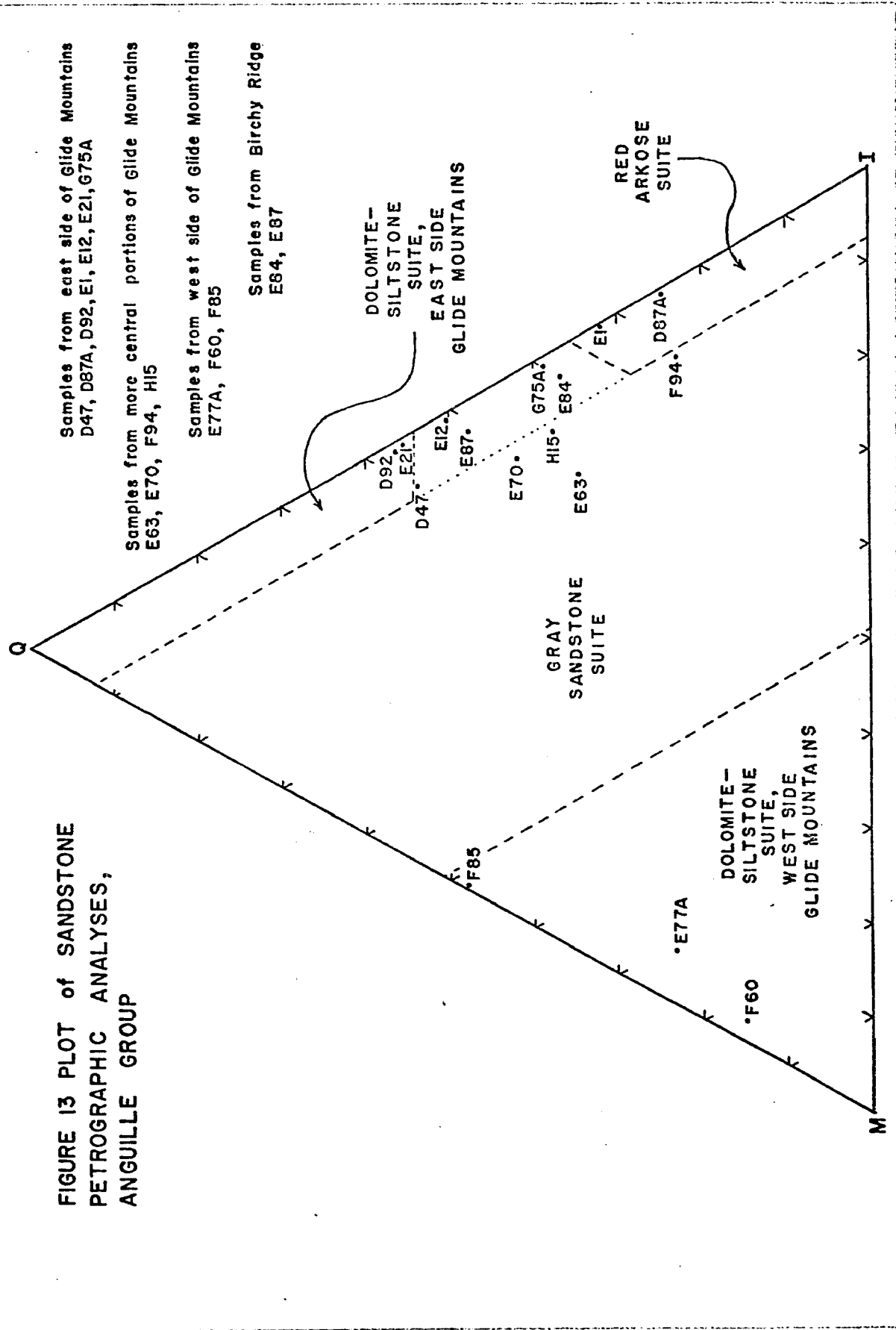
Photomicrograph of feldspathic graywacke F94. Perthite clast (lower left) contains inclusions of twinned plagioclase with altered cores and clear margins. Well-preserved twinning displayed by framework clasts (for example, oligoclase at right). Matrix contains many metamorphic minerals. (F94, crossed nicols, approx. 20X.)

certainly these clasts were derived from a dominantly igneous source (most likely plutonic) rather than a dominantly metamorphic terrain. Thin sections of the plutonic rocks from east of the trans-Newfoundland lineament contain crystals displaying virtually identical characteristics to the complex perthite clasts described above. No such crystals were observed in samples from the metamorphic terrain. Such a source area cannot, however, be the provenance for the dark matrix (23.5%) which contains, in addition to angular feldspar (mostly untwinned) and quartz, abundant chlorite, muscovite, biotite, sphene, euhedral garnet, zircon, epidote and magnetite. Consequently, the composition of the matrix strongly suggests that it was derived from metamorphic source rocks. The reason that these contrasting mineral assemblages are present in one rock may be due to: 1) a mixing of materials (at the site of deposition) derived from distinct provenances, 2) the effect of sedimentary sorting and by-passing during transport from a single provenance of adjacent igneous and metamorphic belts (the foliated metamorphic pebbles disintegrate to finer sizes more readily than do the interlocking crystals of plutonic rocks, thus concentrating the metamorphic minerals in the matrix size material), or 3) derivation from a single provenance of mixed igneous and metamorphic lithologies. The distribution of the basement rocks in west-central Newfoundland indicates that the first alternative is the most reasonable, and an ultimate

dual origin appears certain. Within this rock there is represented a mixing of provenances, the framework contributed by an igneous terrain, the matrix derived from a metamorphic one.

Evidence supporting dual provenances can be shown even more dramatically by plotting the results of thin-section modal analyses of framework minerals on a ternary diagram (Fig. 13). This diagram, devised by Krynine (1948) for classification purposes and revised by Folk (1961) is presented here in modified form; it shows clearly that geographic location influences compositional variations. The three end members are: Q constituents (all types of quartz except stretched metaquartzite and chert); M constituents (metamorphic rock fragments, e.g., schist, gneiss, marble, and stretched metaquartzite; micaceous minerals coarser than .03 mm.); and I constituents (single grains of all types of feldspar both twinned and untwinned; igneous rock fragments both plutonic and extrusive). Since there is a distinct dichotomy of possible source rocks, metamorphic versus igneous (see p. 21), it is presumed that almost all type M clasts were derived from the metamorphic terrain west and southwest of the Glide Mountains and that the dominant proportion of type I clasts (plutonic and volcanic) were derived from an igneous terrain such as that east of the Grand Lake Fault.

**FIGURE 13 PLOT of SANDSTONE
PETROGRAPHIC ANALYSES,
ANGUILLE GROUP**



The framework mineral percentages of 16 modal analyses have been recalculated to 100% (see Q,M,I values, Table 1) and plotted on the ternary diagram. As a result it can be seen that the points representing samples from the western limit of the previously discussed siltstone-dolomite suite (E77A, F60, F85) fall near the left (west) margin of the diagram, while those from the eastern limit of the same suite (D92, E21) occur near the right (east) margin. Similar conditions prevail for samples from the gray sandstone suite; those from the Grand Lake shore (D47, E12, G75A) fall near the right margin of the diagram, while samples located further westward (E63, E70, F94) contain slightly greater percentages of metamorphic fragments and plot more centrally on the diagram. Binocular microscope examination indicates that sandstones from the western side of the Glide Mountains Uplift (other than E77A, F60, F85) contain, in addition to quartz and feldspar, M type fragments of carbonate and schist pebbles, some carbonaceous material, but almost no volcanics. Composition plots of samples from the gray sandstone suite occur closer to the bottom of the diagram (further south) than those of the siltstone-dolomite suite. This resembles the natural areal relationships. Samples from the next-to-be-discussed red arkose suite (D87A, E1) follow suit; they occur still closer to the bottom (south) of the diagram.

The significance of the sample plots on the ternary diagram are summarized as follows:

1. There is a distinct correspondence between geographic location and compositional variation. The coarse, sandy deposits on the west side of the Glide Mountains appear to have been derived from the west and southwest while those on the east appear to have been derived from the east. The mineralogy and overall composition of samples from the east are high in I constituents; those from the west are high in M constituents. Dual sources are thus suggested. This is reflected in the location of sample plots on the ternary diagram. In essence, the spacial relations of samples on the diagram reflect the geographic distribution of the samples, and so the diagram may in turn be thought of as crudely depicting a geologic map of the area. The suggestion of dual provenance reinforces the same conclusion arrived at independently for the previously discussed siltstone-dolomite suite.

2. The more central portions of the diagram (basin of deposition) represent a region of mixing within which varying proportions and size fractions of material have been contributed by each side. (Directional-feature data is too sparse on the western side of the Glide Mountains to be of interpretive significance.)

3. Rocks such as E63, F94, H15, which plot more centrally on the diagram are classified as graywackes (Pettijohn, 1957). They appear in this case to be the result of mixing of sediments from separate source areas and not to

have originated from a single provenance. The viewpoint on their genesis therefore is different in this respect from that held by Folk (1961), who has suggested a single provenance for some graywackes.

Siltstone

Like the more sandy units, the siltstones are well indurated and remarkably even-bedded (Fig. 14); most strata are approximately one to two inches thick but range from one-quarter to five inches. Unlike the sandstones with which they are interbedded, the siltstones are darker in color, contain more disseminated pyrite and much greater amounts of metamorphic minerals. The color difference, in part, is due to the significantly greater percentages of biotite contained in the siltstones and also in part to the large amounts of enclosed macerated carbonaceous (plant) remains. The majority of beds are some shade of gray, although black, dark brown, and olive brown are also common.

Thin sections of siltstones from the east side of Grand Lake show that they are petrographically unlike the sandstones. Some possess large amounts of carbonate as cement and all contain much larger concentrations of metamorphic minerals. Quartz and feldspars (both twinned and untwinned) are present as angular or very angular grains; in addition, there is abundant biotite and considerable quantities of chlorite, muscovite, zircon, garnet, epidote, sphene, magnetite, and clinozoisite. Sericite is also prevalent in

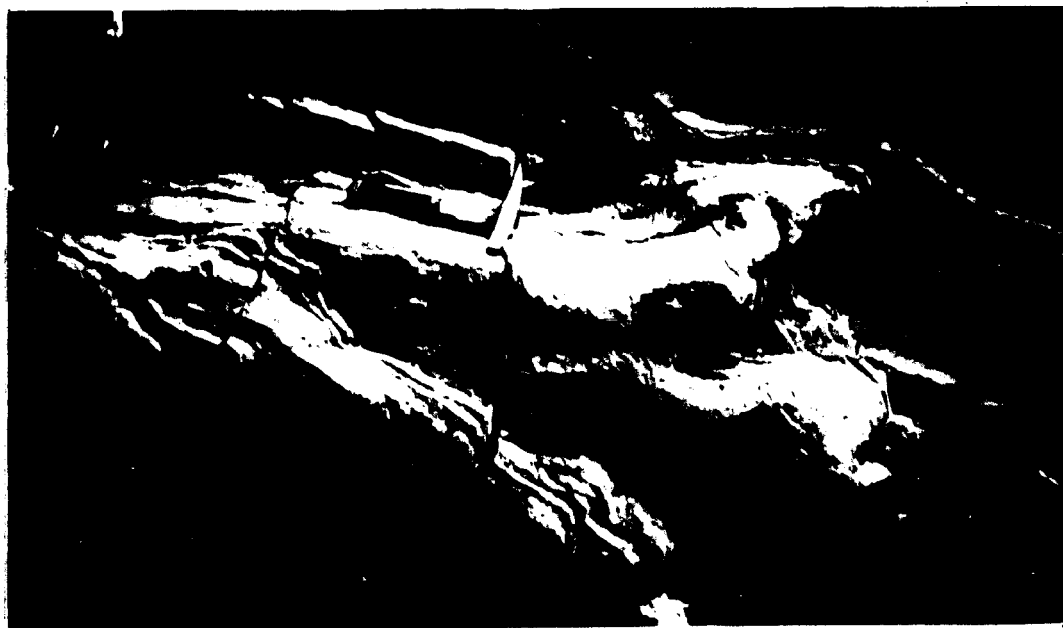


Fig. 14

Even-bedded siltstones
and very fine sand-
stones of the gray
sandstone suite.

Fig. 15

Cut and fill bifur-
cating channel on
bottom of conglomeratic
sandstone bed, gray
sandstone suite.



some samples. In thin section, the carbonaceous material appears as ragged and irregularly shaped opaque masses.

The abundant biotite present in all the siltstones may have been derived from the granitic rocks situated east of Grand Lake (see description, p. 22, and Neale and Nash, 1962, map unit 18d) or, equally likely, from the metamorphic rocks west of the lake. Whatever the source of the biotite however, the garnet, clinozoisite, muscovite and quite likely much of the chlorite were derived from the metamorphic terrain.

The origin of contrasting mineralogies exhibited by the interbedded sandstones and siltstones of the gray sandstone suite can perhaps best be explained as follows. During periods of rapid runoff and high discharge, deposition at the basin margins was dominated by locally derived coarse detritus (I type fragments from the east, M type from the southwest and west). Resultant sedimentation produced arkoses, pebbly sandstones, and graywackes. Presumably this pluvial period was followed by one of slow runoff, low discharge, and temporary higher stands of shallow water. During this time streams carried only fine material and carbonaceous matter, which were kept in suspension and dispersed throughout the lacustrine basin. This fine material contained a preponderance of metamorphic minerals for foliation of the metamorphic source rocks increased their tendency to become abraded and concentrated in the finer sizes.

Silt from both the igneous and metamorphic source areas along with the carbonaceous debris eventually settled out of the water column producing dark siltstones which contain a larger percentage of metamorphic minerals than do the sandstones.

As pointed out earlier, there is an overall increase in the proportion of siltstone beds in a northeasterly direction. Apparently, this is the result of greater accumulation of fine-grained strata in the more distal portions of a northeastward deepening basin. This conclusion is confirmed by primary directional features. The characteristic evenness, persistence, and sharp upper and lower contacts of the bedding in this suite (as well as the other two suites) implies that conditions of deposition were intermittent rather than continuous.

Carbonates

Carbonate rocks are only sparsely distributed in the gray sandstone suite and where present they occur as gray, silty, carbonaceous limestones rather than dolomites. They exist in three forms: as isolated beds surrounded by sandier units; as very thinly interlaminated limestones with fine siltstones; or as small nodules or clasts in clayey siltstones. The ultimate origin for each of these limestones is most likely that of a detrital accumulation of calcite grains. As outlined in the previous siltstone-dolomite section, biogenic origins appear untenable.

Individual beds are gray or less commonly dark brown and contain carbonaceous material and flakes of biotite. White mica is also present and is quite conspicuous at some outcrops. Carbonate beds invariably are thin, most approximately one-half to two inches thick, and with one exception, none are larger than seven inches. The unusual bed is a brown weathering calcarenite, 18 inches thick within which detrital (?) carbonate pebbles occur in the form of a tabular cross-bed (E14). The limestones are largely composed of fine to coarsely crystalline calcite with abundant scattered grains of angular quartz. Muscovite, biotite, plagioclase, and chert are also present.

The laminated deposits are extremely finely layered, most less than 0.2 mm. thick, and consist of cryptocrystalline, pale gray limestone which is interlaminated with darker carbonaceous, very fine siltstone. The general appearance of these units resembles that of the laminated siltstones and dolomites described previously. However, in this case, the carbonate is a gray limestone rather than an orange dolomite, and the siltstone is more commonly gray than black. The laminated units are not as prevalent in this suite as they are in the siltstone-dolomite suite. They are well developed at only two localities: along the west shore of Grand Lake 0.8 miles southwest of the mouth of Porters Brook and on the upper portion of Island Pond Brook where the stream changes flow direction sharply from south-

west to east. Even though these units are located approximately three miles apart, they may be related because: 1) the lithologies are distinctive, yet quite similar, and 2) both are located along the same general tectonic trend, almost on strike with one another. No correlation can be established, however, due to structural complexities and a lack of stratigraphic control. At both localities these units are severely contorted; situated among more competent sandy strata, the thin limestones have yielded readily under pressure.

Lastly, some carbonate is present as pale yellow nodules or clasts which are scattered throughout clayey, olive green, poorly indurated, fine sandstones. Most such nodules are approximately one-eighth of an inch in diameter, though some are as large as one inch across. Many are somewhat circular and some have darker central portions.

Primary Features Associated With the Gray Sandstone Suite

This section describes the type, number and orientations of primary features associated with the gray sandstone suite. The kinds of features present are, by and large, similar to those present in the siltstone-dolomite suite; variations are described below.

Cross-beds and parting lineations. Cross-beds are the most commonly occurring primary structure in the gray sandstone suite; they are nearly four times as prevalent there as in the siltstone-dolomite suite. Even within the

siltstone-dolomite suite itself, the greatest concentration of cross-beds occurs near the transition zone with the gray sandstone suite (south of Woody Brook harbor). Cross-beds of the gray sandstone suite are best developed in gray matrix arkosic sandstones in two outcrop belts along the Grand Lake Shore: 1) between Harbor Brook and the suite's northeastern limit; 2) southwest of the mouth of Porters Brook for a distance of approximately 2.8 miles. In both areas cross-bedded units are no more than one and one-half to two feet thick, so they are referred to as thinly cross-bedded (McKee and Weir, 1953). Where it was possible to view cross-bedding in three dimensions, they were readily determined to be the trough-shaped, festoon variety.

The mean transport directions indicated by cross-bedding varies considerably according to location. From Harbor Brook northeastward the mean azimuth for 23 readings is 10° (standard deviation = 66°). The distribution, however, is orthogonally bimodal (see Plate 4) with prominent modes both to the northeast (mean azimuth = 45°) and northwest (mean azimuth = 360°). The northwest current direction is represented also on Seaplane Brook, 4.0 miles to the north-northwest where two cross-beds have dip azimuths of 328° and 349° . (Bimodal and polymodal distributions have received attention from a number of investigators (see Selley, 1968; also Tanner 1955, 1959; Selley 1967; Hofmann 1966; Picard and High, 1968) who have attempted to: 1) interpret the sig-

nificance of such distributions, and 2) point out some of the complexities and possible errors involved in handling this type of data, e.g., the possible lack of significance of the standard deviation and the danger of using only a single measure of central tendency, the vector mean.)

The bimodal nature of cross-bedding in the gray sandstone suite northeast of Harbor Brook may be a result of:

1. Local preferred directional control in the depositing medium, or
2. The intermittent action of two separate current systems.

Cross-beds formed with a bimodal distribution might be expected to develop in a regularly curving stream pattern which only rarely flows in the actual direction of regional dip. In this instance, the mean azimuth (10°) would indicate the average direction of local slope and sediment transport. As a consequence, resultant lithologies should be relatively uniform.

Alternatively, a bimodal distribution could develop in a near-shore environment, the result of two differently oriented current systems. An example of this would be an intermittently active stream flowing northwesterly into a basin in which there exists a northeasterly directed long shore drift. Little significance could be attached to the mean transport direction under these conditions. In this case, some petrologic differences might be expected between

the northeast and northwest cross-bed sets. Since both sets of cross-beds in this part of the gray sandstone suite occur in gray arkoses of relatively uniform composition, the former interpretation is accepted as the more reasonable one.

Gray sandstone suite strata also crop out extensively further to the southwest from Porters Brook to the entrance of Northern Harbor. In this region 13 cross-beds indicate a general transport direction toward the west-northwest (mean azimuth = 295°). Despite the large dispersion of the data in this southwestern region (standard deviation = 61.5°) confidence is maintained in the significance of the vector mean because of its general agreement with the orientations of other primary structures. These include parting lineations, groove casts and channels.

Further to the northeast on Island Pond Brook, three cross-beds exhibit a marked shift in the sediment transport direction (mean azimuth = 63° , standard deviation = 26.7°). Although similarly sparse, other primary features (parting lineations and ripple marks) also reflect this deviation. As a result of the close correlation in changes of primary feature orientations, it seems reasonable to conclude that the depositing media, presumably streams and/or shallow lacustrine currents, shifted clockwise, from northwest to northeast, as they proceeded in a downcurrent direction.

The conclusion of a clockwise current shift is the same as that reached for cross-beds in the siltstone-dolomite suite (see p. 49).

Cross-beds observed elsewhere in the gray sandstone suite are so few and dispersed that they lack statistical significance. Those on Salmon Creek (azimuth = 08°), the north fork of Pynn's Brook road (E54, azimuth = 355°) and Blue Gulch Brook (azimuth = 294°) show northerly and northwesterly transport directions. Thus they are in agreement with cross-beds in other parts of the suite. Conversely, on Lanes Brook and the south fork of Pynn's Brook road (E70), cross-bed azimuths are 233° and 177° respectively. It can only be suggested that such deviations from the overall trends are due to original topographic control or subsequent structural effects.

Parting lineations of the gray sandstone suite resemble those in the siltstone-dolomite suite; orientations of the former, however, are decidedly more consistent (see Plate 5). Although the overall abundance of parting lineations in these two suites is about equal, their areal distribution in the gray sandstone suite is quite disproportionate. Only four were noted in the section from Harbor Brook northeastward; two along the shore close to the northern facies boundary and two on Harbor Brook; by contrast, 24 occur in the Porters Brook area. Orientations of the four parting lineations in the northeastern area agree closely with one

another (standard deviation = 15.6°) and have a mean sense of 34° . This is similar to the mean direction for the dominant cross-bedding mode (mean azimuth = 45°) for the same region. As it was mentioned previously, in the Porters Brook area cross-beds indicate a marked change of transport direction toward the northwest (mean azimuth = 295°). This too is true of the parting lineations (18 readings) which have similar orientations (mean sense = 150° - 330°) and are very closely grouped (standard deviation = 15.9°). Quite definitely, here paleocurrents moved to the northwest. The two northwesternmost parting lineations on Porters Brook (those furthest in the downcurrent direction) foretoken a clockwise change in the transport direction (mean sense = 9°) which culminates with a distinctly northeasterly trend on Island Pond Brook, not only of the cross-beds, but also of the four parting lineations (mean sense = 26° - 206° , standard deviation = 26.4°).

Conclusions to be drawn from the foregoing are twofold:

1. Parting lineations and cross-beds display a general clockwise shift in orientation, from northwest to northeast, as they enter more deeply into the basin.

2. The average parting lineation orientation is approximately parallel to that of the cross-beds. This is

in contrast to the siltstone-dolomite suite where, for the most part, the two types of features maintain a greater angular relationship.

Locally, however, even within the gray sandstone suite, parallelism between cross-beds and parting lineations is not the case. For example one-quarter mile southwest of Porters Brook there occur several cross-bedded, gray, fine sandstones, the bottoms of which reveal parting lineations. Reliable measurements on one yield a cross-bed dip azimuth of 270° and a significantly different parting lineation sense, 153° - 333° . Another bed, not as well exposed, exhibits yet a greater disparity, a cross-bed dip azimuth of 240° and a corresponding parting lineation sense of 142° - 322° . Therefore, although the mean directions for grouped data of these two types of features are similar, at any one outcrop the parting lineations probably represent the more reliable measure of the average current direction; grouped parting lineation data are generally more consistent, exhibiting less dispersion, than that of cross-beds.

Accordance of parting lineation orientations is also evident on the western side of the Glide Mountains where two such features were observed on Lanes Brook and two on Blue Gulch Brook. On both streams, parting lineations are very closely aligned, having standard deviations of 5° . Although individual readings at the respective localities are slightly different, in both cases their mean senses are 82° -

262°. This forms a moderate angle to the dip azimuth (233°) of the single cross-bed on Lanes Brook and the brush cast sense (57°-237°) on Blue Gulch Brook. In the central portion of the Glide Mountains on Seaplane Brook, a single parting lineation has an orientation (sense = 166°-346°) virtually parallel to the mean azimuth of two cross-beds (338°) which are located slightly farther upstream.

Ripple marks. The form and size of ripple marks in the gray sandstone suite are much like those in the siltstone-dolomite suite. Again, they are most prevalent in gray fine sandstones. Unlike ripple mark orientations in the siltstone-dolomite suite, however, these are distinctly bimodally distributed (see Plate 6). This is true for grouped data in both the northeastern section, northeast of Harbor Brook, and the southern area, in the environs of Porters Brook. Because of the clearly orthogonal bimodal relationship, in this case no significance can be attached to the entire sample mean orientation or standard deviation.

The few ripple marks (nine) in the northern section display a dominant, almost east-west mode (mean sense 80°-260°) and a lesser, almost north-south mode (mean sense = 169°-349°). The relationship of the ripple marks to other primary features in the northern section of the gray sandstone suite can be assessed as follows: The dominant mode is approximately normal to the mean azimuth of the cross-beds (10°) and oblique to the few parting lineations (mean

sense = 34°). (Ripple marks perpendicular to cross-bed dip azimuths have been reported by Fahrig, 1961; Hamblin, 1958, loc. cit. Potter and Pettijohn, 1963, p. 96; Pelletier, 1958; and Potter and Pettijohn, 1963, p. 95.) Neither the dominant nor the subordinate mode, however, is parallel to the northwest-southeast trend of the far greater number of ripple marks in the siltstone-dolomite suite (80 readings produce a unimodal distribution having a mean sense of 135° - 315°). If the ripple marks outline the depositional strike, as it has been suggested previously, then this orientation change may be related to variations in the basin topography. Presumably it reflects a northward deepening in this part of the gray sandstone suite and one slightly more northeastward in the siltstone-dolomite suite. Alternatively, the average orientation of the depositional strike could shift somewhat through time.

As with the other primary structures in the gray sandstone suite, the mean orientation of ripple marks differs considerably between the northeastern and southeastern regions. In both places overall distributions are similarly oriented and are bimodal with subordinate modes nearly at right angles to the major ones. However, in the northeastern area the dominant mode is east-west (mean sense = 80° - 260°) while to the southwest at Porters Brook the dominant mode is north-south (mean sense = 179° - 359°). The

change in orientation of the principal mode therefore agrees with the pattern already described, that of a different dominant paleocurrent direction for the southern part of the gray sandstone suite.

In the southern region the ripple marks' north-south mode is oblique relative to the northwesterly local transport direction indicated by the cross-beds and parting lineations. As shown previously, the westernmost parting lineations on Porters Brook have senses considerably different from those further east (a mean sense clockwise shift of 39°). Similarly on the same stream only the westernmost ripple marks exhibit an east-west marked deviation from the general local north-south trend; again a shift in the current system is suggested. Ripple markings at two other locations contribute to the lesser east-west mode, one near the extreme southern limit of the outcrop belt (south of Leo Brook) and the other on the promontory at the entrance to Northern Harbor (the orientation of a nearby cross-bed is almost perpendicular to it).

Very few ripple marks were observed in the central portions of the depositional basin. On Seaplane Brook, a single set of ripple marks has a northeast orientation (sense = 62° - 242°) which is perpendicular to the mean azimuth of close by cross-beds (338°) and parallel to the mean sense (58° - 238°) of 11 ripple marks on Allday Brook in the

siltstone-dolomite suite. Another set at E73 (on the north fork of Pynns Brook road) shows a sense of 168° - 348° .

Channels. Only four erosion channels were observed in the Anguille Group of the Grand Lake-Deer Lake region (see Plate 7). All occur within or at the margin of the gray sandstone suite, presumably localization is due to greater effectiveness of the forces of stream erosion in this facies. One channel occurs on the Grand Lake shore just north of Harbor Brook and is associated with abundant festoon cross-beds. Its orientation (sense = 69° - 249°) is similar to that of another channel (sense = 39° - 219°) exposed on Harbor Brook a short distance to the southwest, just within the limit of the predominantly subaerial red arkose suite. The mean sense for these channels (54° - 234°) coincides closely with the northeast transport direction suggested by the other local primary features. For the same reason, a quite different current orientation is again evident in the southwestern section. There, one channel on the peninsular at the entrance to Northern Harbor has a northwest-southeast orientation (sense = 130° - 310°). The transport polarity can be ascertained from another channel with very nearly the same sense (140° - 320°) situated just southwest of the mouth of Porters Brook. There, large (five feet long by six-to-twelve inches across) bifurcating lobes which coalesce toward the northwest (Fig. 15) are weathered out in relief on the bottom of a rusty (limonite?) conglomeratic sandstone bed. In all likeli-

hood, these are cut and fill runnels, a result of north-westerly flowing currents.

Plant fragments. Plant fragments and carbonaceous debris are present in abundance throughout the eastern part of the gray sandstone suite; they are truly ubiquitous in the southwest section between Island Pond Brook and the suite's southern limit. There, they occur within and on a great many bedding planes, both as recognizable fossils and as small irregular carbonaceous fragments. Some are partly coalized. Floral remains in this facies differ from those of the siltstone-dolomite suite in the greater maximum size observed, and for some, the better state of preservation. The tear-shaped leaf scars (Fig. 16) suggest that they are conspecific with Lepidodendron corrugatum or L. elegans depicted by Dawson (1859, p. 68; 1868, pp. 253, 451, 486) and Lepidendropsis corrugata (Bell, 1960, 1966, p. 4). A Tournaisian (Early Mississippian) age is therefore suggested for these strata. The best specimens were collected at G23 and G56.

Although most plant remains are small, some approach the size of small trees. Approximately 0.64 miles north of Harbor Brook at H76, six trees, aligned on a bedding plane, are four-to-five inches wide and five-to-seven feet long. Their orientation (sense = 89° - 269°) closely parallels the dominant ripple mark mode (80° - 260°) and is nearly perpendicular to the general cross-bedding transport direction (azimuth = 10°).

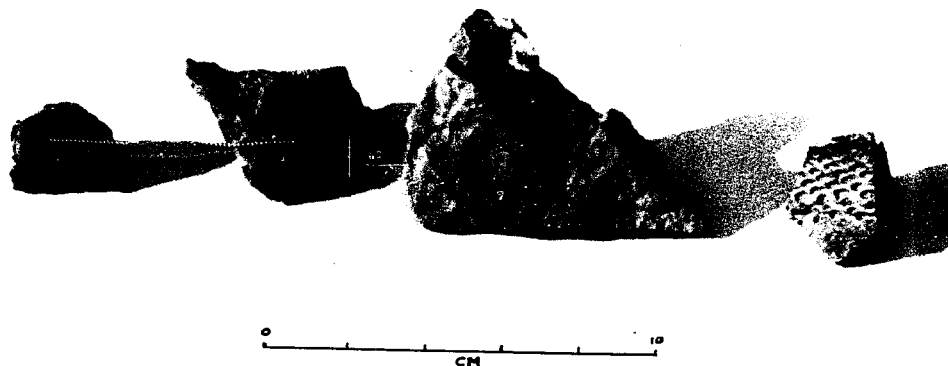


Fig. 16

Plant fragments from the gray sandstone suite.



Fig. 17

Clastic dike at
Northern Harbor, gray
sandstone suite.
Penknife = 2½ inches.

In the southern section of the gray sandstone suite, oriented plant fragments are bimodally distributed. On Island Pond Brook, this relationship can be seen even on one bedding surface (G52) where small plant fragments are roughly parallel to the direction of parting lineations and larger material is more nearly perpendicular. The sense of the primary mode for aligned plant stems (34° - 214°) is significantly different from that in the northern region. Again, the mean sense is almost normal to the average direction of cross-bed azimuths (295°). Limited information suggests, therefore, that in the gray sandstone suite, plant fragments tend to be deposited both perpendicular to the current indicated by primary structures and, to a lesser extent, parallel to it. This is unlike the siltstone-dolomite suite where plant orientations are more closely parallel to the groove cast direction.

The profusion of plant material implies again that deposition took place in the presence of nearby terrestrial vegetation. This is less the case for strata on the western side of the Glide Mountains where plant fossils were discovered only on Blue Gulch Brook and another locality some 2.15 miles to the north-northeast. More striking yet is the total absence of even small recognizable fragments on Seaplane Brook and the rare presence of only very poor remains on Allday Brook (siltstone-dolomite suite). Since these streams occur in the region which has been interpreted as

the more central portion of the paleobasin, (on the evidence of primary directional features as well as the predominance of fine sediments) large plant fragments apparently were not transported to these sites.

Groove casts, graded beds and flute casts. Typical turbidite primary features such as those described for the siltstone-dolomite suite are by and large absent from the gray sandstone suite. Where they do exist, most are of a different character.

For example, groove casts were observed at two outcrops on Grand Lake in the vicinity of Porters Brook. They are longer (four to nine feet), broader (two to three inches), and deeper (one inch) than the more delicate features in the siltstone-dolomite suite. Nor are any striated. Groove casts occur as pronounced ridges on the soles of massive (10-feet thick), non-graded arkoses; they give the appearance of a large tool (perhaps a small tree) having been dragged through the sediments rather than one carried partly in suspension. Such an origin is suggested by Kuenen (1957) for structures which he refers to as "drag marks." "The frequency of drag marks in the German Kulm graywackes with their profuse plant remains may indicate that water-logged stumps and sticks are also suitable plows for making such grooves." As Crowell (1958) points out, "...such (drag) marks are found on rocks other than graded graywackes (and) even occur on ungraded graywackes."

The mean orientation for the two sets of groove-cast readings along the Grand Lake shore (senses = 138° - 318° , 141° - 321°) is 139° - 319° and therefore, similar to that of the local cross-beds (azimuth = 295°) and parting lineations (sense = 150° - 330°), and almost perpendicular to the dominant mode of plant fragments (34° - 214°). On the western side of the Glide Mountains, a single brush cast (sense = 57° - 237°) on Blue Gulch Brook is delicate and therefore more closely resembles the tool markings of the siltstone-dolomite suite.

Graded bedding is present in some units but it is not nearly so common as in the siltstone-dolomite suite. Where it does occur it is confined to individual, thinly-bedded fine-grained graywackes and siltstones.

In the entire gray sandstone suite, only two sets of flute casts were observed, both in the northern section. The one at the base of a coarse pebble conglomerate bed (E15) is very poorly defined but indicates a transport direction toward azimuth 349° . By contrast, very prominent and excellently formed flutes (current movement toward azimuth 37°) occur at H81, near the transition zone to the siltstone-dolomite suite. They are displayed on the sole of a thick-bedded coarse arkose, are clearly isolated from one another and are much larger (up to six inches wide and three feet long) than any in the siltstone-dolomite suite. In that facies, the flutes are smaller, more closely nested, and

associated with graded graywackes and elongate load casts, the latter primary feature being a type absent from the gray sandstone suite. It seems likely that the gray sandstone suite flutes were formed under different environmental conditions. Perhaps they are the result of shallow-water current scour rather than the action of relatively deeper water turbidites. Flutes from non-turbidite basins, shallow water, or those not necessarily derived from turbidity flows have been reported by Dott and Howard (1962), Glaessner (1958), Cummins (1958, Sen (1967), Eastler (1969), Pryor and Barr (1968), and Klein (1965). Potter and Pettijohn (1963, pp. 120-121) mention that although flute casts are most characteristic of the flysch facies, they do occur in other facies and in some cases, even on the soles of limestones. "...It would be erroneous to attribute them solely to turbidity currents."

Desiccation cracks and other structures. All desiccation cracks (five localities) in the gray sandstone suite occur in its southern portion between Island Pond Brook and the Lower Carboniferous-basement contact. They are mostly small, approximately one to four inches across, and are formed in beds of gray or black siltstone or shaley siltstone into which has been filled a fine micaceous sand. On Island Pond Brook (H3) the cracks occur in a gray silty limestone.

Presumably the southern area represents the shallowest part of this depositional regime for in addition to the desiccation cracks, primary directional features indicate that currents generally moved outward from this region toward the west and northwest, veering clockwise as they proceeded deeper into the basin. Additionally, the existence of small-scale, finely lenticular bedding and intraformational shale-chip conglomerates (Fig. 10) is consistent with an interpretation of shallow-water conditions. Reineck (1967) points out that finely lenticular bedding (his flaser bedding) is best developed in areas subject to intermittent subaerial exposure. Pettijohn (1957, p. 367) describes similar bedding as "...typical of a zone of intermittent turbulence."

Several related sedimentary injection structures are present in this same part of the suite. These include sand polygons, clastic dikes and sand volcanoes; all are interpreted as early-formed and shallow in origin.

Sand polygons superficially resemble desiccation cracks and occur in association with small clastic dikes on the tip of the peninsula at the entrance to Northern Harbor. They appear as polygonal, rounded ridges of medium sandstone, each several feet across, which protrude above the bedding surface. These polygons bear a remarkable resemblance to Recent ones formed in Libya and depicted by Oomkins (1966, Fig. 2). There, alluvial fans rim a hard-crustated playa lake basin

which contains subjacent water-saturated sands and clays. Oomkins attributes the origin of the polygons to upward flowage of a sandy slurry, through previously formed desiccation cracks, as a result of density differences between the dry and watery sediments. Sands intruded along the escape avenues solidify in the subsurface as clastic dikes and above ground as sand polygons. He also mentions that the cracks can be generated by earthquakes which, in addition to rupturing the hard surface bed, also increase the pressure of the formation water. Thus, mudspouts and perhaps smaller sand volcanoes can be associated with polygonal cracks. This very phenomenon was observed on the mud flats of Cordova, Alaska, subsequent to the 1964 Good Friday earthquake (Reimnitz and Marshall, 1965); the authors, however, judge the formation of the cracks to have taken place after the earthquake and resultant mudspouts.

An alternative explanation for the genesis of sand polygons is given by Dzulynski and Walton (1965, p. 167). They propose that in a sand-shale sequence, polygons can be created (through compaction?) by the greater lateral expansion of liquified sandy layers relative to the shales. It is suggested that this will form hexagonal tension cracks in the finer sediments. If true, however, sand polygons ought to be a much more commonly occurring primary feature in sedimentary rocks.

One of the clastic dikes at Northern Harbor is illustrated in Fig. 17; its sinuosities are reminiscent of igneous pygmatic veins. As Potter and Pettijohn (1963, p. 163) have pointed out, if this is attributable to compaction and thickness reduction of the host siltstones and shales with consequent adjustment of the enclosed dikes (Dzulynski and Radomski, 1956), then early, pre-compaction injection is implied. The inclusion of siltstone fragments within the dike also tends to indicate early emplacement.

Potter and Pettijohn (1963, p. 165) summarize the prevailing thoughts on the genesis of sand dikes as follows:

"The mechanism most commonly invoked is earthquake shock, momentary liquefaction of water-saturated sand, and injection into fissures opened by the shock. The driving force is the pressure of the overlying strata. The formation of sills suggests that the injected material is capable of making space for itself."

Clastic dikes have been reported as being derived from both overlying and underlying strata. In the Northern Harbor area, the three sand dikes all taper downward to narrower widths. Therefore they appear to have been injected from above, though not necessarily from the directly overlying bed.

A small mound structure (D57, Fig. 18) was discovered approximately 3.2 miles northeast of the mouth of Northern Harbor. Hemispheric in shape, it is widest at the flat base (diameter = 12 cm.) and highest in the center, 7.5 cm. A central, more sandy core is surrounded on all sides by



Fig. 18
Mound structure, gray sandstone suite.



Fig. 19
Fossil trees, red arkose suite. Dip of bedding is toward left.

finely interlaminated creamy gray limestone and black shale. Contortion of these extremely fine layers increases toward the core. Under cursory examination it might be tempting to suggest a bioturbate origin, perhaps the construction of some burrowing organism. However, this is most improbable in light of the lack of any other evidence of fauna. Thin-section analysis establishes rather that the structure is injective in nature, likely akin to sand volcanoes (Dzulynski and Walton, pp. 163-165). Interlaminated layers consist of cryptocrystalline carbonate and thinner, darker portions abundant in biotite. The central "pipe" contains a large percentage of more coarsely crystalline carbonate along with angular quartz, feldspar and laths of biotite and muscovite. Close to the core walls there is a distinct preferred orientation; alignment of micas and long axes of quartz and feldspar grains parallel the walls, demonstrating that the material of the central core was forcefully injected under hydrostatic pressure.

In summary, it appears likely that all these injective primary features were emplaced under shallow-water conditions relatively early in the depositional history; at least some of the sediments were still water saturated. Injection as a result of earthquake shock seems reasonable as an ultimate cause for each type of structure described.

Summary of the Gray Sandstone Suite Environment of Deposition

Based on the foregoing discussion, it appears likely that rocks of the gray sandstone suite are fluvial and shallow lacustrine in origin. The environments of deposition, therefore, are transitional between the relatively deeper water deposits of the siltstone-dolomite suite and the predominantly subaerial units of the red arkose suite.

Correlation

Rocks of the gray sandstone suite are correlative with a portion of the Anguille sequence exposed in the Birchy Ridge area. This is attested to by plant remains as well as the distinct similarity of lithologies in outcrop, appearance in thin section, and overall composition. Point counts of two samples from Birchy Ridge (E84, E87) plot on the ternary diagram (Fig. 13) within the same general region as that outlined for the gray sandstone suite on the eastern side of the Glide Mountains.

The Red Arkose Suite

General Statement

Rocks of the red arkose suite constitute a sequence of very thickly-bedded red arkoses and arkosic conglomerates (weathering to pastel shades) alternating with gray or black, even, thinly-bedded argillaceous siltstones and graywackes. The graywackes are quantitatively much less important than the arkoses. Where present, they are generally similar to those described previously. The one exception is that in

this suite, graywackes do not exhibit turbidite structures. Plant material is present in much of the section. The various rocks represent several different environments of deposition; these include alluvial fan, paludal, and shallow-water lacustrine.

The suite exists solely on the eastern side of the Glide Mountains (see Plate 2). There it has been delineated on the presence of red arkose, which occurs in large amounts and provides the suite name. The suite is areally smallest and persists stratigraphically highest (youngest). The lowermost portion is interbedded with, and therefore time equivalent with, at least the upper part of the gray sandstone facies.

Conglomerate and Sandstone

The most distinctive rock type in this suite is the red arkose, or conglomeratic arkose. Its characteristic color is due primarily to the presence of reddish-orange potash feldspar (moderate reddish orange 10YR 6/6 or moderate orange pink 10 YR 7/4). However, as a result of weathering and staining, outcrop surfaces are colored white, buff, rose, yellow-orange, and pale blue-green. In most cases these coatings mask the true nature of the rock texture.

Beds are well indurated and massive with the majority of units 30 to 70 feet thick yet lacking noticeable internal stratification. Although other types of clasts are present, feldspars and quartz are overwhelmingly predomi-

nant (see Table 1) and in many places the arkose truly represents what has been described as a "granite wash" (Levorsen, 1958, pp. 55-56). The feldspars are fresh and unweathered. Both quartz and feldspars are quite angular, showing very little or no evidence of rounding as a result of transport; in fact, euhedral crystals and fresh cleavage faces are common in hand specimen and outcrop. In thin section some clasts even exhibit re-entrant angles.

The red arkoses generally are composed of large, angular particles with smaller grains in the medium-to-coarse sand or granule size ranges. The largest individual potash feldspar clasts on Popcorn and Shiquee Brooks are up to 20 mm. in diameter. This contrasts with the 5 mm. maximum diameter of potash feldspars in the few red arkose outcroppings on Harbor Brook to the northeast (D73, D93, E36, E37).

Sorting is uniformly poor. Within the conglomerates very coarse pebbles (50 mm.) and small cobbles (75 mm.) are prevalent. The largest cobbles (125-130 mm.) occur along the Grand Lake shore near Shiquee Brook. For the most part, these clasts are more rounded and of a different mineralogy than the angular arkose matrix within which they are set. (The single largest clast observed is a boulder with a maximum exposed diameter of 40 cm.. It occurs at the margin of the red arkose suite in a gray polymictic conglomerate (D68) at the base of an ancient stream channel on Harbor Brook.) Largest and most abundant clasts invariably are fragments of

green-brown or dark gray intraformational siltstone. Present in addition to pebbles of red and white granite and subrounded quartz are: plutonic rocks of intermediate composition; dark fine-grained volcanics; jasper and prase; and possibly some fine-grained quartzite.

Analysis of red arkose thin sections reveals that the characteristic color primarily is due to the presence of red perthitic microcline. To a lesser extent it is attributable to small amounts of hematite staining apparently derived from the weathering of iron oxides in the volcanic clasts. The perthites are very distinctive and, except for color, are identical to those described for graywacke sample F94 (p. 79). Small, twinned and zoned plagioclase crystals with altered cores and clear margins are enclosed in larger crystals of patch and veined microcline perthites (Fig. 28). The plagioclase cores are altered to a sericite or fine muscovite. Individual grains of plagioclase that are twinned range in composition from albite to oligoclase. In these same thin sections, especially the lake shore samples, the quartz is laced throughout with bubble trains and inclusions. Almost all types of grains have very irregular margins. This is a result of: preserved original angularity (grains entirely surrounded by matrix are quite angular); pressure solution at grain boundary contacts; and fracturing. This last is likely also responsible for the rectilinear suturing (rather than irregular, elongate meta-

morphic suturing) which results in the composite nature of quartz grains. In spite of the marked grain angularity compaction is so complete that porosity is very low.

Not all portions of these feldspathic units may be classified as arkoses. For example, using the system proposed by Pettijohn (1957), some parts of a single thick unit contain almost no matrix (arkose) while others contain a gray-green fine sandy matrix in proportions greater than 15% (feldspathic graywacke). These two classically different lithologies often have been interpreted as indicating deposition in contrasting sedimentary environments, yet here is an example in which both were deposited under virtually identical conditions of sedimentation. Similar relations are present in gray sandstones of the red arkose suite.

Euhedralism of the feldspars and the marked angularity of other clasts suggests that deposition must have taken place close to the source area, i.e., the transport history must have been of short duration. This can also be inferred from fact that feldspar clasts are more abundant than quartz (see Table 1). On experimental grounds and by comparison with naturally occurring sediments, Morris and Fan (1962) suggest that a ratio of feldspar greater than quartz in sediments derived from acid igneous rocks will be retained only for the first 30 miles of transport (primarily a result of abrasion, selective sorting notwithstanding). The re-

lationship, quartz greater than feldspar, is the proportion expected in the average sand-sized sediment. Since here reverse conditions exist, it is concluded again that deposition took place relatively close to the source area.

The freshness and unweathered appearance of the feldspars is further testimony to their rapid deposition and burial. This conclusion is substantiated by the fact that fossilized tree trunks stand upright across the layers of red arkose bedding. Hills (1963, p. 42) comments upon such conditions.

One of the most striking evidences of rapid deposition in a non-marine environment is afforded by the burial in erect position of growth, of large trees of the Carboniferous coal measures of Europe and Great Britain, which must have rotted had the enclosing deposits of sandstone been slowly laid down... In the Ruhr the sandstones were deposited chiefly from turbidity currents (Teichmuller, 1955).

Plainly, deposition was so rapid that trees were entombed in the growth position. The lack of internal stratification in these units suggests that sedimentation took place during a single phase of deposition. Additionally, the burial of trees in situ establishes that the depositional environment most definitely was a subaerial one.

On the basis of the characteristics described above it seems likely that the red arkose strata represent ancient alluvial fan deposits. Such an environment would account for: the short distance of sediment transport prior to deposition; the rapid deposition and burial of unweather-

ed feldspars in a subaerial environment; the great thickness of the red arkoses as measured on Popcorn Brook (minimum thickness of 3200 feet); and the decrease in maximum size of feldspar clasts (from 20 mm. on Shiquee Brook to 5 mm. on Harbor Brook) in the general direction of sediment transport as inferred from directional features.

The combined weight of several lines of evidence indicates that the red arkoses definitely were derived from the granitic-type rocks exposed east of the trans-Newfoundland lineament. The evidence is summarized as follows:

1. The excellently developed and well preserved twinning of plagioclase and perthite is suggestive of a plutonic (or hydrothermal) provenance (rather than one composed of medium to high grade metamorphic rocks). See Turner (1951); Coombs et. al. (1958).

2. The complex and distinctive perthite which occurs as clasts in the red arkoses is also present as crystals in red granite on Glover Island (p. 23) and in the granites of the White Bay area. (It was not possible to obtain samples of granites from the intervening area, therefore no statement concerning their nature can be made.)

3. Cross-bed orientations (seven) in the red arkoses suggest that these sediments were transported from a southerly direction (mean dip azimuth = 4°).

The only red coarse crystalline rocks in west-central Newfoundland from which the arkoses could have been derived

are the granites and associated igneous rocks almost all of which are located east of the trans-Newfoundland lineament (see p. 18). According to Riley (1957)

"The granitic upland between Grand Lake and Red Indian Lake is composed of fine- to coarse-grained red granites and associated porphyry, syenite, and granodiorite, and these evidently provided much of the red arkosic material found in the Carboniferous sedimentary rocks to the west."

5. The granite pluton east of the trans-Newfoundland lineament is rimmed by a belt of volcanic rocks. The large volcanic pebbles associated with the red arkoses could have been derived from the proximal portions of this terrain.

Siltstone

Siltstones of the red arkose suite are similar to siltstones in the other suite. Even-bedded, with a maximum thickness of seven inches, they are shades of gray or black on fresh surfaces. Those somewhat sandier are classified as graywacke sandstones. Some, especially those located on the lower portion of Popcorn Brook, are slightly calcareous and interbedded with sandy gray limestones. Thin sections show that siltstones of the red arkose suite contain lesser amounts of metamorphic minerals than similar rocks of other suites, yet present in noticeable quantities are some minerals possibly derived from a metamorphic terrain. These include abundant biotite, muscovite, zircon, chlorite, and a few garnets. Megascopic characteristics serve to distinguish these argillaceous units from those of the other suites.

Most notable are the lack of graded bedding and the absence of tool or other sole markings in gray siltstones or the red arkose suite. This contrasts with the relative abundance of such features in the fine clastic units of the siltstone-dolomite suite.

Weathered surfaces tend to be gray, black or brown. In places, however, gray siltstones associated with arkoses are stained maroon or pastel red, a characteristic not observed elsewhere. The distinctive coloring appears to be a result of weathering and oxidation of specific iron-bearing minerals in these siltstones.

Plant fragments are especially abundant on bedding planes in the siltstones. Locally, they form a thin, coaly horizon or solid mat of black carbonaceous debris. The siltstones and coaly horizons are interpreted as representing deposits of a dominantly reducing, paludal environment which flourished at the margin of the red arkose alluvial fan.

Since the nature of the depositional environment to some extent controls the type of clay mineral species present, a number of authors have proposed that these minerals might be used as paleoenvironmental indicators (Adams, et. al., (1965); Walker, 1968); Parry and Reeves, (1968; and Dickson, (1968). X-ray analyses show, however, that there are no recognizable differences in the clay-mineral portion of siltstones from the various suites.

Carbonates

The few carbonate rocks present in the red arkose suite are thin-bedded, silty, gray limestones (calcarenites). They resemble somewhat the limestones of the gray sandstone suite, however weathered surfaces have large irregular "vesicles" which give the rock a striking spongy appearance. This characteristic, not noted in limestones of the other suites, is a result of the slightly greater resistance to weathering of irregular concentrations of silt and sand within the limestones.

By analogy with the carbonates of the other suites, it seems likely that these too are ultimately detrital in origin.

Primary Features Associated With the Red Arkose Suite

In comparison with the other suites, primary structures are least abundant within the dominantly subaerial deposits of the red arkose suite (see Table 2). Those present are similar in appearance to primary features already described.

Cross-beds of this suite were observed only in red arkoses along the Grand Lake shore near the suite's northeastern limit. Orientations of the few dip azimuths (seven) indicate that the arkoses were derived from the south or south-southeast (mean azimuth = 4° , standard deviation = 75° , see Plate 4). This transport direction correlates

closely with that of cross-beds in the northeastern portion of the gray sandstone suite (mean azimuth of 23 readings = 10°).

Lithologic type also controls the occurrence of parting lineations in this suite for they are found only on micaceous, gray siltstones and fine sandy beds. Most were observed on Shiquee Brook. Their distribution is concentrated (standard deviation of 26° for nine readings) and the mean azimuth (36°) agrees closely with northeast-southwest parting lineation trends in the gray sandstone (northern section) and siltstone-dolomite suites. Since parting lineations in each of these suites occur in the fine-grained psammitic units (as opposed to the coarser, cross-bedded sandstones) and mean azimuths are consistently more northeasterly oriented than the average northerly cross-bed trends, it seems likely that here these two types of primary features are related to different current systems; the coarser sandstones belonging to the more competent one.

Roughly parallel to the parting lineation trend is one groove cast or drag mark (sense = 55° - 235°), and one flute cast (transport toward 41°). Another flute cast indicates a northwest transport direction (azimuth = 307°). It is located on Shiquee Brook at the base of a gray conglomeratic bed; its orientation may reasonably be related to the cross-bed direction. The axis of the large channel on Harbor Brook (D68) has a sense of 39° - 219° . This compares moderate-

ly well with the sense of the nearby channel in the gray sandstone suite (70° - 250°). Elongate load casts are absent from this suite just as they were from the gray sandstone suite. Ripple marks, present only on fine-grained gray strata are too few, too dispersed, and too poorly developed to allow for interpretations having statistical significance. The limited sample size (four) yields an oblique bimodal distribution. No desiccation features were observed. This is unusual for a depositional environment which certainly was dominantly subaerial. Possibly this can be attributed to the general coarseness of the strata.

Fossil Trees

As it was pointed out, floral fossils occur as coaly plant debris in the plane of the bedding, and as molds and internal casts of individual trees in the growth position perpendicular to bedding. In spite of their abundance, the fallen and flattened plant fragments exhibit some alignment (sense = 38° - 218°) at only one outcrop, a micaceous, gray fine sandstone on Shiquee Brook.

The upright trees are exceptionally profuse and well exposed at H71 (see Fig. 19). They are mostly small, four to eight inches across and three to five feet high. In situ they stand one to four feet apart. The exhumed base of one is slightly larger (30 cm. in diameter) than the rest of the tree and has carbonaceous and sandy layers near the base which parallel the concave downward lower surface. At least



Fig. 20
Portion of fossil tree,
red arkose suite.

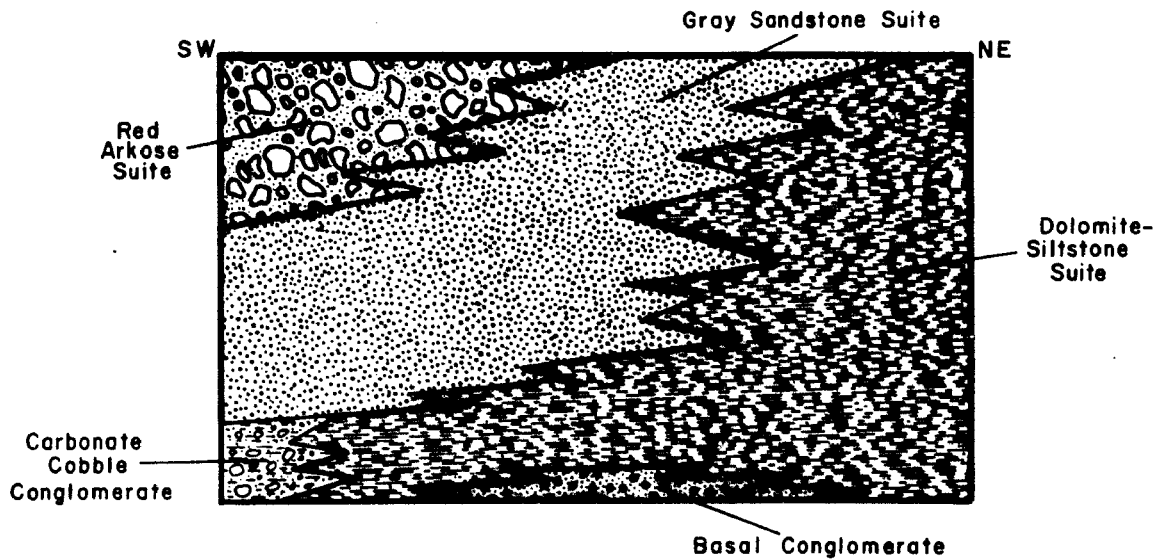
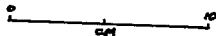


Fig. 21

Diagrammatic representation of the sedimentary suites
as facies.

nine trees occur standing upright, disregarding tectonic tilt, while more than 31 others are inclined at steep angles to the bedding. Many exhibit leaf scars which are arranged in a linear vertical pattern as small protruding dots regularly spaced five mm. apart and set within shallow furrows one cm. apart. A portion of one small tree was identified by Dr. Francis Hueber of the U.S. National Museum as a lycopod arborescent with *Sigillaria* affinities (Fig. 20). These fossil casts are composed of gray and red arkosic sandstones and granule sandstones which are present also between the trees. Within some, carbonaceous remains are preserved; many are coated with a hematite staining. No soil horizons are apparent.

Summary of the Red Arkose Suite Environment of Deposition

A sequence of alternating massive red arkoses and even-bedded gray fine-grained sandstones and siltstones is exposed along the Grand Lake shore between Harbor and Shiquee Brooks. These deposits apparently represent a transition zone at the margin of the thick alluvial fan arkoses, so well displayed on Popcorn Brook, and the gray, finer sandstones and siltstones of the paludal-shallow lacustrine environments further to the northeast. The contrasting lithologies represent interfingering, time-equivalent facies, dominated by oxidizing and reducing conditions respectively. The different facies displaced one another in response to tectonic uplift and/or intermittent flash flooding, and fluc-

tuations in lake water depth levels. Trees fossilized upright attest to extremely rapid deposition of the red arkoses; they further confirm that these sediments were laid down in the subaerial, shallowest portion of the basin. The arkoses undoubtedly originated from a granitic source and were transported only very short distances, thus preserving their angular crystal and cleavage faces and unweathered appearance. The direction of sediment transport across the alluvial cone was toward the north, northwest and northeast as determined by cross-bed azimuths and (decrease) in maximum grain size. Deeper in the basin the transport direction of gray fine sands and silts was primarily northeasterly. This is deduced from parting lineation orientations and the presence of several mineral types most likely derived from the southwestern metamorphic source area.

The cyclic recurrence of these different facies suggests that intermittent uplift took place concomitantly with basin subsidence. If basin formation occurred without accompanying uplift and development of local relief, the resultant deposits would resemble those of a starved basin (characterized by a lack of detrital material, Krumbein and Sloss, 1963, p. 230), which they do not. Alternatively, if uplift took place without basin development, the resultant alluvial fan sediments would prograde continuously into the basin. Interdigitation of units demonstrates that this also is not the case. Therefore the two processes must have been active concurrently

and basin filling must have been discontinuous. A model could be fashioned in which the alluvial fan coarse clastic debris derived from spasmodic uplifts is covered with paludal-lacustrine deposits in response to periodic rises in lake level. This requires that the original basin be of considerable relief, as a consequence of which coarsest deposits would be present near the base of the sequence. Rather, the reverse is true, for the Lower Mississippian section is a regressive one in which youngest strata (Popcorn Brook arkoses) are also coarsest.

Seismic disturbances responsible for the outpouring of coarse arkoses may also have been the mechanism which initiated slumping of unstable deposits and turbidity flows deeper in the basin as well as the injection-type structures of the gray sandstone suite. Others who have implied or indicated that Carboniferous deposition in Newfoundland was related to fault activity include: Twenhofel and MacClintock (1940, p. 1722); Neale and Nash (1963, p. 33); Baird and Cote (1964); Baird (1966); and Belt (1967a).

The picture thus emerges of a basin in which alluvial fan and paludal-lacustrine conditions existed simultaneously. After fault uplift of the source area, terrigenous material was transported farther into the basin. This encroachment covered trees at the fan margins as well as the fine sandstones and siltstones of the more reducing paludal-lacustrine environment. Denudation continued until temporary deepening

of the lake level reestablished the paludal environment over the distal portions of the alluvial fan. With uplift resulting from renewed tectonic activity, the cycle began again. Eventually basin development halted. As deposition of coarse detritus completed the regressive cycle, a more uniformly shallow basin was created and Upper Mississippian (Rocky Brook Formation) sedimentation began.

Correlation

Baird and Cote (1964) refer to the Seacliffs Formation (youngest in the Anguille Group of southwestern Newfoundland) as massive, coarse red and gray arkosic and friable sandstones and silty shales. The rocks vary according to location within the basin and are also described as indurated ... "thickly bedded, medium- to coarse-grained, feldspathic, gray sandstone and graywacke, with more thinly bedded, gray siltstones and minor gray, thinly bedded to fissile argillaceous siltstones... However, thickly bedded, cross-bedded, fissile, micaceous, red and gray arkoses and red silty shales outcrop (sic) along the outer coast..." (For a complete description, see Baird, 1951.) In part they are thought to represent channels of old rivers that wandered across broad alluvial plains and deltas. Based on their highest stratigraphic position within the Anguille Group and some lithologic similarity, strata of the red arkose suite appear to be correlative with those of the Seacliffs Formation.

In the White Bay region no lithologies closely resemble those of the red arkose suite. Nevertheless a steeply inclined sequence of subaerially deposited (desiccation polygons are present in abundance) reddish fine-grained sandstones and siltstones of uncertain age crop out west of Saltwater Cove. If they are Lower Mississippian, as Heyl (1937) believes then they could represent a fine-grained facies, time-equivalent to the red arkoses of the Grand Lake area. These red fine sandstones and siltstones bear a distinct resemblance to: 1) the Cape Rouge Formation, known to be youngest in the Lower Mississippian section of the Conche area 90 miles to the north (Baird, 1966), and 2) the Rocky Brook Formation exposed on the western shore of Grand Lake between Island Pond and Popcorn Brooks and presumed to be oldest in the Upper Mississippian sequence (Belt, pers. comm.). Correlation of the red arkoses with either of these sections therefore remains tentative at best.

Stratigraphy - Summary and Conclusions

The Sedimentary Suites as Facies

The combined weight of several lines of evidence strongly suggests that the individual sedimentary suites are separate lithofacies (Fig. 21) which are in part, time equivalents:

1. Transitions between suites are marked by inter-tonguing of distinctive units rather than sharp lithologic breaks.

2. Time equivalency of the alluvial-fan red arkoses and sediments of the gray sandstone suite is suggested by the fact that the stratigraphic limit of the red arkoses (the contact between the different sedimentary suites) does not coincide with form line contours (Badgley, 1959 p. 81) defined by the bedding.

The various interrelations possible between lithosomes in a non-folded, inclined sequence are illustrated in Fig. 22. Figure 22-A shows a simple layered sequence in which deposition of gray sandstones is succeeded by deposition of red arkoses. In this case the lower stratigraphic limit of the red arkoses (A-A') coincides with the bedding surface. Antithetical conditions are shown in Fig. 22-B. Here the red arkose alluvial fan persists vertically adjacent to gray sandstones for the duration of the sequence and the limit of the fan margin (B-B') remains relatively constant. In this case the surface representing the intertonguing contact between the red arkose and gray sandstone suites is normal to bedding surfaces. Intermediate facies relationships are depicted in Figs. 22-C and 22-D. In each case the line representing the contact surface between sedimentary suites is oblique to the bedding planes. Figure 22-D, which most closely approximates the conditions on Harbor Brook, shows the fan enlarging through time, with red arkoses laterally replacing gray sandstone strata.

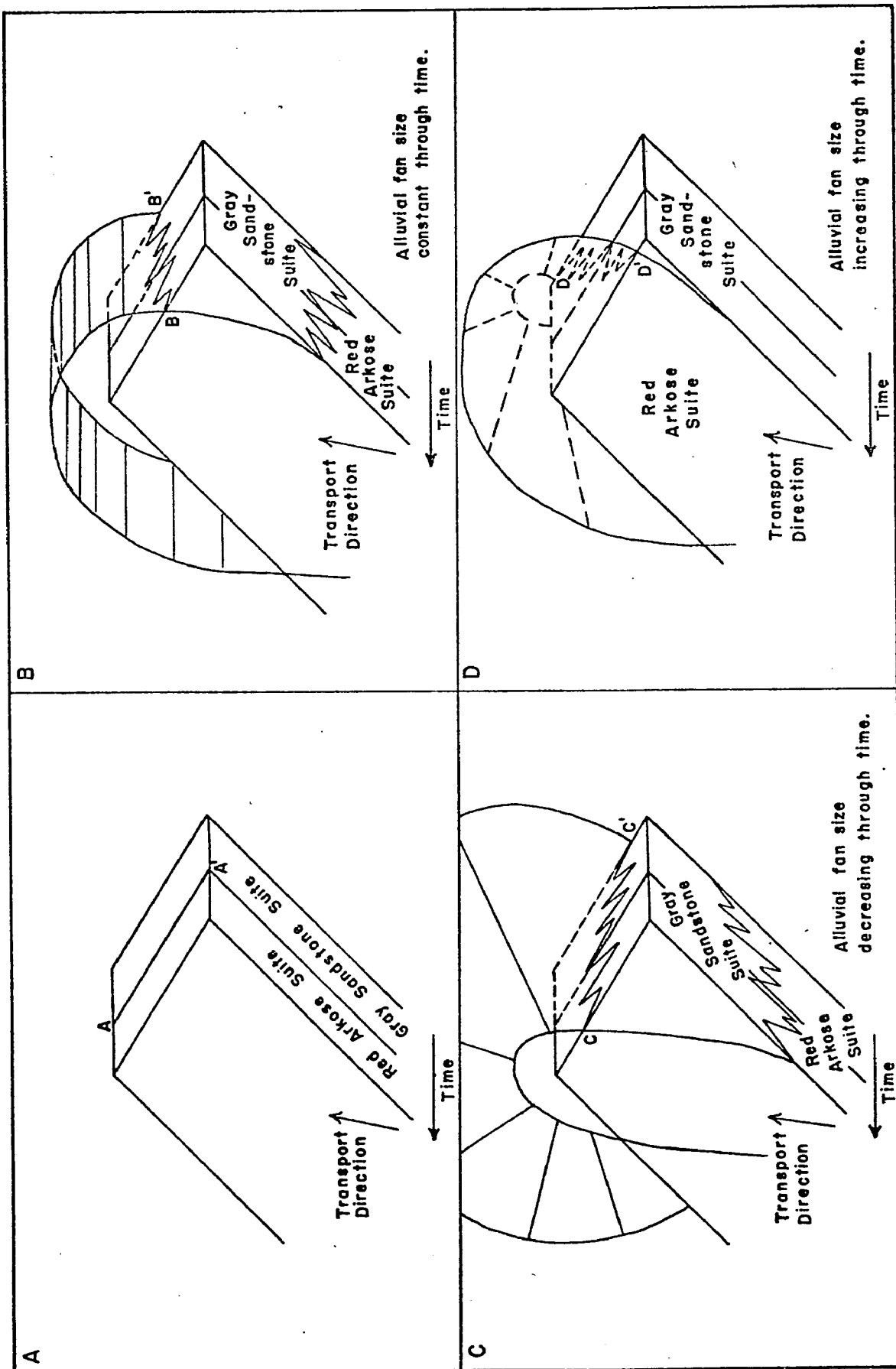


FIGURE 22 POSSIBLE RELATIONSHIPS BETWEEN STRUCTURAL FORM LINES AND LITHOSOME LIMITS

3. Due to structural complexities and lack of control in covered sections, thickness estimates of the Anguille Group are tenuous. Nevertheless, considerations of reasonable total accumulation indicate that the three suites cannot represent a simple stratigraphic succession. The thickness of the sequence shown in cross-section B-B' (see Plate 8) is on the order of 12,000 feet. In computing this figure an attempt was made to account for facies changes as well as duplication of some units due to thrust faulting. If the concept of a facies relationship between suites is neglected, then this already sizeable estimate must be more than doubled. Unquestionably, such a sum is excessive. The maximum borehole thickness for the entire Horton Group of the Southern Canadian Maritimes is 9,480 feet (Howie and Cumming, 1963). Published values for Lower Mississippian deposits in Newfoundland range from 2,600+ feet along the southwest coast (Riley, 1962), to 8,000± feet in the White Bay region (Heyl, 1937). Approximately 5,000 feet are exposed in the Conche area (Baird, 1966). The Anguille section cropping out on the West Hampden River is calculated to be some 5,700 feet thick.

4. A facies change is suggested by the fact that a progressive decrease in the red arkose/gray sandstone ratio is apparent in three successive sections (Popcorn, Shiquee, and Harbor Brooks) which cross separate, possibly synchronous, parts of the same syncline. The traverses are transverse to the general sediment transport direction.

5. In a terrestrial environment it seems very likely that relatively deeper water turbidite deposits should have shallow-water counterparts.

Elsewhere in the Maritimes, authors have noted facies relationships for deposits of Carboniferous basins (Belt, 1964, 1965; Carr, 1968).

In conclusion, the distribution of lithic fill in the Grand Lake basin may be likened to either of two stratigraphic models. Both are presented by Dunbar and Rodgers (1957, p. 139) in their discussion of the Middle and Upper Devonian units of New York. One emphasizes the superposition of strata representing various sedimentary environments; in this case, time planes parallel lithologic boundaries. The other (based on the work of Chadwick, 1924 and Cooper, 1942) stresses the time equivalence of different lithologies with time planes cutting diagonally across lithologic boundaries. In this interpretation, the one generally accepted today, Catskill red sandstones were deposited in the east coeval with the Marcellus black shales further west. Although the basins are not comparable in size, this last pattern of sedimentation is the one envisioned for the Lower Mississippian of the Grand Lake Basin.

Environment of Deposition and Provenance

Deposition of Anguille strata took place during the Lower Mississippian in a structurally controlled, dominantly lacustrine basin in west-central Newfoundland. Detritus

was supplied from the south, southeast, and southwest flanks and then transported axially along a generally north-eastward deepening lake. Reasons for concluding that the environment of deposition was primarily lacustrine are as follows:

1. In spite of the fact that thousands of feet of section were examined in detail both in the Grand Lake and White Bay areas, no faunal fossils were uncovered. Even in an inhospitable marine environment some evidences of a depauperate fauna might be expected.
2. By contrast, terrestrial floral remains abound, therefore indicating that the basin must have been adjacent to an area capable of supporting and supplying abundant terrestrial plants.
3. The major portion of the red arkose suite definitely was deposited under terrestrial, subaerial conditions. Attesting to this are trees buried in situ by rapidly deposited arkoses at the margins of what is interpreted as an ancient alluvial fan. Strata of the other suites, which are in part equivalent in age to the red arkoses, were deposited in relatively deeper waters.
4. Varved laminites occur within the siltstone-dolomite suite. This stratification, common in lacustrine deposits, is comparable to descriptions of other such units which have been ascribed a limnological origin.

5. Equivalent aged strata have been interpreted as lacustrine by Dawson (1868, p. 239), Wright (1922), Bell (1929), Gussow (1935), and Greiner (1962).

Sedimentation rates undoubtedly responded to variable seasonal supply of detritus. Where unstable, the deposits were subject to intermittent resedimentation as a result of: earthquake shocks; through reduction of support due to lowering of lake water level; and the affect of storm floods. In all likelihood the fault activity responsible for creating the paleobasin may also have accounted for several of the sedimentary features produced therein. These features, possibly contemporaneous in origin, include graded-bed turbidites initiated by subaqueous slumping in the siltstone-dolomite suite, clastic dikes and injection phenomena of the gray sandstone suite, and massive beds of rapidly deposited arkose in the red arkose suite.

Although local variations are apparent, the lake generally deepened toward the northeast. This conclusion is based upon the mean downcurrent orientation of polar directional features as well as a northeasterly decreasing average sediment size of synchronous strata.

In spite of the fact that the respective suites contain deposits laid down under essentially different conditions, most of the common types of primary structures are present in each. There is, however, a definite predominance of one or more primary feature types within any one suite. It is

not so much the presence or absence of particular sedimentary features that serve to distinguish the different sedimentary regimes; rather, it is the relative frequency of their occurrence. This observation has been stated by Potter and Pettijohn (1963, p. 115). "...few, if any, primary sedimentary structures only occur in a specific environment. In general, environmental contrasts are expressed by the differences in abundance rather than in kinds of primary sedimentary structures." These relations are displayed in Table 2. For example, although most types of primary features are present in both the siltstone-dolomite and gray sandstone suites, there are far fewer ripple marks, groove casts, and flute casts in the gray sandstone suite; elongate load casts are absent. By contrast, cross-beds occur in greater abundance, and stream or erosion channels, absent from the siltstone-dolomite suite are present in the gray sandstone suite. Desiccation cracks occur in both suites with about equal frequency, but those in the siltstone-dolomite suite are present only locally in the northeastern, sandier (and presumably shallower) section. The disparity in the number of observations in the two different depositional regimes cannot be attributed to the amount of exposure available, for although the siltstone-dolomite suite is much smaller in areal extent, it contains a far greater number of primary features. In paleoenvironmental interpre-

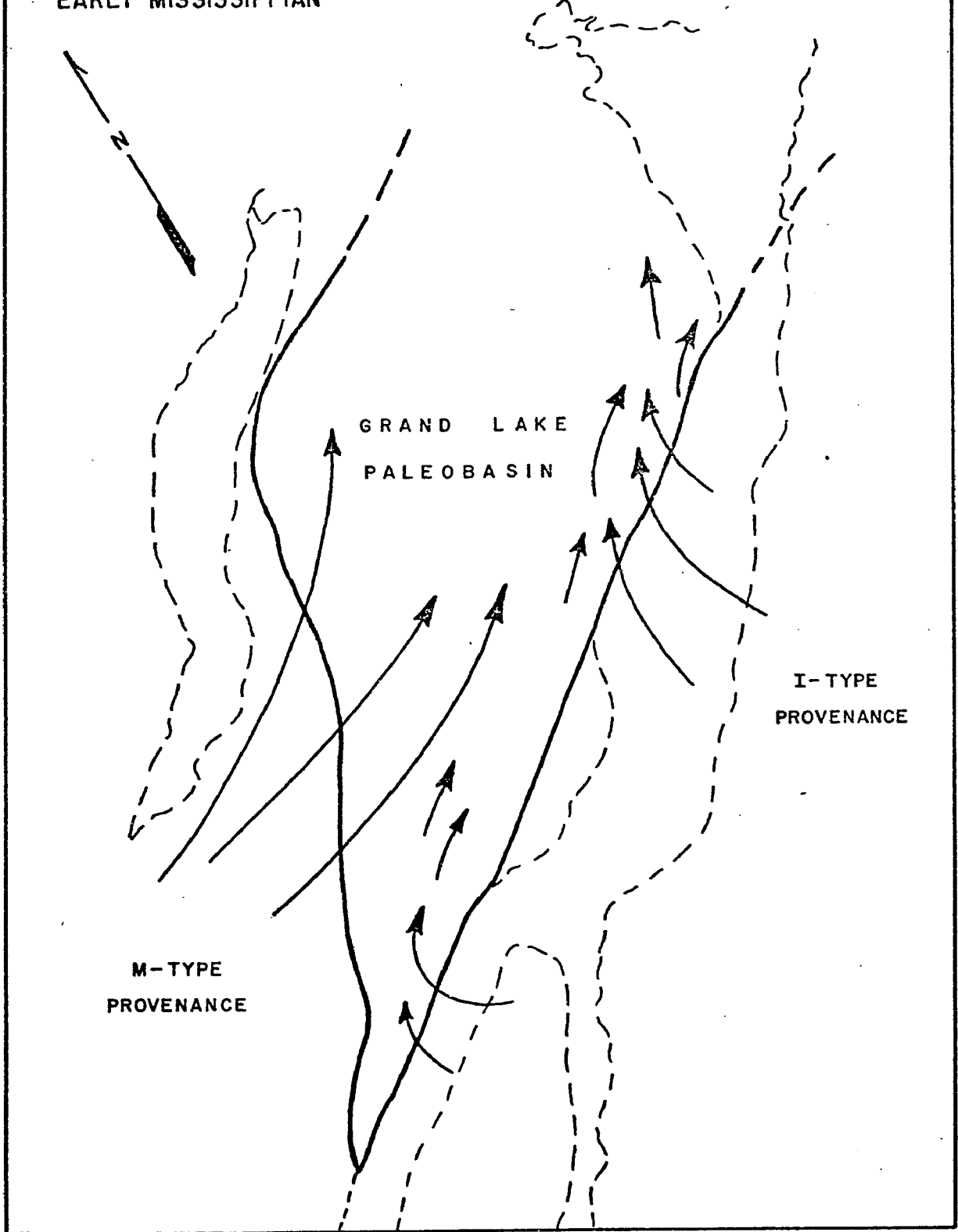
TABLE 2 RELATIVE ABUNDANCE OF PRIMARY FEATURES IN THE (Numerical Frequencies)										BAR GRAPH SUMMARY		
Type of primary feature	Suite	Red Arkose Suite		Gray Sandstone Suite				Dolomite-Siltstone Suite	Totals	Red Arkose Suite	Gray Sandstone Suite	Dolomite-Siltstone Suite
		other	W	SW	NE	Total						
Channels		1		2	1	3		4				
Cross-beds		7	4	3	16	23	12	65				
Parting and current lineations		9	1	4	24	4	34	76				
Plant fragments		1			6	1	7	15				
Desiccation cracks					5	5	4	9				
Ripple marks		4	1	1	25	9	91	131	-80			
Groove casts		1		1	2	3	49	53	-60			
Flute casts		2				2	5	9	-40			
Elongate load casts							11	11	-20			
Totals		25				135	213	373				

tations therefore, the relative abundance of a particular primary feature is of greater significance than its mere presence or absence.

The predominance of a particular type of feature or assemblage of features in one suite or the other reflects a classic distinction made by Baily (1936) between current bedding and graded bedding as "the distinguishing marks of two different sandstone facies." Presumably, the gray sandstone suite with its preponderance of cross-beds and channels would belong to the current-bedded facies, while characteristics of the siltstone-dolomite suite assign it more closely to the graded-bedded facies. Further, Bailey's conclusions concerning water depth of formation are also applicable. That is, the current-bedded sandstones are deposited in relatively shallow water (or subaerially), and the graded-bedded sandstones in relatively deeper water. In conclusion, it appears that a complex interplay of water depth, sediment size, type and velocity of currents, availability of sole-marking tools, and inclination of the depositional slope combine to produce a distinct environmental control on the relative abundance of the various primary features.

Interpretations of provenance and sediment transport directions are based on primary directional feature orientations and recognition of distinctive minerals and lithologies. As a result, it is concluded that the earliest (basal conglomerate) and latest (red arkose) deposits of the Anguille

FIGURE 23 SUMMARY PALEOCURRENT DIAGRAM
GRAND LAKE BASIN,
ANGUILLE GROUP,
EARLY MISSISSIPPIAN



Group were derived dominantly from the east, southeast, or south. Through the remainder of the depositional sequence, the Grand Lake Basin acted as the mixing site for detritus derived from two primarily different source areas. The one to the southwest consisted primarily of low to high grade metamorphic rocks; the other, comprising an eastern or southern source, was composed of volcanic and plutonic rocks. The granite presently exposed in the south-central part of the basin (north of Northern Harbor) in all likelihood represents a later feature, for it did not actively shed sediments during the Early Mississippian. As the sediments which originated in the eastern igneous terrain were carried deeper into the basin, their direction of transport veered clock-wise, eventually paralleling the northeast trending basin axis. Interrelations of these various transport trends are portrayed in Fig. 23, a summary paleocurrent diagram for the Anguille Group. With some modifications, this model approximates that suggested by Potter and Pettijohn (1963, p. 194, Fig. 8-1-4).

Structure

General Statement

The following section discusses the large structural features in Anguille Group and adjacent rocks of the Grand Lake-Deer Lake region. Previous to this study practically nothing was known about the structural geology of the Glide Mountains. More detailed analyses yet remain as avenues for

further research. Folds and faults described below are illustrated on Plates 2 and 9.

Folds

Folds in Anguille strata are, almost without exception, of the flexural slip type. The relative intensity of deformation apparently is lithologically controlled. Within competent, sandy and conglomeratic beds of the red arkose suite and parts of the gray sandstone suite, folds are broad and open; by contrast, toward the northeast, in the less competent siltstones, carbonates, and fine sandstones of the siltstone-dolomite suite, small-scale folds tend to be tight, even, and isoclinal and often are associated with fractures and faulting. This condition of disharmonic folding in strata of differing competencies is similar to that observed by Currie et. al. (1962).

Folds with axial plan cleavage do occur however, in gray and black argillites on Seaplane Brook. This locale near the center of the paleobasin is the only place in the Grand Lake-Deer Lake area where such folding was observed. As Poole (1967) has pointed out, the development of cleavage is a rare phenomenon in Carboniferous rocks of the Atlantic Provinces. It has, however also been reported by Schiller (1962), Stevenson (1964), and Fyson (1967).

Present in each of the three suites are sections of vertical or overturned beds. They are of interpretive significance, for the overturning is locally consistent, and

consequently these sequences can be used to establish the direction of local tectonic transport.

Folds range from small structures several feet wide with varying attitudes to large, gently plunging features more than a mile across. The shallow plunge of these major structures can be established by the fact that, in most cases, dips measured close to or at the fold axes are low. By contrast, some small folds exhibit exceptionally steep plunges (i.e., 73°). On both sides of the Glide Mountains Fault, large folds are oriented northeast-southwest except in the northeastern part of the Glide Mountains where axes bear more closely north-south (see Plate 2). Almost all of these large folds trend en echelon to the major bounding faults.

Tectonic tilt correction of paleocurrent features is simplified by the fact that the large folds have shallow plunges. This being the case, application of the standard correction--rotation of beds about the strike through an angle equal to the amount of dip--sufficiently restores features to their original orientations to permit paleocurrent interpretations. As demonstrated by ten Haff (1959, loc. cit. Potter and Pettijohn, 1963, p. 262), neglecting fold plunges as great as 30° results in only a 10° angular error for linear features on beds of 45° structural dip. Planar directional features are, however, significantly more sensitive.

For convenience, the following discussion of folds is divided into two regional groups, those southeast and those northwest of the Glide Mountains Fault.

Folds southeast of the Glide Mountains Fault. The predominant southwesterly dip of the lake shore section between Shiquee and Wrong Brooks (see Plate 2) reflects the fact that these strata represent the eastern limb of a large, south-plunging syncline. Bedding attitudes can be projected and traced inland on the basis of stream bed outcrops and photolinerals. Such linears are exceptionally well defined between Popcorn and Harbor Brooks where individual beds of resistant arkose can be outlined for the length of the vertical western limb, around the synclinal trough, and through minor flexures on the more gently dipping eastern limb to the Grand Lake shore. The axial trace of this prominent syncline continues in a north-northeast direction, thereby governing the structure for much of this northeastern portion of the Glide Mountains.

The syncline's northwest limb is a truly remarkable structural feature. Indurated beds of arkose are upturned to vertical for 0.6 miles on Popcorn Brook. These steep dips appear to be maintained for 2.2 miles to the west where the arkoses terminate against the Glide Mountains Fault. This limb therefore represents a section, perhaps 13,000 feet thick, standing virtually upright.

The shore section description of the gray sandstone suite (p. 73) mentions the southwestward (Woody Brook to Harbor Brook) increase in the number of sandstone beds and the overall coarsening of sediment particle size. (This sequence represents the northeast limb of the aforementioned syncline.) Repetition of the same general conditions in a southeastward direction on Seaplane Brook establishes that these strata represent the northwest limb of the same syncline. It can be concluded therefore, that the fold's axial trace lies east of the Seaplane Brook section even though in this region its exact position is somewhat poorly defined.

On Allday Brook there is a definite northwestward progression from siltstone-dolomite suite strata to those of the gray sandstone suite. Bedding attitudes confirm that for the most part, this sequence forms the southeast limb of a northeast plunging syncline. It is separated from the previously described syncline either by a narrow anticline or by a fault associated with a narrow anticline.

Currie et. al. (1962) have suggested that the wave length between major regional folds is approximately 27 times the thickness of the most competent unit in the stratigraphic sequence. If this is indeed the case then here the controlling competent member is more than 320 feet thick for the fold wave length is a minimum of 1.6 miles.

In addition to these regional north-south trending folds, there exist in each of the suites along the Grand

Lake shore smaller folds (wave lengths measurable in tens of feet) which are oriented approximately eastnortheast-west-southwest. Their axes are close to horizontal, and the folds are asymmetrical toward the south.

Further to the south, in the gray sandstone suite between Leo and Island Pond Brooks, the large-scale anticlines and synclines have a more northeast-southwest orientation. This trend is reflected by the parallelism of smaller associated folds. The majority of their axes plunge gently northeast (angles less than 11°), and although the actual plunge direction of the larger folds could not be ascertained, presumably it is similar to that of the smaller folds.

Folds northwest of the Glide Mountains Fault. Two broad folds can be outlined on the northwest side of the Glide Mountains Fault (Plate 2). These consist of a related anticline and syncline, both having northeast axial strikes and plunges. Beds on the southeast limb of the anticline strike obliquely into the fault and are truncated by it; across the fault to the southeast, the regional northeasterly structural grain resumes.

The anticline provides an excellent example for use of the down-plunge method of viewing structure. That is, in plan view the plunging structure tends to duplicate the cross-sectional view. The presence of the granite body at depth in section A-A' (Plate 10) represents its projection in a down-plunge direction.

Located northwest of the anticline is the complimentary syncline. Bedding attitudes indicate that the curvature of this flexure becomes increasingly sharp southwestward, and the fold quite likely is faulted in the trough. The presence of a small outcrop of volcanic basement rocks (E71A) directly on the axis tends to support such a conclusion.

Faults

The succeeding discussion is a description of the characteristics, nature and ages of movement of the large faults in west-central Newfoundland. Within the area studied these faults comprise one segment of a remarkable zone of structural dislocation which extends for at least 200 miles through the western side of the island. This feature, first recognized by Alexander Murray in 1881 (Murray and Howley, 1881, p. 90), was described as a "great fault...(which) intersects the island diagonally from shore to shore, running in an almost perfectly straight line from near the entrance of the Little Codroy River to White Bay." More recently the importance of Murray's discovery has been re-emphasized by Betz (1943), Wilson (1962), Rodgers and Neale (1963), Williams (1964), Kay (1966, 1967), Kay and Colbert (1965), Belt (1967a), Webb (1967, 1968), and Popper (1968), as well as others. The northern portion actually consists of a series of subparallel faults and, perhaps because of this, no general agreement exists on the name assigned to the

entire structure. In whole or in part, it has been referred to as the transinsular zone of weakness, Cabot Fault, Long Range Fault, White Bay Fault, or Hampden Fault. Here, in order to avoid confusion, it is termed the trans-Newfoundland lineament. It may be thought of as being composed of two sections. The southern portion, following the western edge of the Long Range Mountains and Glover Island, forms a single, continuous feature 110 miles long. The northern section begins at the southern margin of the area studied, some two miles southwest of Northern Harbor (see Plates 2, 9). There the single fault bifurcates into the first of a series of "horsetail" splays which become increasingly more numerous northeastward. The westernmost of these splays (South Brook-Deer Lake-Doucens Brook Faults) coincides with Newfoundland's westernmost extent of granitic batholith intrusions. This fault, along with others in the same system (Birchy Ridge Fault, Spear Point Fault, White Bay and Hampden Faults), represents the main branch of the trans-Newfoundland lineament. There is, however, another series of faults which diverge more sharply northeastward (Grand Lake-Birchy Lake Faults). The easternmost splay of this branch may be continuous with the Lobster Cove and Luke's Arm Faults in Notre Dame Bay.

Regions adjacent to the southern portion of the trans-Newfoundland lineament and within the northern area were sites of Carboniferous deposition. Fault activity in the

north was responsible for Early Mississippian basin development and localized accumulation of Anguille sediments. Subsequent movements, very likely along the same faults which created the basins, uplifted two separate blocks of Anguille strata, the Glide Mountains and Birchy Ridge with its northeast extension. Significantly enough, all exposed contacts of Anguille rocks with those adjacent, both older and younger, are marked by faults. Noteworthy in this respect is the fact that in the Grand Lake-Humber Valley-White Bay region, Anguille rocks invariably occupy higher topographic positions than Upper Mississippian and Recent strata. These younger units are found in the valleys and lowlands.

The cross-section of the Glide Mountains uplift (Plate 10) is one of a wedge-shaped block. Nine and one-half miles across at the widest point on top, its steeply dipping marginal faults converge in a downward direction. As such, it does not resemble the classical upfaulted horst, a structure flanked by downward diverging normal faults. Although the exact amount of dip of the fault planes is still uncertain, their attitudes must be steep because they cross significant variations in topography, yet maintain relatively undeviating trends. The inclination direction of the bounding faults is indicated by the direction of overturning of adjacent strata. This differs on either side of the Glide Mountains. On the southeast, overturning is dominantly

in an easterly direction; reverse conditions exist on the northwest side. The assumption that folding is related to fault movements seems reasonable, for the intensity of deformation decreases away from the faults. This is especially true for Upper Mississippian strata, which are upturned and overturned adjacent to the faults but possess what are very likely original dips over most of the remaining area.

From the foregoing discussion it is evident that fault activity occurred prior to, during, and after deposition of Anguille strata. Baird (1966) reached similar conclusions for the time-equivalent Conche basin further to the north. Although sporadic fault movements and resultant uplift continued into the Upper Mississippian, the rate of basin formation decreased relative to that of uplift; Lower Mississippian deposits represent a regressive sequence, whereas younger sediments were deposited almost entirely under sub-aerial and shallow-water conditions.

Grand Lake Fault (southern portion). The fault or series of faults which constitute the northeastern extension of the Long Range Fault occurs in Grand Lake, west of Glover Island. Although direct evidence of faulting is lacking, a rift approximately a mile wide and one-half a mile deep is present in this area. Such a precipitous profile undoubtedly has been accentuated by glacial affects. Yet it seems most unlikely that this represents simply an eroded contact zone, for resistant crystalline rocks crop out on

either side. Expression of the fault is also evident as a series of magnetic "lows" which are situated along the length of this portion of Grand Lake (see Geological Survey of Canada, Magnetic Survey Map 272G, 1956).

A series of faults, in all likelihood related to the major one, occur in the uplands to the west. There Riley (1957) has reported vertical or steeply dipping fault zones in the schists of the Grand Lake Brook Group.

The Grand Lake Fault bifurcates just southwest of Northern Harbor. One branch (the northern portion of the Grand Lake Fault) continues with a northeasterly strike intersecting the Glide Mountains east of Porters Brook; further along strike, it forms the eastern border of the uplift. The other branch trends more north-northeasterly, and within a short distance splays into a series of faults which include the Leo Brook and Glide Mountains Faults, South Brook Fault, and Deer Lake Fault.

Leo Brook Fault. The best exposure of a fault zone in the entire region occurs at the Lower Mississippian basement contact on the Grand Lake shore approximately two miles southwest of Northern Harbor. Bedrock is pulverized to a one-quarter mile wide gouge or incoherent fault pug (Reed, 1964) which ranges in color from pale yellow-green to dark or light gray. Contained within the fine powder are isolated, rounded, more competent nodules which apparently are remnants of country rock. A thin section of one of these shows it to be an anorthosite composed of fractured and

altered, twinned plagioclase grains (An = 32) liberally interspersed with an opaque mineral, most likely magnetite. Some portions are so intensely mylonitized that they are glassy and appear isotropic under crossed nicols (Fig. 24). Alteration products present in moderate quantities include chlorite and epidote; secondary veins of calcite are abundant.

Adjacent to the fault zone on its eastern side is an intensely deformed and fractured pebble conglomerate. Clasts of dolomite (marble), foliated metamorphic rocks, and a few volcanics (?) are markedly attenuated; somewhat less so are white quartz and red jasper, but these in turn are abundantly fractured. The matrix is composed predominantly of fragmental material derived from a dark green chlorite schist. Poorly sorted, the maximum size clasts are six to seven inches except for large chunks of red siltstone (argillite) which are two to three feet across. Slickensides and calcite veins are present throughout.

The fault can be traced as a topographic lineation crossing Leo and Larry Brooks. Further northeastward it is continuous and on strike with the Glide Mountains Fault. At its intersection with Leo Brook, the existence of the fault is confirmed by the presence of: poorly indurated, pale gray-green cataclasite; well foliated mylonite; gray or orange irregular weathering ("rotten appearance") quartz veins; and dark-green highly silicified schist containing veins of calcite. "Float" blocks of a remarkably flattened carbonate cobble conglomerate occur near the base of Larry Brook

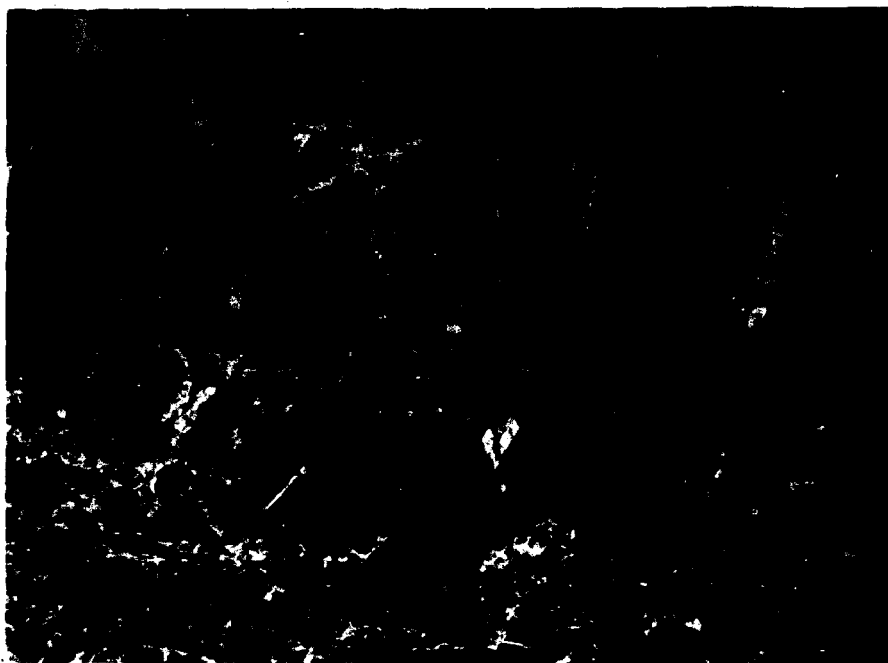


Fig. 24

Photomicrograph of fault pug near Leo Brook. Calcite veins in glass (dark area). (D50, crossed nicols, approx. 20X.)

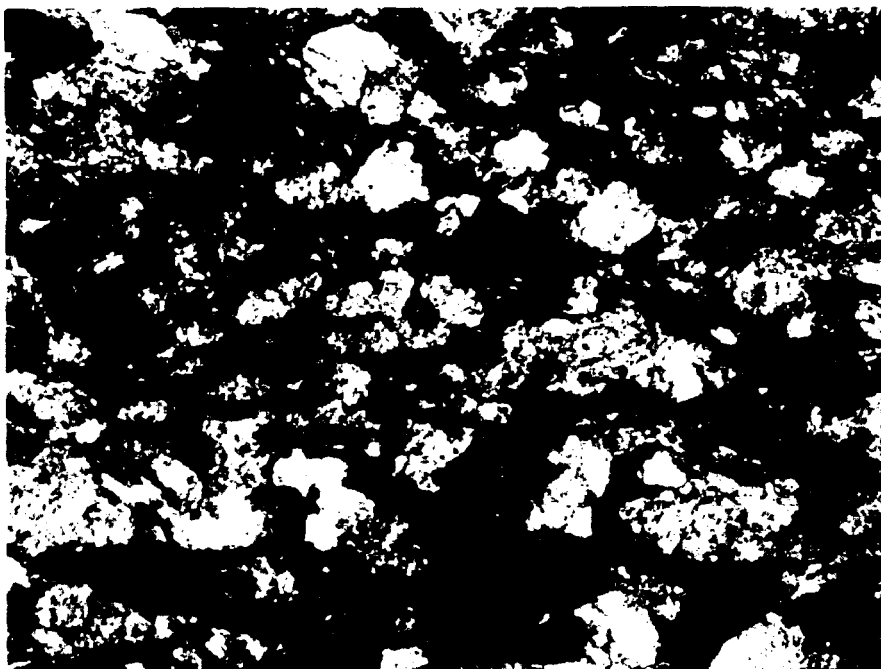


Fig. 25

Photomicrograph of mylonite on Apologize Brook, Glide Mountains Fault. Sheared feldspars in chlorite. (G30A, crossed nicols, approx. 20X.)

(Figs. 26, 27). In all respects except for its deformed appearance, the conglomerate is identical to the one observed on Salomon Creek (see p. 67). Stretching and flattening is so marked that the gray, orange, white pink, and buff carbonate clasts are pancake-like in shape. White quartz pebbles are fractured and attenuated.

South Brook Fault. The occurrence of a prominent fault in the South Brook Valley has been indicated by Baird (1954), Riley (1957), and Williams (1967). Its presence is perhaps the least well documented of any of the major faults and must be inferred on the basis of a linear topographic depression and the discontinuity of dissimilar lithologies to the north of Northern Harbor. Masking by glacial deposits in the South Brook Valley may largely account for its very poor exposure. There is also no direct evidence for a southward extension of the fault into Northern Harbor. The youngest possible age of movement along the fault is at the end of the Early Mississippian. This is based on the lack of deformation in Upper Mississippian strata which, as Williams (1967) has shown, overlap the fault.

Deer Lake Fault. The Deer Lake Fault, located east of the lake itself, forms the western margin of the Glide Mountains Uplift. It can be traced on air photos as an intermittantly well-defined topographic lineament from South Brook to a point southeast of the town of Deer Lake. For the most part, deformed Anguille strata strike obliquely into the fault and are truncated by it. Upper Mississippian



Fig. 26

Deformed carbonate cobble conglomerate (side view). Light colored quartz pebbles more resistant. Penknife = $2\frac{1}{2}$ inches.



Fig. 27

Deformed carbonate cobble conglomerate (top view).

redbeds on the western side of the lake and those near South Brook on the eastern side are practically undeformed. However, adjacent to the fault itself, these same units are severely folded, upturned, and overturned. Since 1) in all likelihood the fault is steeply inclined, 2) older strata are upraised on the eastern side of the fault, 3) folding appears to be related to fault movements, 4) overturning, where noted in Upper Mississippian strata on Eastern Brook and east of Deer Lake Village is consistently toward the west, and 5) fold morphology of Anguille strata on Blue Gulch Brook suggests westward movement along a reverse fault, it seems reasonable to conclude that: 1) the Deer Lake Fault dips steeply eastward, 2) it clearly has at least some component of reverse fault movement, and 3) the local tectonic transport is toward the west.

A large mass of crystalline rock has been emplaced along a portion of the fault's length (from Eastern to Lanes Brooks) and is interposed between the Lower and Upper Mississippian strata. Structures of this type have been referred to as pressure ridges by Wallace (1949, p. 793) and as fault-slice ridges by Sharp (1954). The emplacement must have taken place during the Upper Mississippian. This conclusion is based upon the presence of distinctive cobbles in an Upper Mississippian conglomerate on Lanes Brook. Quite definitely, these were derived from the phyllite, schist, and white quartz of the immediately adjacent basement block. (Comparable relationships exist on the eastern side of the Uplift at

Basement Brook. There, however, the faulted horse is smaller and the major fault dips westward.) The western crystalline elongate fault slice has been described by Baird (1959) as being composed of crenulated, quartz-mica-feldspar-chlorite schists and gneises, minor quartzite, and minor amphibolite layers. On Pynn's Brook, the schists contain grains of blue-tinted quartz and are associated with massive veins (up to eight feet thick) of white bull quartz. A thin section of the schist shows that the large quartz and feldspar grains are attenuated, brecciated and sutured; they are set within a matrix of finer, irregular quartz, feldspar, chlorite, and muscovite-sericite. Decidedly not a simple schist, the rock exhibits mylonitic characteristics. Where the eastern segment of the fault crosses Pynn's Brook, the crystalline basement has been mapped as a serpentized ultrabasic rock (Baird, 1959); the occurrence of this lithology is quite in keeping with the localization of the fault. The boundaries of this body have been approximated by delineating the area lacking vegetation. In part, these rocks are composed of a strikingly light or dark blue, highly fibrous mineral, which is very likely crocidolite. Deer, Howie and Zussman (1966, p. 183) mention that the development of this asbestiform variety of riebeckite may be related to shearing stresses.

The Deer Lake Fault (and/or the South Brook Fault) may be continuous in the subsurface with the Doucers Brook Fault (see Plate 9); roughly on strike with each other, the two possibly are uninterrupted beneath the Upper Mississippian

cover of the Humber Valley. Some surface expression of this continuity apparently exists at John's Falls on the Humber River where normally flat lying Upper Mississippian strata are mildly deformed (see Betz, 1943, p. 692).

Since blanket-like Upper Mississippian sediments appear to overlap and therefore to postdate fault movements in the Humber Valley, it must be concluded that the age of activity varies according to location along the fault or that there is local variability in the vertical throw along the fault. Undeformed strata imply quiescence, whereas crustal instability is indicated by the severe deformation of Upper Mississippian strata on the western side of the Glide Mountains and the deposition of Upper Mississippian coarse "fault scarp" conglomerates on Lanes Brook.

Glide Mountains Fault. The Glide Mountains Uplift is bisected by a major but previously unrecognized fault, one quite likely continuous to the southwest with the Leo Brook Fault. In many respects, the Glide Mountains Fault resembles the Deer Lake Fault just described. Similarities include:

1. The truncation of Anguille strata by the fault and upturning of Upper Mississippian strata adjacent to it.
2. The presence of mylonites.
3. The steep inclinations of the fault zone which, in the case of the Glide Mountains Fault, may be close to vertical for its linearity is virtually die-straight.

4. The eastward dip of the fault plane and the westward directed tectonic transport along at least a portion of the fault.

5. The disappearance of the fault toward the northeast beneath a blanket of Upper Mississippian clastic deposits.

The Glide Mountains Fault, however, differs in its overall scissors-like nature. This becomes apparent by noting the relative ages of rocks on either side of the fault along its length. Between Apologize and Way-Out Brooks, basement rocks on the west are juxtaposed with Lower Mississippian strata, indicating that the Western side represents the upthrown block. Further to the northeast conditions are reversed and Anguille units on the east have been brought up in fault contact against Upper Mississippian strata on the downthrown western side.

Either in outcrop or as a topographic lineament, the Glide Mountains Fault zone can be traced with relatively un-deviating trend from Apologize Brook northeastward to Allday Brook. A bright orange-red granite, exposed on Apologize Brook, is exceptionally well jointed and fractures with ease. In thin section the quartz is sheared, sutured and greatly elongated; plagioclase crystals are uniformly sericitized. A mylonitized schistose rock is intimately associated with the granite and is possibly intruded by it. Petrographic examination of the mylonite shows it to be composed of intensely altered and very irregularly shaped feldspar crystals which are set within a sheared chlorite and magnetite pasty

matrix (Fig. 25). The chlorite, most likely pennine, exhibits a very deep anomalous blue interference color and virtually no birefringence. In addition, the rock contains considerable secondary carbonate and epidote.

The fault zone is distinctly displayed as an isomagnetic lineament from Apologize Brook to Way Out Brook (see Geologic Survey of Canada, Airborne Magnetic Survey Map 272 G). Its topographic reflection can be traced over this same interval with varying degrees of ease. Cataclasite with abundant fractures which have opened and been partially resealed with secondary quartz can be found at the base of Way Out Brook. To the northeast the fault continues along the same trend, again following a topographic lineament, and at Easy Plunkin' Creek dark gray, thinly bedded siltstones are sheared, slickensided, veined with calcite, and folded into vertical. The stream itself is a subsequent one, much of it following along the trace of the fault. Projected farther along strike, the fault is present on Seaplane Brook at its anticipated locality. Upper Mississippian red sandstones to the west are separated from Lower Mississippian black argillites on the east by an ultramylonite and fault gouge. In thin section this rock is almost entirely isotropic except for the small, very angular fragmental grains of quartz and veins of ragged carbonate which permeate throughout. Dips of Upper Mississippian strata are low near the mouth of the stream but become steadily steeper to vertical as the fault is approached. The implication, therefore,

is that the fault plane, although steep, is inclined somewhat toward the east and that the hanging wall moved westward, deforming the Upper Mississippian beds. This conclusion is supported by the presence of folded Lower Mississippian argillites on the east side of the fault which display eastward dipping axial planes; the fold morphology is consistent with the transport direction of the proposed deformation.

On Allday Brook, relationships are somewhat similar. Upper Mississippian strata are almost flat-lying on the stream flowing out of Glide Lake while equivalent units are vertical where they abut the fault (see Baird, 1959). To the east, Lower Mississippian white and gray sandstones are vertical or very steeply inclined toward the west.

Latest movements on the Glide Mountains Fault must have taken place after the deposition of Upper Mississippian strata. As noted on Seaplane and Allday Brooks, these deposits have been deformed by the fault activity.

Grand Lake Fault (northern portion). Southern and northern portions of the Grand Lake Fault are directly continuous with one another, the subdivision being strictly for convenience of the discussion. The northern portion is well exposed in the environs of Basement Brook. There, as a double fault, it forms the bounding surfaces of a diorite block which underlies a small, steep-sided hill located one mile east of the brook. The diorite is coarsely phanocrystalline near the core, somewhat brecciated, and contains

abundant white quartz veins. It is mylonitized at the marginal faults, both of which are exposed clearly along shore; additionally, Mississippian strata on either side of the diorite are upturned. Thus, it seems reasonable that this block represents a sliver of basement rock or horst, caught between faults and brought up as a result of movements along them. As such, it is akin to the much larger crystalline mass exposed on the western flank of the uplift along the Deer Lake Fault.

The greater part of Basement Brook is a subsequent stream flowing along the Grand Lake Fault. Where the brook emerges at the shoreline, the rocks, although very dense and well indurated, are foliated, sheared and contorted, and contain abundant chlorite, calcite veins, and flattened nodules composed predominantly of calcite. Small folds within these pale-to-dark green mylonites are asymmetrical toward the southeast and plunge northeastward at approximately 25° . Large blocks of interbedded black shale and orange dolomite occur at the western margin of this fault zone; still farther to the west, Lower Mississippian coaly black shales are deformed and small folds plunge northeastward at approximately 31° . These strata give the overall appearance of having been "turned up" toward the west as a result of upfaulting of the crystalline basement. The same is true of the Upper Mississippian red, sandy-matrix conglomerates adjacent to the eastern splay of the fault except that there the strata are steeply inclined toward the east. Deformation of these con-

glomerates fixes the age of emplacement of the horst as Late Mississippian or younger. In summary, the diorite block appears to have been uplifted along steep, downward converging faults as a result of activity which took place during or subsequent to the Late Mississippian.

Between Basement Brook and Island Pond Brook the Grand Lake Fault is expressed as a moderately well defined topographic lineament. Still farther to the northeast (from Island Pond Brook to Popcorn Brook), the fault can be discerned only as a weak photolinear even though its presence is clearly established in rocks along the lake shore northeast of Popcorn Brook. The reappearance of the fault at this latter locality is directly on strike with its last noted prominent trend southwest of Island Pond Brook. Proceeding with only a slight deviation in strike, the fault extends northeastward from Shiquee Brook and presumably is continuous with the Birchy Lake Fault. At the projected location of the fault on Island Pond Brook there is a covered zone, on opposite sides of which crop out Lower and Upper Mississippian strata. They dip into the proposed fault at 76° SE and 50° NW, respectively. No disconformable relationships were observed between the younger and older rocks.

The existence of the Grand Lake Fault at Popcorn Brook and northeastward is confirmed by the following evidence:

1. At the base of Popcorn Brook occurs a gray arkose which in thin section exhibits a pronounced cataclastic texture.

2. Northeast of Popcorn Brook the shoreline is marked by steep banks and a rectilinear character; for a distance of some 1.3 miles a zone of shearing is clearly displayed. In the southern part, bedding is almost totally unrecognizable and all lithologies are deeply stained with hematite. Nearly all exposed surfaces have a greasy luster, a result of fault polishing. Fresh surfaces resemble Lower Mississippian red arkoses and Upper Mississippian red siltstones, however, the rocks are so intensely fractured, sheared and stained that identification is most tenuous. Associated lithologies include red fault breccias containing white calcite and quartz veins, as well as gray-green pervasively fractured mylonites. At a gouge zone near H65, thoroughly fractured Lower Mississippian arkoses appear to overlie sheared Upper Mississippian red siltstones. From this point to Shiquee Brook only pastel weathering, pale orange, red, and green cataclasites (formerly Anguille red arkoses?) are present. Unlike the sequence immediately to the southwest, the thick or massive bedding is still recognizable in these units even though they are pervasively fractured and slickensided.

3. Along the shoreline, both north and south of Popcorn Brook, Upper Mississippian red sandstones have been overturned toward the east. It seems reasonable that their upturning is directly related to fault activity, for correlative beds on the east side of Grand Lake are unaffected and relatively flat lying.

Eastward overturning of the Upper Mississippian units combined with the linearity of the fault implies that the Grand Lake Fault plane dips steeply westward and that movement on it has at least some reverse component. The same sense of movement is also suggested by a) the redbeds east of the diorite block at Basement Brook and b) some of the shallow-plunging, asymmetrical folds--tens of feet across--in Anguille strata which have very steep eastern limbs and almost horizontal western limbs. Thus, it appears that local tectonic transport along the Grand Lake Fault was toward the east and as such opposite to the westerly movement inferred for the Deer Lake Fault.

The resulting morphology of the Glide Mountains Uplift is therefore one of a wedge-shaped block, bounded by steeply dipping faults which converge in a downward direction (Plate 10). Reverse movements along the faults must have occurred during or after deposition of Upper Mississippian strata. This is concluded because: 1) along both flanks these units have been deformed by the uplifting process; 2) nearly flat-lying Upper Mississippian beds (Rocky Brook Formation) are found atop the Glide Mountains, northwest of Allday Brook. In all likelihood these strata were deposited contiguous with correlative units which crop out in the lowlands; uplift must therefore have taken place subsequent to their deposition.

Other Faults. In the northeast part of the Glide Mountains there are several smaller faults which trend

approximately north-south (Plate 2); as such they are roughly parallel to the large local folds and en echelon to the Grand Lake Fault. Two of the more obvious faults--one crossing Woody Brook and the other crossing Wrong Brook--are well exposed at the shoreline and clearly traceable as photo-linears. Deformation of Anguille strata adjacent to the Woody Brook Fault suggests that it dips westward and is largely a thrust or high-angle reverse fault. By the same reasoning the Wrong Brook Fault also appears to be a high-angle reverse fault, but one dipping eastward. Since the predominant dip of strata in this region is toward the southwest, displacements on the Woody Brook Fault tend to increase the thickness of the exposed section, perhaps significantly so; opposite conditions prevail for the Wrong Brook Fault.

At individual outcrops small normal faults are visible which have displacements measurable in less than tens of feet. Fault planes are undeformed and therefore appear to postdate the episodes of folding. It seems likely that these faults and the resultant "horsts and grabens" are related to uplift of the Glide Mountains (slickensides indicate that latest movements were oblique-slip in nature) or possibly are a later feature, a consequence of post-tectonic relaxation of stresses.

Strike-Slip Faulting

Up to this point only the dip-slip component of movement on the major faults has been emphasized. However, these large structures display a number of features which are

similar to prominent faults known to be dominated by strike-slip offsets. The occurrence of such transcurrent faulting not only explains the observed geological relationships (see p. 178), but also provides the basis for an inclusive tectonic synthesis and geologic history. A listing of strike-slip fault characteristics with some comments relating the applicability of these characteristics to the faults of western Newfoundland follows.

1. The traces of strike-slip faults are most often remarkably long, continuous and rectilinear. The presence of these elements in western Newfoundland has already been discussed in the preceding section. Also see Plate 9 and Fig. 2.

2. Strike-slip fault planes dip very steeply. The constant trend of major faults through uneven topography demonstrates that they are indeed very steeply inclined.

3. Topographic expression of strike-slip faults is generally excellent. All of the major faults are traceable with relative ease as air photo topographic lineaments or depressions. This is true except for the region of the Humber Valley where faults are overlapped by younger strata.

4. Cataclastic rocks such as mylonite, cataclasite, and fault pug are present along fault lines. The occurrence and local excellent development of these lithologies has already been described.

5. "The vertical throw along the fault varies greatly either because synclines abut upon anticlines and vice-versa,

or because some independent vertical warping occurred," (deSitter, 1964, p. 160). It was pointed out (pp. 158, 159) that along the length of the Deer Lake Fault and Glide Mountains Fault, Upper Mississippian strata both overlap and are truncated by the faults. Local variability in the vertical throw of the fault is thus indicated.

6. "Very often (strike-slip faults)...merge into thrust faults, making (an) oblique angle with their own strike at their extremities, or thrust-faults merge into the wrench-fault along their course," (deSitter, 1964, p. 160). Examples of thrust faults oriented obliquely to the Grand Lake Fault include the Woody Brook Fault, the fault north of Minto Brook and possibly the Lobster Cove Fault of north-central Newfoundland.

7. The splaying nature at the extremities of strike-slip faults has been commented upon by deSitter, (1964), E. Popper (1966), and Chinnery (1966). Excellent examples of this characteristic include the West Bay Fault in the Yellowknife District (Brown, 1955), the Philippine Fault (Allen, 1962; Rutand, 1968), the Denali Fault (St. Amand, 1957), the San Andreas Fault (Reed and Hollister, 1936; Hill and Dibblee, 1953) and the Atacama Fault (Allen, 1962). In these cases, the large translational movements on the main faults presumably have been accommodated at the terminus by lesser offsets along the branching series of subparallel splays. The splaying or "horsetail" nature of the Newfoundland fault system is shown in Fig. 2.

8. En echelon structures are commonly reported in association with strike-slip faults (Moody and Hill, 1956; Reed and Hollister, 1936; Campbell, 1958; Badgley, 1965, p. 108; Heine, 1962; Bishop, 1968; Baltz, 1967; and Smith, 1968). The presence of such features cannot by itself be used as evidence to support strike-slip faulting unless it can be shown separately that they are a direct result of the same deformation which caused the faults. If the en echelon structures located west of the Grand Lake Fault (Plate 2) are in fact related to movements on the fault, then their orientations signify that faulting was dominated by right-lateral strike-slip offsets. This type of movement along the large Newfoundland faults has been suggested by Webb (1967, 1968), Heyl (1966, 1967), Belt (1967, 1968), and Lock (1969).

9. Laterally offset features are perhaps the only type of evidence capable of unequivocally substantiating the strike-slip nature of a particular fault. Because of the character of these faults, however, recognition of such features and establishment of their common origin is usually difficult. Nevertheless, four possible such indicators are present in the Grand Lake-Deer Lake region.

(a) The deformed carbonate cobble conglomerate which crops out southwest of Leo Brook and at the base of Larry Brook is compositionally very much like the one exposed along the western flank of the Glide Mountains Uplift. Since no other examples of this conglomerate occur on the Grand Lake side of the Uplift, the presence of this lithology

southwest of Northern Harbor appears to be anomalous. Inasmuch as the cobbles quite definitely have been derived from the Ordovician carbonates, their occurrence on Grand Lake can be explained in three ways:

i. These sediments might have been transported to their present site by southeasterly directed currents blowing along the length of the present South Brook valley. Such an origin seems most unlikely because 1) virtually no primary features in the entire Anguille sequence indicate southeastward transport, and 2) the coarseness of the deposit suggests derivation from a much closer source.

ii. The crystalline rocks west of Leo and Delta Brooks (Grand Lake Brook Group, p. 23) may once have been covered by Ordovician carbonates which were subsequently removed by erosion. This genesis for the cobble conglomerate seems likewise untenable because 1) such extensive denudation ought to leave behind a more substantial record than this thin band of conglomerate, and 2) the former presence of carbonates in this area would be confirmed if some vestiges of this lithology could be shown to overlie the Grand Lake Brook Group; Riley (1957) and Baird (1959) show none.

iii. The conglomerate on Grand Lake is situated adjacent to a major fault, and cobbles in it are markedly deformed (see Figs. 26 and 27). Undoubtedly they have been affected by movements along this fault. The "anomalous" position of these rocks can then perhaps best be explained if they are thought of as representing the truncated, onetime

southern continuation of the thin belt of carbonate conglomerate which presently crops out on the western side of the Glide Mountains (Plate 2). A cumulative left-lateral strike-slip offset of some three or four miles is thus suggested for the Leo Brook-South Brook Faults. Deformation of the cobbles appears to be directly associated with movements along the fault. Therefore, more precise determinations of the direction of net slip might be accomplished through strain measurements of the flattened carbonate clasts, and fracture orientation studies in the more brittle quartz and jasper pebbles.

(b) The alluvial fan red arkoses were derived from a nearby granitic source situated south or southeast of the Popcorn Brook-Harbor Brook area. Immediately suspect as the most likely provenance is the large pluton located south and east of the trans-Newfoundland lineament in the region between Grand Lake and Red Indian Lake (Fig. 2; Riley, 1957, unit 15; Williams, 1967, unit 8). At its closest point, however, this pluton is located more than five miles to the southeast of the fan arkoses, a transport distance far too great to preserve the characteristic euhedralism of the feldspars. Since the provenance must have been closer, this batholith could not have acted as the source for the detritus, at least not in its present location. Separation of the fan arkoses from their source area may have been accomplished either by tensional rifting or strike-slip movements.

In addition, provenance rocks must be composed of the distinctive feldspars described on page 116. Unfortunately, the petrology of the batholith has not yet been investigated, and so until further research is undertaken no definite statement can be made about the location of the source rocks.

Very few samples of granites were obtained from east of the trans-Newfoundland lineament. Nevertheless, under petrographic examination, the feldspars in one granite show a degree of similarity to those in the arkoses. Compare Figs. 28 and 29. This particular red granite is located at the north end of Sandy Lake (F51, Plate 9). If this does eventually prove to be the source rock, then it indicates a left-lateral strike-slip offset of more than 30 miles. It must, however, be reiterated that the sampling is far too small to draw definite conclusions. Similar comparisons can be made for a lithic graywacke (Fig. 30) at Woody Brook harbor (D92) and a granite (Fig. 31) on the western side of Birchy Ridge (E96, Plate 9). In each rock there occur perthites which contain plagioclase inclusions with altered cores and clear rims.

(c) Primary feature orientations indicate that the coarse Anguille strata which crop out southwest of Porters Brook were derived from the east and southeast. This is a region where at present there are extensive exposures of the Glover Island Formation and other associated volcanic rocks. If no strike-slip movements took place along the Grand Lake Fault, one should expect to find considerable



Fig. 28

Photomicrograph of arkose, red arkose suite. Angular perthite clast containing plagioclase inclusions with altered core and clear margin. (D87A, crossed nicols, approx. 20X.)



Fig. 29

Photomicrograph of granite located east of Birchy Ridge. (F51, crossed nicols, approx. 20X.)

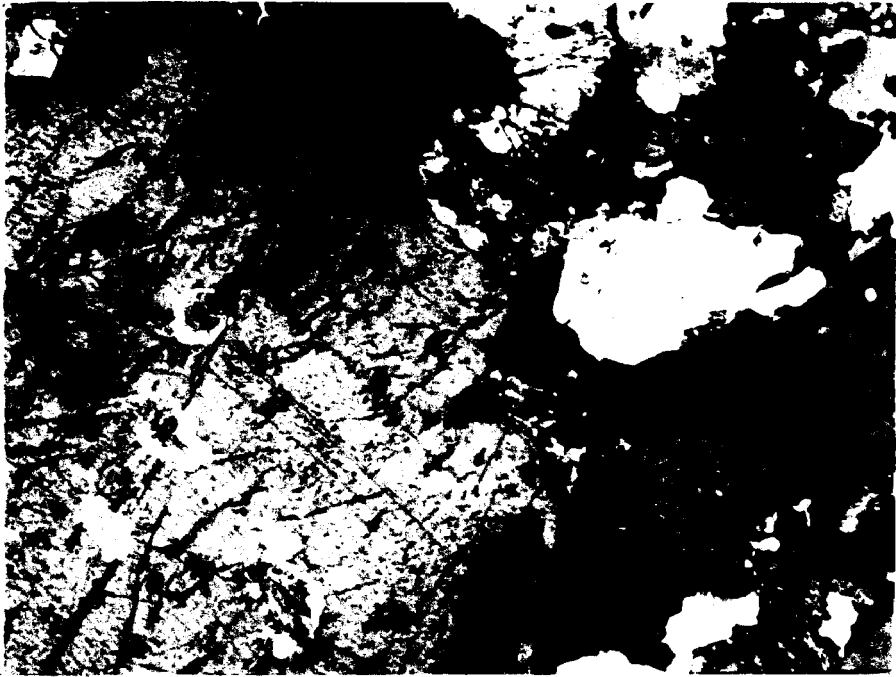


Fig. 30

Photomicrograph of lithic graywacke, siltstone-dolomite suite. (D92, crossed nicols, approx. 20X.)

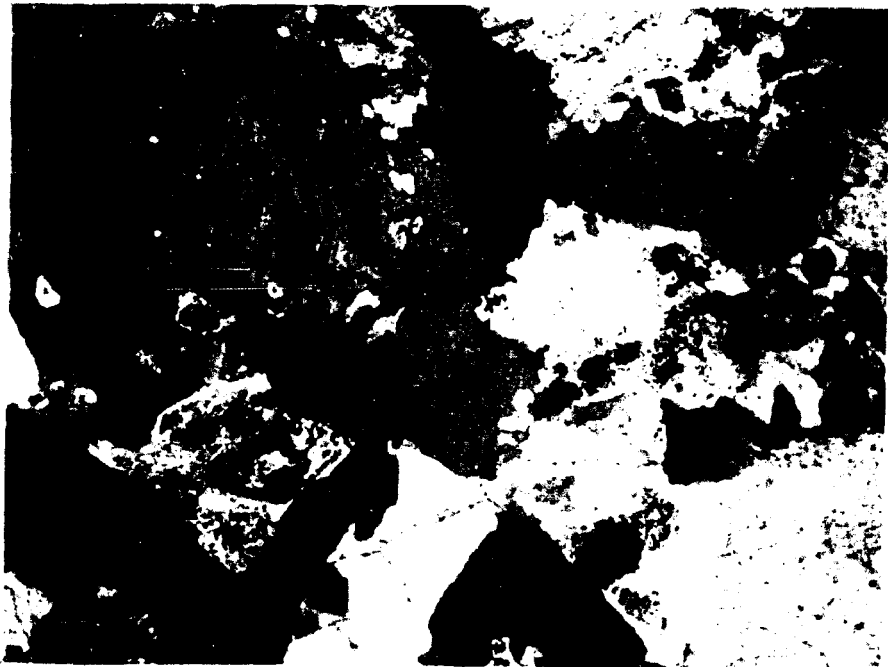


Fig. 31

Photomicrograph of granite located on west side of Birchy Ridge. (E96, crossed nicols, approx. 20X.)

quantities of these volcanic fragments in the Anguille strata. This in fact is not the case, and in sample D47 (located at the mouth of Northern Harbor) such expected clasts are conspicuous by their absence (see Table 1). A reasonable explanation is that the presumed source rocks were not in their present position at the time of Anguille deposition; rather they have subsequently been transported to this location along transcurrent faults.

(d) The presence of anorthosite clasts (see p. 36 and p. 151) also suggests that strike-slip movements have taken place. An anorthosite body which could have acted as the source rock has not been reported anywhere in the immediate vicinity. A large anorthosite mass is, however, located over 35 miles to the southwest.

10. The existence and tectonic significance of wedge-shaped blocks in a strike-slip fault zone was recognized as early as 1938 by Willis, yet until recently (Kingma, 1958; Lensen, 1958; Popper, 1968) such structures have received little further attention. These blocks, apparently characteristic of strike-slip fault zones, are bounded by downward converging, high-angle reverse faults. In plan view, they are elongate, possibly as much as 20 miles wide, and tapered at either or both ends. The resultant overall morphology thus resembles that of a steep-hulled boat. A number of these structures have been recorded by Crowell (1952) and Wallace (1949) along the San Andreas and related faults. Webb (1963) and Cameron (1966, p. 129) indicate that wedge-

uplifts occur in association with major faults in the Canadian Maritimes, and Kingma (1958) and Lensen (1958) note their importance in association with strike-slip faults in New Zealand. As it was pointed out earlier (p. 165), the cross-sectional profile of the Glide Mountains Uplift is one of a wedge-shaped block.

The formation of wedge-blocks in transcurrent fault zones is supported by experimental studies which, although not adhering to the principles of scale-model theory, do offer some intriguing comparisons. Experiments performed by Riedel (1929, loc. cit. deSitter, 1964, p. 158) and Baltz (1967, pp. 70, 71) are similar. In each case, two adjoining flat base-plates of competent material such as wood or cardboard were covered with a more plastic substance such as clay, parafin or flour batter. One plate was then moved laterally past the other. In both examples there developed 1) steep wedge-faulted uplifts immediately above the base-plate joint, and 2) en echelon structures adjacent to the high-angle faults. Furthermore, in Baltz's study, folds produced on the downthrown side of the block were overturned in the direction of local transport away from the upthrown block. This is comparable to the natural conditions adjacent to the Glide Mountains Uplift.

11. Other geologists have suggested that significant strike-slip movements took place along Canadian Maritime faults. Although certainly not offered as confirmation, their interpretations do lend support to the validity of the

strike-slip hypothesis. Some of these people include Belt (1967 a, 1968); Cameron (1966); Fletcher (1883, loc. cit. Cameron, 1966); Fyson (1966, 1967); Goldthwait (1924, loc. cit. Cameron, 1966); Heyl (1966, 1967); Kay (1967); Lock (1969); Neale (1963, loc. cit. Fyson, 1967); Neale and Nash (1963); Popper (1965, 1968); Webb (1963, 1967, 1968); and Wilson (1962).

It should be pointed out, however, that there are others who do not agree with these conclusions. Helmstaedt's (1968) study of pebble fractures along the presumed strike-slip Beaver Harbour fault indicates that the maximum compressive stress was oriented nearly perpendicular to the fault. If this is representative of the entire stress field, it would be most unfavorable for the creation of a strike-slip fault. His analysis is based on the perhaps debatable assumption that:

- (a) The pebble fractures are tensional in origin.
- (b) Fracturing of pebbles was caused by the same stresses responsible for the faulting.
- (c) The fractures have not been rotated.
- (d) The orientation of the strain ellipse at the surface is the same as that at depth. On experimental grounds, Tanner (1962) has suggested that this need not necessarily be so.

Summarizing then, it seems reasonable, or even very likely, that west-central Newfoundland represents a zone of former strike-slip faulting within which considerable dip-

slip movements have also taken place. Although lacking the direct evidence created by the dip-slip component of movement, it appears that strike-slip offsets played at least an equally important role in the deformation. Conclusive proof of these movements, however, awaits further investigations.

Tectonic Synthesis

Any tectonic synthesis will have to account for the following geological relationships:

1. The conversion of the paleobasin into a present region of uplift.
2. The topographic-stratigraphic inversion, in which outcroppings of Lower Mississippian rocks are situated everywhere topographically higher than adjacent Upper Mississippian units.
3. Contacts between Lower and Upper Mississippian strata invariably are marked by faults.
4. The late or post-Mississippian age of uplift.
5. The origin of the wedge-shaped blocks and mechanism of uplift.
6. The overturning of strata on both sides away from the uplift.
7. The discontinuity of the Lower Mississippian outcrop belt between the Glide Mountains and Birchy Ridge. The origin of this lowland is perhaps the most difficult to explain for two reasons. First, Lower Mississippian lithologies in both uplifts are similarly well indurated and there-

fore approximately equally resistant to erosion. Second, fold axes in the two regions are roughly on strike with each other. This being the case, why then is there a low land between the uplifts rather than a continuous ridge as might be expected?

As a result of his work along transcurrent fault zones in New Zealand, Kingma (1958) has proposed a tectonic model for the development of piercement structures. (A preliminary statement of this concept is mentioned by Davis (1927.)) This model is remarkably well suited to west-central Newfoundland. Along with the work of Lensen (1958), and another concept presented here, it provides the foundation for a unifying theory which accounts for the geological observations outlined above.

The general conditions as described by Kingma so closely parallel those in the Anguille basin that it seem worthwhile outlining them here. Kingma reports that deposits of great thickness (15,000 feet) were laid down in small fault-bounded basins. These basins, termed geosynclinettes, are 6-10 miles wide and 15-20 miles long. They are particularly common where transcurrent fault zones die out, occurring between two parallel systems of faults or along a single transcurrent fault zone. Presently, rocks from within these basins are recognized as large isolated blocks surrounded by younger deposits and bounded on all sides by faults. Kingma proposes that the horst-like blocks have been upraised and pierced through the younger beds. Since the piercements,

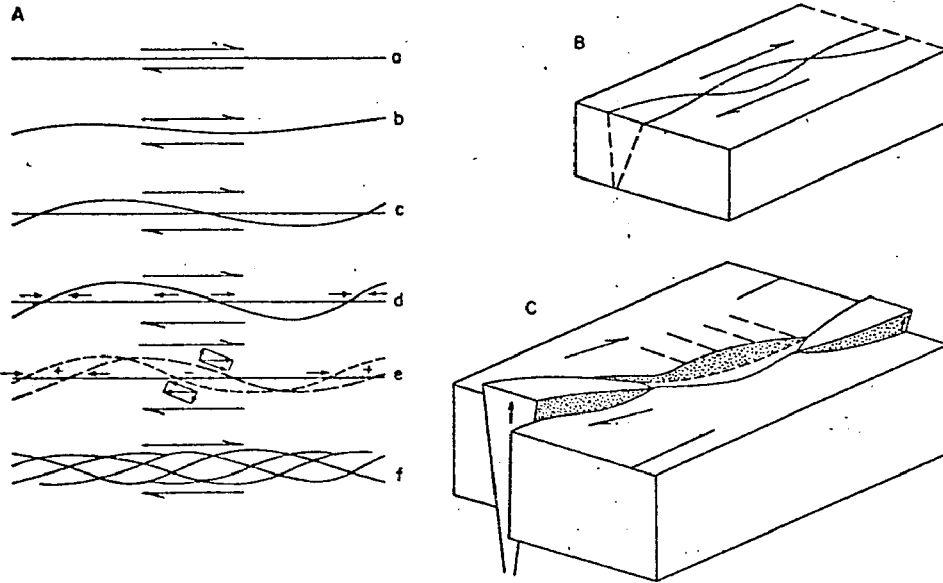
like the basins, are commonly associated with transcurrent fault zones, ..."It seems that there is some casual relation between transcurrent faulting and the differential elevation of troughs and highs." The piercement bodies are wedge-shaped, bounded by very steep faults which probably merge downward into a single crush zone. (For an alternative viewpoint see Cotton, 1957.) Creation of the wedge-blocks and formation of the horsts and grabens is viewed as follows (see Fig. 32).

In Fig. (32) the development of a transcurrent crush-zone from an originally straight, transcurrent fault is illustrated (the curvature of the faults is exaggerated for emphasis). It is argued that with an originally straight, transcurrent fault, any differences in lithology on opposite sides of the fault will give rise to frictional differences and uneven movements along the fault plane. The original, linear fault will in places change direction because of this friction, and undulations and widening of the zone will result. With continued movement along an undulating fault alternating areas of tension and compression must result, and corresponding to these sinking and rising areas are created--that is, small lensoid grabens and horsts, or fault angle depressions and tilted blocks. ...

On continued movement past the stage illustrated in Fig. 32A, e. it is possible that another fault will be initiated and that this in turn may adopt an undulation. If the newer undulations are appreciably offset from the earlier, then it becomes possible for the original horsts to subside and for the basins to be everted. In a transcurrent fault zone, therefore, large and small blocks can move up and down individually and thus cause radical changes in lithology in place and time.

(Kingma, 1958)

Fig. 32 Development of piercement structures within a transcurrent fault zone.

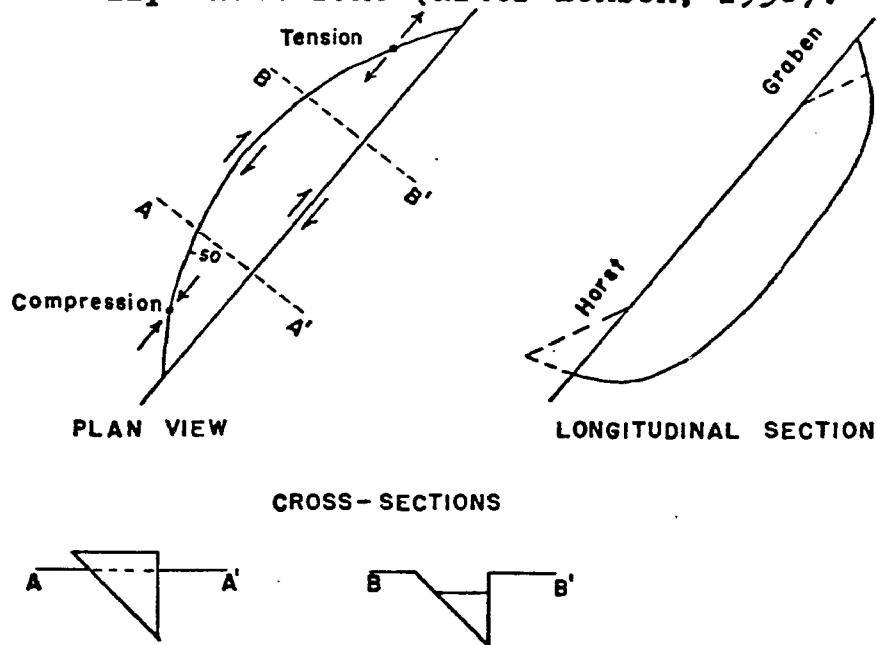


Development of a transcurrent braided fault zone. Differences in lithology on opposite sides of the fault give rise to frictional differences and uneven movements, thus creating undulations.

Continued movement gives rise to alternating areas of tension and compression. (After J. T. Kingma [1958], *New Zealand Jour. Geol. and Geophys.*, 1.) (After Kingma as redrawn by Badgley, 1965.)

Fig. 33

Formation of a pitching horst and graben in a strike-slip fault zone (after Lensen, 1958).



CROSS-SECTIONS

It should be pointed out, however, that unlike the Newfoundland blocks, those in New Zealand have suffered little internal folding. Those in California were uplifted without appreciable tilting (Willis, 1938).

In a complimentary study, Lensen (1958) has attacked the same problem on purely geometrical considerations. His theory of transcurrent horst and graben formation does not require that rocks on either side of the fault differ in nature or degree of induration. Rather it is "based on the assumption that the friction along the plane of a reverse fault (compressional) is greater than that along the plane of a normal fault (tensional)." He shows that, in a bifurcating fault system dominated by strike-slip movements, displacements occurring within the fault zones must be accommodated by the raising or lowering of the wedge-shaped central block. Figure 33 shows the development of a pitching horst and graben. Note that, as strike-slip movements take place, local stresses at the northern end of the central block are tensional and as a result it will subside. Reverse conditions exist at the southern end. In an open-ended system, one in which the splaying branch does not rejoin the main fault, either a tilted horst or tilted graben will be formed. The actual dip of the fault planes is for most cases immaterial (except for cases where the intersection of the planes is above the ground surface, although Lensen does not seem to acknowledge this). Limiting conditions exist only where the faults are parallel in strike and have a con-

stant difference in dip, or dip by the same amount in the same direction. In these cases no vertical movement results.

An interesting extension of Lensen's theory is that within a single strike-slip zone grabens can be everted to form horsts and vice versa without any change in direction of movement on the bounding faults or orientation of the overall stress field. This can occur where bifurcating faults intersect beneath the surface and where initial strike-slip movements take place along one of the splays in preference to the other. The fault along which the initial movements take place is here called the active fault. In response to movements along this fault, offsets can then occur along the reactive fault. In Fig. 34-I, the eastern fault is the active fault. As movement occurs along this fault (tending to separate block C from blocks A-B) an extensional environment is created in block B. As a result, normal faulting occurs along the western reactive fault and block B drops down to form a basin or graben. Conversion of this block into an area of uplift occurs by a simple change in the active fault from the eastern to the western one (Fig. 35-II). With movement along a western active fault, a compressional environment is created in block B and high-angle reverse faulting takes place along the reactive eastern fault. If a regional sedimentary cover had been deposited in the interim between the shift in the active faults, block B would then have been pushed as a wedge-shaped uplift through the relatively flat-lying strata.

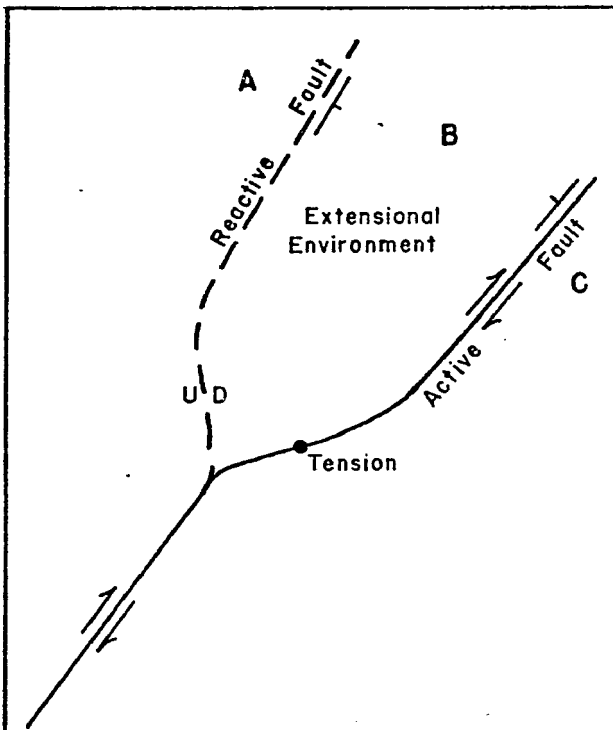


Fig. 34-I

Initial movement Block C vs. A-B creates extensional environment in Block B. As a result, normal faulting occurs along reactive fault with the consequent formation of Block B as a graben.

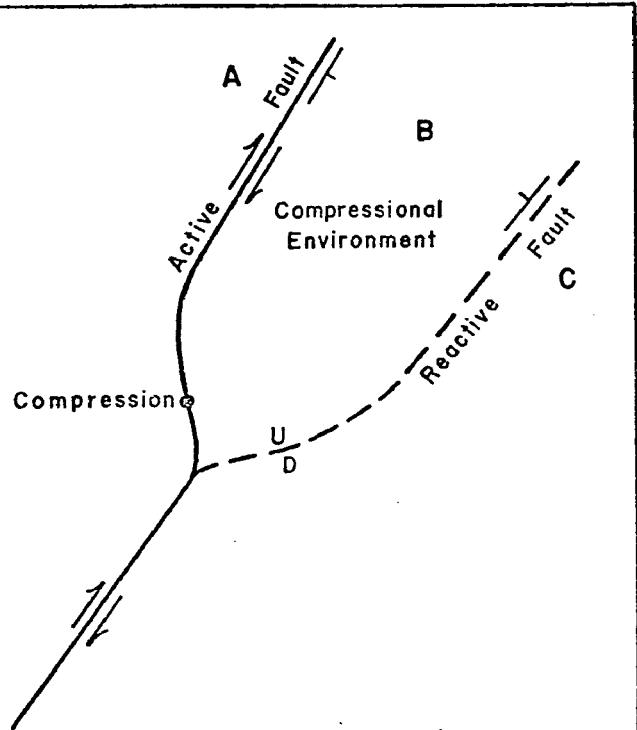


Fig. 34-II

Initial movement Block A vs. Block B-C creates compressional environment in Block B. As a result, high angle reverse faulting occurs along reactive fault with the resultant formation of Block B as a horst.

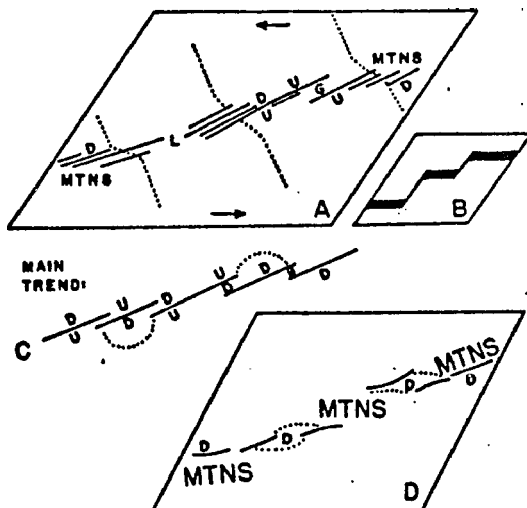


Fig. 35

Structural model study. Surface patterns in a strike-slip zone (after Tanner, 1962).

As in the case of the formation of wedge-blocks, here again the plausibility of the foregoing theories is reinforced by structural model studies. Tanner's experiments (1962) somewhat resemble those mentioned earlier but in his, a partial attempt was made to adhere to the principles of scale-model theory. The faulted, rigid basement consisted of diamond-shaped plywood plates over which was spread a "sedimentary cover" of soft, wet clay. In a number of trials Vaseline was placed between the basement blocks. A few of the general results are summarized as follows.

1. Surface movements were almost entirely vertical, even when the purely horizontal displacements of the basement blocks were at a maximum (scaled to approximately 60 km.). This suggests that actual strike-slip offsets need not be observed at the surface and in some cases may perhaps be demonstratable only in deeply eroded terrains.

2. The effects of strike-slip movements along a narrow line in the basement were spread out toward the surface.

3. Resultant surface patterns (see Fig. 35) included:

- (a) The formation of end-on-end chains of uplifts and depressed areas (as shown by Kingma).

- (b) The development of en echelon fault zones above the basement shear.

- (c) The development of scissor-type faulting (compare Fig. 35 with the Glide Mountains Fault on Plate 2).

From the foregoing considerations it seems reasonable to conclude that the west-central Newfoundland former Grand Lake

basin was everted into a wedge-shaped, keystone uplift, having been squeezed upward under pressure and out of a bifurcating or anastomosing strike-slip fault zone. In this region, therefore, both strike and dip-slip components of movement are present. Blocks rose through a cover of Upper Mississippian strata which was thrown aside during ascent of the piercement structures. These tectonic features may represent only the surface expression of sub-crustal movements along a deep geosuture.

Geologic History of the Grand Lake Basin, West-Central Newfoundland

1. Prior to the formation of the Mississippian basins, granite plutons were emplaced within the Newfoundland Central Mobile Belt. One of these intruded crystalline rocks at the site of the future Grand Lake Basin.

2. With the beginning of the Mississippian, a north-eastward trending, elongate graben-basin was formed in west-central Newfoundland. Bordered by steep, downward converging faults it was produced either as a purely tensional gravity feature or as the result of shearing stresses related to movements in a transcurrent fault zone. (Fyson, 1967 mentions that the occurrence of strike-slip faults of approximately this age in Nova Scotia.) The basin was created along the trans-Newfoundland lineament at the boundary between an igneous provenance to the east and south, and a metamorphic one to the west and southwest.

3. Earliest sediments supplied to the basin consisted primarily of volcanic rock debris from an igneous terrain to the east. Shortly thereafter a western dispersal system developed which transported metamorphic detritus into the basin. Coarse material derived from each of these distinctly different areas was deposited at the basin margins as pebble and cobble conglomerates. Finer particles from both sources were carried farther into the basin forming strata of mixed origin. Directional features indicate that paleocurrents originated in the south and east and then turned northeastward following the long axis of the basin into relatively deeper waters. Taken as a whole then, the basin closely resembles an ideal current dispersal system depicted by Potter and Pettijohn (1963, p. 194, Fig. 8-1-4).

Within this depositional framework Early Mississippian sediments accumulated under both subaqueous (lacustrine) and subaerial conditions. Differing lithologic associations, formed in three successively shallower portions of the basin, have here been referred to as: the siltstone-dolomite suite; the gray sandstone suite; and the red arkose suite. In the relatively deepest lake waters (characterized by stagnant, reducing and anaerobic conditions) formation of laminated siltstones, shales and dolomites was interrupted occasionally by turbidity flows (siltstone-dolomite suite). These bore sands which had been previously deposited by streams entering the shallow waters (gray sandstone suite).

In the subaerial environment the lake was flanked by alluvial fans which emerged from the nearby uplands. Periodic northward progradation of an arkosic fan entombed trees in the growth position; simultaneously, the coarse sediments covered swamps which flourished in the near-shore areas (red arkose suite).

Although most of the common types of primary features are present in each of the suites, their proportionate distributions are not equal. For example, cross-beds and parting lineations predominate in strata of relatively shallow-water origin (red arkose and gray sandstone suites) while groove casts, flute casts, elongate load casts and ripple marks are more prevalent in units deposited in deeper waters (siltstone-dolomite suite).

Deposition in the Grand Lake paleobasin was intermittent. This sporadic sedimentation was controlled by: periodic fluctuations in the seasonal supply of detritus; seismic disturbances which were responsible for resedimentation within the basin as well as the rejuvenation of relief in the source areas; and perhaps also flash flooding accompanied by high runoff.

Summarizing, it has been possible to recognize the following environments of deposition: relatively deep lacustrine, shallow lacustrine, fluvial, paludal, and terrestrial alluvial fan. The three suites, like the composite environments which they represent, are at least in part, time-equivalent and therefore facies of one another.

Rainfall in the region was sufficient to support abundant plant life and even large plant fragments were often enclosed in the sediments. There are no perceptible faunal remains.

Uplift of the source areas took place concomitantly with basin formation. This resulted in the formation of interdigitated cyclic deposits. Subsidence eventually ceased and coarse arkoses filled the basin, thus completing the overall regressive pattern of sedimentation. The abundance of arkoses high in the stratigraphic succession attests to the unroofing of a granite pluton in the source area to the south.

The Grand Lake paleobasin probably was isolated from the time-equivalent Anguille basin in the type area to the southwest. The presence of coarse deposits at the southwest end of the Grand Lake Basin suggest a basin margin or terminus. Furthermore, the Anguille basin (sensu stricto) was shallower at its northeast end (Baird, 1951). On the other hand, it seems likely that the Grand Lake basin was at one time continuous (and perhaps still is today in the subsurface) with the Birchy Ridge-White Bay basin to the north. This is based on the persistent orientation of north-northeast directed polar paleocurrent indicators in both areas, and the lack of any obvious coarsening of detritus where Lower Mississippian strata were last observed (in the downcurrent direction of transport) in the Grand Lake basin. Former continuity of the

two outcrop belts also is suggested by their lithologic similarities and corresponding stratigraphic sequences. The present separation is most likely due to downfaulting and infilling by younger sediments.

4. The Upper Mississippian Canso strata are significantly less deformed than those of the Anguille Group. This suggests a post-Anguille, pre-Canso deformation. The disconformity expected between the two groups, however, is nowhere observed in the thesis area. Instead, contacts invariably are marked by faults.

An alternative interpretation is that during a single later period of deformation and uplift, Anguille strata--having been deposited in a fault-bounded basin--were subjected to more intense deformation than the Canso units overlying the platform areas to either side. The difference in degree of deformation could not be lithologically controlled because many of the rock types present in both groups are similar and Anguille strata are the much better indurated of the two.

5. Canso deposition was blanket-like (except near major faults) and covered the region with a sequence of sub-aerial redbeds and shallow lacustrine gray shales. The presence of Canso red sandstones atop the central portion of the Glide Mountains indicates that the Grand Lake paleobasin was covered by these deposits.

6. During and possibly after Canso deposition, wedge-shaped blocks of Anguille strata were upfaulted through the

overlying units. Movements took place along high-angle, downward converging, reverse faults which, in all likelihood, were pre-existing planes of fracture. As a result of the faulting, strata were overturned away from the uplift flanks.

The development of these piercement structures probably is related to strike-slip fault movements. The existence of strike-slip faults has been inferred on the basis of: the linearity, steepness, and splaying nature of the faults; the keystone wedge morphology of blocks within the fault zone; the character of the faults themselves as observed in outcrop; the pattern of the overall deformation plan; and the suggested occurrence of laterally offset geologic features. Dislocations at depth along a geosuture may have been responsible for creation of the strike-slip fault zone.

At this same time fault slices of crystalline basement were exposed. These acted as source rocks for some of the Canso strata (such as the very coarse conglomerates on Lanes Brook). Uplift along the Glide Mountains Fault uncovered the granite and associated pale volcanic rocks. The age of unroofing (and movement along the fault) can be fixed because this crystalline mass provided pale orange volcanic clasts for the Canso conglomerates to the north, yet such fragments are not present in the underlying Anguille gray sandstones.

BIBLIOGRAPHY

- Adams, T.D., Haynes, H.R., and Walker, C.T.
 1965: Boron in Holocene Illites of the Dovey Estuary, Wales, and its Relationship to Paleosalinity in Cyclothems; Sed., vol. 4, pp. 189-195.
- Allen, C.R.
 1962: Circum-Pacific Faulting in the Philippines-Taiwan Region; J. Geophys. Res., vol. 67, pp. 4795-4812.
 1960: The Mamtor Sandstones: A "Turbidite" Facies of the Namurian Deltas of Derbyshire, England; J. Sed. Pet., vol. 30, pp. 193-208.
 1964: Primary Current Lineation in the Lower Old Red Sandstone (Devonian), Anglo-Welsh Basin, Sed., vol. 3, pp. 89-108.
- Anderson, R.Y., and Kirkland, D.W.
 1960: Origin, Varves and Cycles of Jurassic Todilto Formation; Bull. Amer. Assoc. Petrol Geol., vol. 44, pp. 37-52.
- Badgley, P.C.
 1959: Structural Methods for the Exploration Geologist; Harper & Bros., New York.
 1965: Structural and Tectonic Principles; Harper and Row, New York.
- Bailey, E.B.
 1936: Sedimentation in Relation to Tectonics; Bull. Geol. Soc. Amer., vol. 47, pp. 1713-1726.
- Baird, D.M.
 1950: Oil Shales of the Deer Lake Region; Report on Field, Dept. of Mines, Agriculture and Resources, Mineral Resources Branch, St. John's, Newfoundland, pp. 9-23.
 1951: Gypsum Deposits of Southwestern Newfoundland; Can. Inst. Min. Bull., pp. 155-164.
 1954: Compiler, Geological Map of Newfoundland; Geol. Surv., Newfoundland, St. John's.
 1959a: Sandy Lake (West half), Newfoundland; Geol. Surv., Canada, Map 47-1959.

Baird, D.M. (cont.)

1959b: Development of Gypsum Deposits in Southern Newfoundland; Bull. Can. Inst. Min. Met., vol. 52, pp. 495-502.

1966: Carboniferous Rocks of the Conche-Groais Island Area, Newfoundland; Can. Earth Sc., vol. 3, pp. 247-257.

Baird, D.M., and Cote, P.R.

1964: Lower Carboniferous Sedimentary Rocks in Southwestern Newfoundland and Their Relations to Similar Strata in Western Cape Breton Island; Bull. Can. Inst. Min. Met., pp. 509-519.

Baltz, E.H.

1967: Stratigraphy and Regional Tectonic Implications of Part of Upper Cretaceous and Tertiary Rocks East-Central San Juan Basin New Mexico; U.S. Geol. Surv., Prof. Paper 552, 101 pp.

Bell, W.A.

1929: Horton-Windsor District, Nova Scotia; Geol. Surv., Canada, Mem. 155.

1948: Early Carboniferous Strata of St. George's Bay Area, Newfoundland; Geol. Surv., Canada, Bull. 10, 40 pp.

1960: Mississippian Horton Group of Type Windsor-Horton District, Nova Scotia; Geol. Surv., Canada, Mem. 314.

1966: Illustrations of Canadian Fossils-Carboniferous Plants of Eastern Canada; Geol. Surv., Canada, Paper 66-11, 76 pp.

Belt, E.S.

1964: Revision of Nova Scotia Middle Carboniferous Units; Amer. J. Sci., vol. 262, pp. 653-673.

1965: Stratigraphy and Paleogeography of Mabou Group and Related Middle Carboniferous Facies, Nova Scotia, Canada; Bull. Geol. Soc. Amer., vol. 76, pp. 777-802.

1966: Carboniferous Continental Sedimentation, Atlantic Provinces, Canada; Abs., Geol. Soc. Amer., N.E. Sect., 1st Ann. Meeting, Phila., Pa., program notes, pp. 11-12.

Belt, E.S. (cont.)

1967a: Newfoundland Carboniferous Stratigraphy and Its Relation to the Maritimes and Ireland; Abs., Gander Conf., Gander, Newfoundland, pp. 1-2.

1968: "Post-Acadian Rifts and Related Facies, Eastern Canada"; in Studies in Appalachian Geology, Northern and Maritime; (Zen, White, and Hadley - eds.), Wiley, New York.

Belt, E.S., Freshney, E.C., and Read, W.A.

1967b: Sedimentology of Carboniferous Cementstone Facies, British Isles and Eastern Canada; J. Geol., vol. 75, pp. 711-721.

Betz, F. Jr.

1943: Late Paleozoic Faulting in Western Newfoundland; Bull. Geol. Soc. Amer., vol. 54, pp. 687-706.

1948: Geology and Mineral Deposits of Southern White Bay; Geol. Surv., Newfoundland, Bull. 24, 26 pp.

Bishop, D.G.

1968: The Geometric Relationships of Structural Features Associated with Major Strike-Slip Faults in New Zealand; New Zealand J. Geol. Geophys., vol. II, pp. 405-417.

Bradley, W.H.

1929: The Varves and Climate of the Green River Epoch; U.S. Geol. Surv., Prof. Paper 158-E, pp. 87-110.

1948: Limnology and the Eocene Lakes of the Rocky Mountain Region; Bull. Geol. Soc. Amer., vol. 59, pp. 635-648.

Brown, I.C.

1955: Late Faults in the Yellowknife Area; Proc. Geol. Assoc., Can., vol. 7, pp. 123-138.

Bruckner, W.D.

1966: "Stratigraphy and Structure of West-Central Newfoundland"; in Guidebook, Geology of Parts of Atlantic Provinces; Geol. Assoc. Can., and Min. Assoc. Can., Ann. Meetings, Halifax, pp. 137-151.

Bucher, W.H.

1944: The Stereographic Projection, a Handy Tool for the Practical Geologist; J. Geol., vol. 52, pp. 191-112.

- Cameron, H.L.
 1966: "The Cabot Fault Zone"; in Continental Drift, The Royal Society of Canada Special Publication No. 9; (Garland, G.D. - ed.), University of Toronto Press, Toronto.
- Campbell, J.D.
 1958: En Echelon Folding; Econ. Geol., vol. 53, pp. 448-472.
- Carr, P.A.
 1968: Stratigraphy and Spore Assemblages, Moncton Map-Area, New Brunswick; Geol. Surv., Canada, Paper 67-29, 47 pp.
- Chadwick, G.K.
 1924: The Stratigraphy of the Chemung Group in Western New York; N.Y. St. Mus. Bull. 251, pp. 149-157.
- Chinnery, M.A.
 1966: Secondary Faulting, I. Theoretical Aspects II. Geological Aspects; Can. J. Earth Sci., vol. 3, pp. 163-174, 175-190.
- Church, W.R.
 1967: The Metamorphic Rocks of the Burlington Peninsula and Adjoining Areas; Abs., Gander Conf., Gander, Newfoundland, pp. 7-8.
- Cloos, Hans
 1938: Primare Richtongen in Sedimenten der rheinischen Geosynkline; Geol. Rundschau, vol. 59, pp. 357-367.
- Coombs, D.S., Ellis, A.J., Fyfe, W.S., and Taylor, A.M.
 1958: The zeolite facies, with comments on the interpretation of hydrothermal syntheses; Geochim. et Cosmichim. acta, vol. 17, pp. 53-107.
- Cooper, G.A., and others
 1942: Correlation of the Devonian Sedimentary Formations of North America; Bull. Geol. Soc. Amer., vol. 53, pp. 1729-1794.
- Cotton, C.A.
 1957: Geomorphic Evidence and Major Structures Associated with Transcurrent Faults in New Zealand; Geographique Physique et Geologie Dynamique, vol. 1, pp. 16-30.
- Crowell, J.C.
 1952: Geology of the Lebec Quadrangle, California; Calif. Div. Mines, Spec. Rpt. 24, 23 pp.

- Crowell, J.C. (cont.)
 1955: Directional-Current Structures from the Prealpine Flysch, Switzerland; Bull. Geol. Soc. Amer., vol. 66, pp. 1351-1384.
- 1958: Sole Markings of Graded Graywacke Beds: A Discussion; J. Geol., vol. 66, p. 333.
- Cumming, L.M.
 1967: "Platform and Klippe Tectonics of Western Newfoundland: A Review"; in Appalachian tectonics, The Royal Society of Canada Special Publication No. 10; (Clark, T.H. - ed.), University of Toronto Press, Toronto.
- Cummins, W.A.
 1958: Some Sedimentary Structures from the Lower Keuper Sandstones; Liverpool Manchester Geol. J., vol. 2, pp. 37-43.
- Currie, J.B., Patnode, H.W., and Trump, R.P.
 1962: Development of Folds in Sedimentary Strata; Bull. Geol. Soc. Amer., vol. 73, pp. 655-674.
- Daley, B.
 1968: Sedimentary Structures From a Non-Marine Horizon in the Bembridgs Marls (Oligocene) of the Isle of Wight, Hampshire, England; J. Sed. Pet., vol. 38, pp. 114-127.
- Davis, R.A. Jr.
 1965: Underwater Study of Ripples, Southeastern Lake Michigan; J. Sed. Pet., vol. 35, pp. 857-866.
- Davis, W.M.
 1927: The Rifts of Southern California; Amer. J. Sci., 5th ser., vol. 13, pp. 57-72.
- Dawson, J.W.
 1859: On the Lower Coal-Measures, as Developed in British America; Quart. J., Geol. Soc., London, vol. 15, pp. 62-76.
- 1868: Acadian Geology, 2nd Ed.; Macmillan, New York.
- Deer, W.A., Howie, R.A., and Zussman, J.
 1966: An Introduction to the Rock Forming Minerals; J. Wiley and Sons Inc., New York.

- DeRaaf, J.F.M.
 1964: "The Occurrence of Flute Casts and Pseudomorphs After Salt Crystals in the Oligocene 'Gres a Ripple-Marks' of the Southern Pyrenees"; in Turbidites, Developments in Sedimentology, No. 3, (Bouma, A.H., and Brouwer, A. - eds.), Elsevier Pub. Co., Amsterdam.
- deSitter, L.U.
 1964: Structural Geology, 2nd E.; McGraw-Hill Book Co. Inc., New York.
- Dickson, K.A.
 1968: Clay Mineral Facies in Upper Turassic Rocks in Northeastern Texas and Adjacent Parts of Louisiana and Arkansas; Abs., Bull. Amer. Assoc. Petrol. Geol., vol. 52, pp. 524-525.
- Donohoe, H.V. Jr.
 1968: The Structure and Stratigraphy of the Halls Bay Head Area, Notre Dame Bay, Newfoundland; Final Report for British Newfoundland Exploration and Department of Geological Sciences, Lehigh University, 84 pp.
- Dott, R.H., and Howard, J.K.
 1962: Convolute Lamination in Non-Graded Sequences; J. Geol., vol. 70, pp. 114-121.
- Duff, P. McL.D., Hallam, A., and Walton, E.K.
 1967: "Cyclic Sedimentation."; in Developments in Sedimentology, No. 10, Elsevier Pub. Co., Amsterdam.
- Dunbar, C.O., and Rodgers, J.
 1957: Principles of Stratigraphy; J. Wiley and Sons, New York.
- Dzulynski, S.
 1965: New Data on Experimental Production of Sedimentary Structures; J. Sed. Pet., vol. 35, pp. 196-212.
- Dzulynski, S., and Radomski, A.
 1956: Clastic Dikes in the Carpathian Flysch; Ann. Soc. Geol. Pologne, vol. 26, pp. 225-264.
- Dzulynski, S. and Walton, E.K.
 1965: "Sedimentary Features of Flysch and Graywackes"; in Developments in Sedimentology, No. 7, Elsevier Pub. Co., Amsterdam.

- Eastler, T.E.
 1969: Sole Marks in Non-Turbidite Sequences Program; Abs., Geol. Soc. Amer., N.E. Sect., 4th Ann. Meeting, Albany, N.Y. program notes, pp. 15-16.
- Ermanovics, I.F., Edgar, A.D., and Currie K.L.
 1967: Evidence Bearing on the Origin of the Belleoram Stock, Southern Newfoundland; Can. J. Earth Sci., vol. 4, pp. 413-431.
- Fahrig, W.F.
 1961: The Geology of the Athabasca Formation; Geol. Surv., Canada, Bull. 68, 41 pp.
- Fletcher, H.
 1883: Geology of Northern Cape Breton; Ann. Rept., Geol. Surv., Canada.
- Folk, R.L.
 1961: Petrology of Sedimentary Rocks; The University of Texas, Hemphill's, Austin, Texas.
- Fyson, W.K.
 1966: Structures in the Lower Paleozoic Meguma Group, Nova Scotia; Bull. Geol. Soc. Amer., vol. 77, pp. 931-944.
 1967: Gravity Sliding and Cross Folding in Carboniferous Rocks, Nova Scotia; Amer. J. Sci., vol. 265, pp. 1-11.
- Geological Survey of Canada
 1956: Airborne Magnetic Survey, Map 272G, Corner Brook, Newfoundland; Ottawa, Ontario.
- Gillis, J.W.
 1965: "Port Aux Basques (11 0) Map Area"; in Report of Activities: Field, 1964; (Jenness, S.E. - ed.), Geol. Surv., Canada, paper 65-1.
 1966: "Great Northern Peninsula"; in Report of Activities, May to Oct., 1965; Jenness, S.E. - ed.), Geol. Surv., Canada, paper 66-1.
- Glaessner, M.F.
 1958: Sedimentary Flow Structures on Bedding Planes; J. Geol., vol. 66, pp. 1-7.
- Goldthwait, J.W.
 1924: Physiography of Nova Scotia; Geol. Surv., Canada, Mem. 140.

- Gradzinski, R., Radonski, A., and Unrug, R.
 1959: Preliminary Results of Sedimentological Investigations in Silesian Coal Basin; Bull. Acad. Sci. Polonaise, Series Chim Geol., et Geogr., vol. 7, pp. 433-440.
- Greiner, H.R.
 1962: Facies and Sedimentary Environments of the Albert Shale, New Brunswick; Bull. Amer. Assoc. Petrol. Geol., vol. 46, pp. 219-234.
- Grossman, I.
 1946: Preliminary Report on the Geology of the Deer Lake Area, Newfoundland; Geol. Surv., Newfoundland, Unpub. MS., p6.
- Gussow, W.C.
 1953: Carboniferous Stratigraphy and Structural Geology of New Brunswick, Canada; Bull. Amer. Assoc. Petrol. Geol., vol. 37, pp. 1713-1816.
- Haff, E. ten
 1959: Graded Beds in the Northern Apennines; Ph.D. Thesis, Rijks University of Groningen, 102 pp.
- Hamblin, W.K.
 1958: Cambrian Sandstones of Northern Michigan; Mich. Geol. Surv., Pub. 51, 149 pp.
- Hatch, H.B.
 1919: Deer Lake, Humber River and Grand Lake Shale Areas; MS on file, Dept. of Mines, Agriculture and Resources, Mineral Resources Branch, St. John's, Newfoundland.
- Hayes, A.O., and Johnson, H.
 1937: Preliminary Report on Gypsum Deposits of Bay St. George, Southwestern Newfoundland; Newfoundland Dept. Nat. Re., Geol. Sect., Bull. 3.
 1938: Geology and Mineral Deposits of the Bay St. George's Carboniferous Area; Geol. Surv., Newfoundland, Bull. 12, 62 pp.
- Heim, A.
 1908: Uber Rezente und Fossil Subaquatische Rutschungen und Deren Lithologische Bedeutung; Neues Jahrb. f. Min., etc., Jhg. 1908, Band II, pp. 136-57.
- Heine, R.W.
 1962: An Interpretation of the Tectonic Features of The Tararua and Rimutaka Ranges; Trans. R. Soc. N.Z., Geol. 1, pp. 201-204.

Helmstaedt, H.

- 1968: Structural Analysis of the Beaver Harbour Area, Charlotte Co., New Brunswick; Unpubl. Ph.D. Dissertation, University of New Brunswick, Fredericton, N.B., Canada.

Heyl, G.R.

- 1937a: The Geology of the Sops Arm Area, White Bay, Newfoundland; Newfoundland Dept. Nat. Res., Geol. Sect., Bull. 8, 42 pp.
- 1937b: Silurian Strata of White Bay, Newfoundland; Bull. Geol. Soc. Amer., vol. 48, pp. 1773-1784.
- 1966: Deformation of Northernmost Appalachians as Delineated in Areas in Notre Dame Bay, Newfoundland, Canada; Abs., Geol. Soc. Amer., N.E. Sect., 1st Ann. Meeting, Phila., Pa., program notes.
- 1967: The Tectonic Pattern of Major Structural Features in North Central Newfoundland; Abs., Gander Conf., Gander, Newfoundland, p. 13.

Hill, M.L., and Dibblee, T.W. Jr.

- 1953: San Andreas, Garlock and Big Pine Faults, California; Bull. Geol. Soc. Amer., vol. 64, pp. 443-458.

Hills, S.

- 1963: Elements of Structural Geology; John Wiley & Sons, Inc., New York.

Hofmann, H.J.

- 1966: Ordovician Paleocurrents Near Cincinnati, Ohio; J. Geol., vol. 74, pp. 868-891.

Hopkins, M.E., Murray, F.N., Simon, J.A., Smith, W.H. and Swann, D.H.

- 1966: "Field Trip Road Log, St. Louis, Missouri to Carbondale, Illinois"; in Field Guidebook, Series 7, Sedimentary Structures and Morphology of Late Paleozoic Sand Bodies in Southern Illinois; Semi-Cent. Conv., Amer. Assoc. Petrol. Geol., St. Louis, Mo., and Ill. St. Geol. Surv., Urbana, Ill.

Howie, R.D. and Cumming, L.M.

- 1963: Basement Features of the Canadian Appalachians; Geol. Surv., Canada, Bull. 89.

Howie, R.D. and Cumming, L.M.

- 1963: The World Rift System: Report of International Upper Mantle Symposium; Geol. Surv., Canada, Paper 66-14, 471 pp.

Irvine, T.N. (ed.)

- 1966: The World Rift System; Report of International Upper Mantle Symposium; Geol. Surv., Canada, Paper 66-14, 471 pp.

Johnson, H.

- 1939: The Geology of Western Newfoundland; Report on file, Dept. of Mines, Agriculture and Resources, Mineral Resources Branch, St. John's, Newfoundland, 127 pp.

Jukes, J.B.

- 1843: General Report of the Geological Survey of Newfoundland; John Murray, London.

Kalliokoski, J.

- 1953: Springdale, Newfoundland; Geol. Surv., Canada, Paper 53-5.

- 1955: Gull Pond, Newfoundland; Geol. Surv., Canada, Paper 54-4.

Kaplan, I.R., and Rittenberg, S.C.

- 1963: "Basin Sedimentation and Diagenesis"; in The Sea, vol. 3; (Hill, M.N. - ed.), Wiley, New York

Kay, M.

- 1966: Comparison of the Lower Paleozoic Volcanic and Non-Volcanic Geosynclinal Belts in Nevada and Newfoundland; Bull. Canadian Petrol. Geol., vol. 4, pp. 579-599.

- 1967: Stratigraphy and Structure of Northeastern Newfoundland Bearing on Drift in North Atlantic; Bull. Amer. Assoc. Petrol. Geol., vol. 51, pp. 579-600.

Kay, M., and Colbert, E.H.

- 1965: Stratigraphy and Life History; John Wiley & Sons, New York.

King, P.B.

- 1948: Geology of the Southern Guadalupe Mountains, Texas; U.S. Geol. Surv., Prof. Paper 215, 183 pp.

Kingma, J.T.

- 1958: Possible Origin of Piercement Structure, Local Unconformities, and Secondary Basins in the Eastern Geosyncline, New Zealand; New Zealand J. Geol. Geophys., vol. 1, pp. 269-274.

- Kelley, D.G.
1967: "Some Aspects of Carboniferous Stratigraphy and Depositional History in the Atlantic Provinces"; in Collected Papers on Geology of the Atlantic Region; Geol. Assoc. Canada, Spec. Paper No. 4, 292 p.
- Kelley, D.G., and MacKasey, W.O.
1965: Basal Mississippian Volcanic Rocks in Cape Breton Island, Nova Scotia; Geol. Surv., Canada, Paper 64-34.
- Klein, G. deV.
1965: Observation of Modern Flute Mark Formation in a Quarry Delta; Geol. Soc. Amer., Ann. Meeting, Kansas City, Mo., program notes, p. 88.
- Krumbein, W.C., and Sloss, L.L.
1963: Stratigraphy and Sedimentation, 2nd Ed.; Freeman and Company, San Francisco.
- Krynine, P.D.
1940: "Petrology and Genesis of the Third Bradford Sand"; in the Penn State College Bulletin; Min. Indust. Exper. Sta., Bull. 29, 134 pp.
1948: The Megascopic Study and Field Classification of the Sedimentary Rocks; J. Geol., vol. 56, pp. 130-165.
- Kuenen, P.H.
1957: Sole Markings of Graded Graywacke Beds; J. Geol., vol. 65, pp. 231-258.
- Landell-Mills, T.
1922: The Carboniferous Rocks of the Deer Lake District of Newfoundland; Geol. Soc. London, Abs. Proc. No. 1083, pp. 53-54.
- Lensen, G.J.
1958: A Method of Graben and Horst Formation; J. Geol., vol. 66, pp. 579-587.
1959: Secondary Faulting and Transcurrent Splay Faulting at Transcurrent Fault Intersections; New Zealand J. Geol. Geophys., vol. 2, pp. 729-734.
- Levorsen, A.I.
1958: Geology of Petroleum; Freeman and Co., San Francisco.

- Lilly, H.D.
 1967: "Some Notes on Stratigraphy and Structural Style in Central West Newfoundland"; in Collected Papers on Geology of the Atlantic Region; Geol. Assoc. Canada, Spec. Paper No. 4, 292 pp.
- Lock, B.
 1969: Personal communication related to Ph.D. dissertation on the Lower Paleozoic Rocks of the Sops Arm Area, Newfoundland; Cambridge University, Cambridge, England.
- Lombard, A.
 1963: Laminites: A Structure of Flysch-Type Sediments; J. Sed. Pet., vol. 33, pp. 14-22.
- Lowdon, J.A.
 1960: Age Determinations by the Geological Survey of Canada, Rept. 1, Isotopic Ages; Geol. Surv., Canada, Paper 60-17, 51 pp.
 1961: Age Determinations by the Geological Survey of Canada, Rept.-2, Isotopic Ages; Geol. Surv., Canada, Paper 61-17, 127 pp.
 1962: Age Determinations and Geological Studies; Geol. Surv., Canada, Paper 62-17.
- Lowdon, J.A., Stockwell, C.H., Tipper, H.W., and Wanless, R.K.
 1963: Age Determinations and Geological Studies (Including Isotopic Ages - Rept. 3); Geol. Surv., Canada, Paper 62-17, 140 pp.
- Mamet, B.
 1967: Foraminifera From the Marine Lower Carboniferous in the Maritime Provinces; Geol. Surv., Canada, Paper 68-1, p. 107.
- Mangin, J. Ph.
 1962: Traces de Pattes D'Oiseaux et Flut-Casts Associes Dans un "Facies Flysch" du Tertiaire Pyreneen; Sed., vol. 1, pp. 163-166.
- McIver, N.L.
 1961: Upper Devonian Marine Sedimentation in the Central Appalachians; Unpublished Ph.D. Thesis, The Johns Hopkins University, 347 pp.
- McKee, E.D., and Weir, G.W.
 1953: Terminology for Stratification and Cross-Stratification in Sedimentary Rocks; Bull. Geol. Soc. Amer., vol. 64, pp. 381-389.

- Menard, H.W.
1952: Deep Ripple Marks in the Sea; J. Sed. Pet., vol. 22, pp. 3-10.
- Moody, J.D., and Hill, M.J.
1956: Wrench Fault Tectonics; Bull. Geol. Soc. Amer., vol. 67, pp. 1207-1248.
- Moore, E.S.
1914: Mud Cracks open under water; Amer. J. Sci., 4th ser., vol. 38, pp. 101-102.
- Morris, W.J., and Fan, P.F.
1962: Abrasion Effects of Arkose Mixtures; J. Sed. Pet., vol. 32, pp. 226-230.
- Muir, R.O. and Walton, E.K.
1957: The East Kirkton Limestone; Trans. Geol. Soc., Glasgow, vol. 22, pp. 157-168.
- Murray, A., and Howley, J.P.
1881: Geological Survey of Newfoundland for 1864-1880; Edward Stanford, London.
1918: Reports of the Geological Survey of Newfoundland for 1881-1909; Edward Stanford, London.
- National Research Council, Interdivisional Committee on Density Currents, Subcommittee on Lake Mead
1949: Lake Mead Density Current Investigations, 1937-1940, vols. 1, 2; 1941-1946, vol. 3; U.S. Bur. Reclam., Wash.
- National Research Council
1948: Rock Color Chart; Geol. Soc. Amer., New York
- Neale, E.R.W.
1959: Relationship of the Baie Verte Group to Gneissic Groups of Burlington Peninsula, Newfoundland (Abs.); Bull. Geol. Soc. Amer., vol. 70, pp. 1650-1651.
1963: Dingwall, Nova Scotia; Geol. Surv., Canada, Map 1124A, with marginal notes.
- Neale, E.R.W. and Kennedy, M.J.
1967: "Relationship of the Fleur DeLys Group to Younger Groups of the Burlington Peninsula, Newfoundland"; in Collected Papers on Geology of the Atlantic Region; Geol. Assoc. Canada, Spec. Paper No. 4.

- Neale, E.R.W., and Nash, W.A.
 1963: Sandy Lake (Eastern half) Map-Area, Newfoundland;
Geol. Surv., Canada, Paper 62-28, 40 pp.
- Neale, E.R.W., and Williams, H.
 1967: Collected Papers on Geology of the Atlantic
 Region, High Lilly Memorial Volume; Geol. Assoc.
 Canada, Spec. Paper No. 4.
- Nipkow, H.F.
 1928: Uber Das Verhalten der Skelette Planktischer
 Kieselalgen in Geschichteten Tiefenschlamm des
 Zurich und Baldegersees; Rev. Hydrobiol., vol. 4,
 pp. 71-120.
- Oomkens, E.
 1966: Environmental Significance of Sand Dikes; Sed.,
 vol. 7, pp. 145-148.
- Parry, W.T., and Reeves, C.C. Jr.
 1968: Clay Mineralogy of Pluvial Lake Sediments, South-
 ern High Plains, Texas; J. Sed. Pet., vol. 38,
 pp. 516-529.
- Pelletier, B.E.
 1958: Pocono Paleocurrents in Pennsylvania and Maryland;
Bull. Geol. Soc. Amer., vol 69, pp. 1033-1064.
- Pettijohn, F.J.
 1957: Sedimentary Rocks, 2nd Ed.; Harper & Row, New York.
- Pettijohn F.J., Potter, P.E., and Siever, R.
 1965: Geology of Sand & Sandstone - Syllabus for Confer-
 ence; Dept. of Geology, Indiana University,
 Bloomington, Ind.
- Phair, G.
 1948: Geology of the Southwestern Part of the Long
 Range, Newfoundland; Ph.D. Thesis, Princeton
 University, N.J.
- Picard, D.M.
 1967: Paleocurrents & Shoreline Orientations in Green
 River Formation (Eocene), Raven Ridge & Red Wash
 Areas, Northeastern Uinta Basin, Utah; Bull. Amer.
 Assoc. Petrol. Geol., vol. 51, pp. 383-392.
- Picard, D.M. and High, L.R. Jr.
 1968: Shallow Marine Currents on the Early Triassic
 Wyoming Shelf; J. Sed. Pet., vol. 38, pp. 411-423.

- Poole, W.H.
 1967: "Tectonic Evolution of Appalachian Region of Canada"; in Collected Papers on Geology of the Atlantic Region; (Neale, E.R.W., and Williams, H. - eds.), Geol. Assoc., Canada, Spec. Paper No. 4.
- Poole, W.H., Kelley, D.G., and Neale, E.R.W.
 1964: "Age and Correlation Problems in the Appalachian Region of Canada"; in Geochronology in Canada; (Osborne, F.F. - ed.), R. Soc. Canada, Spec. Publ. No. 8, University of Toronto Press, Toronto.
- Popper, E.
 1966: Facts and Theories About Strike-Slip Faults; Unpub. Term Report, Lehigh University, Bethlehem, Pa., 29 pp.
- Popper, G.
 1965: Stratigraphic and Tectonic History of the Memra-cook Terrestrial Redbeds of New Brunswick, Canada; Unpub. M.S. Thesis, Univ. of Mass., Amherst, Mass., 129 pp.
 1968: Tectonic Framework of Carboniferous Deformation in West-Central Newfoundland; Abs., Geol. Soc. Amer., N.E. Sect., 3rd Ann. Meeting, Wash., D.C., program notes. p. 47.
- Potter, P.E., and Mast, R.F.
 1963: Sedimentary Structures, Shape Fabrics and Permeability, Part I; J. Geol., vol 71, pp. 441-471.
- Potter, P.E., and Pettijohn, F.J.
 1963: Paleocurrents and Basin Analysis; Springer-Verlag, Berlin, Göttingen, Heidelberg.
- Prentice, J.E.
 1962: Some Sedimentary Structures From a Weald Clay Sandstone at Warnham Brickworks, Horsham, Sussex; Proc. Geol. Assoc., London, vol. 73, pp. 171-186.
- Pryor, W.A., and Barr, J.L.
 1968: Sole Marks in Siltstone of Nonturbidite Origin; Abs., Bull. Amer. Assoc. Petrol. Geol., vol. 52, p. 546.
- Rayner, D.H.
 1963: The Achanarras Limestone of the Middle Old Red Sandstone, Caithness, Scotland; Proc. Yorkshire Geol. Soc., vol. 34, pp. 117-138.

- Reed, J.J.
 1964: Mylonites, Cataclasites, and Associated Rocks Along the Alpine Fault, South Island, New Zealand; New Zealand J. Geol. Geophys., vol. 7, pp. 645-684.
- Reed, R.D., and Holister, J.S.
 1936: Structural Evolution of Southern California; Amer. Assoc. Petrol. Geol., Tulsa, Oklahoma.
- Reimnitz, E., and Marshall, N.F.
 1965: Effects of the Alaska Earthquake and Tsunami on Recent Deltaic Sediments; J. Geophys. Res., vol. 70, pp. 2363-2376.
- Reineck, H.E.
 1967: "Layered Sediments of Tidal Flats, Beaches and Shelf Bottoms of the North Sea"; in Estuaries; Amer. Assoc. Adv. Sci., Pub. No. 83, pp. 191-205.
- Riedel, W.
 1929: Zur Mechanik Geologischer Brucherscheinungen; Central bl. Min., etc., Ser. B, pp. 354-368.
- Riley, G.C.
 1957: Red Indian Lake (West half), Newfoundland; Geol. Surv., Canada, Prelim. Ser., Map 8-1967.
 1962: Stephenville Map-Area, Newfoundland; Geol. Surv., Canada, Mem. 323.
- Rodgers, J.
 1965: Long Point and Clam Bank Formations, Western Newfoundland; Proc. Geol. Assoc. Can., vol. 16, pp. 83-94.
 1967: Chronology of Tectonic Movements in the Appalachian Region of Eastern North America; Amer. J. Sci., vol 265, pp. 408-427.
- Rodgers, J, and Neale, E.R.W.
 1963: Possible "Taconic" Klippen in Western Newfoundland; Amer. J. Sci., vol. 261, pp. 713-730.
- Rubey, W.W.
 1930: Lithologic Studies of Fine-Grained Upper Cretaceous Sedimentary Rocks of the Black Hills Region; U.S. Geol. Surv., Prof. Paper 165A.
- Rutland, R.W.R.
 1968: A Tectonic Study of Part of the Phillipine Fault Zone; Quart. Jl, Geol. Soc., London, vol. 123, pp. 293-325.

- Schiller, E.
1961: Guysborough, Nova Scotia; Geol. Surv., Canada, Map 27-1961.
- Schuchert, D., and Dunbar, C.O.
1934: Stratigraphy of Western Newfoundland; Geol. Soc. Amer., Mem. 1.
- Seibold, E.
1955: Rezente Jahresschichtung in Der Adrea; Neues Jahrb. Geol. Palaeontol., pp. 11-13.
- Selley, R.C.
1967: Paleocurrents and Sediment Transport in Nearshore Sediments of the Sirte Basin, Libya; J. Geol., vol. 75, pp. 215-223.
1968: A Classification of Paleocurrent Models; J. Geol., vol. 76, pp. 99-110.
- Sen, D.P.
1967: Turbidite Structures From Barakar Rocks of Ramgarh Coal-Field, Bihar, India; J. Sed. Pet., vol. 37, pp. 699-702.
- Sharp, R.P.
1954: "Physiographic Features of Faulting in Southern California"; in Geology of Southern California; Calif. Div. Mines, Bull. 170, pp. 21-28.
- Smith, J.G.
1968: Tectonics of the Fitzroy Wrench Trough, Western Australia; Amer. J. Sci., vol. 266, pp. 766-776.
- Snelgrove, A.K.
1928: The Geology of the Central Mineral Belt of Newfoundland; Bull. Can. Inst. Min. Met., vol. 21, pp. 1057-1127.
- St. Amand, P.
1957: Geological and Geophysical Synthesis of the Tectonics of Portions of British Columbia, The Yukon Territory, and Alaska; Bull. Geol. Soc. Amer., vol. 68, pp. 1343-1370.
- Stevens, R.K.
1967: The Thurst Sheets of Western Newfoundland; Abs., Gander Conf., Gander, Newfoundland, p. 36.
- Stevenson, I.M.
1964: Chedabucto Bay, Nova Scotia; Geol. Surv., Canada, Map 1156A, with marginal notes.

Stokes, W.L.

- 1947: Primary Lineation in Fluvial Sandstones, a Criterion of Current Direction; J. Geol., vol. 55, pp. 52-54.

Sullwold, W.H. Jr.

- 1960: Tarzana Fan, Deep Submarine Fan of Late Miocene Age of Los Angeles County, California; Bull. Amer. Assoc. Petrol. Geol., vol. 44, pp. 443-457.

Tanner, W.F.

- 1955: Paleogeographic Reconstructions From Cross-Bedding Studies; Bull. Amer. Assoc. Petrol. Geol., vol. 39, pp. 2471-2483.
- 1959: The Importance of Modes in Cross-Bedding Data; J. Sed. Pet., vol. 29, pp. 221-226.
- 1962: Surface Structural Patterns Obtained From Strike-Slip Models; J. Geol., vol. 70, pp. 101-107.

Teichmuller, R.

- 1955: Sedimentation und Setzung im Ruhrkarbon; Neues Jahrb. Geol. Paleontol., Monatshefte, pp. 146-168.

Tuke, M.F., and Baird, D.M.

- 1967: "Klippen in Northern Newfoundland"; in Appalachian Tectonics; (Clark, T.H. - ed.), R. Soc. Canada, Spec. Publ. No. 10, University of Toronto Press, Toronto.

Turner, F.J.

- 1951: Observations on Twinning of Plagioclase in Metamorphic Rocks; Amer. Mineral., vol. 36, pp. 581-589.

Twenhofel, W.H.

- 1923: Development of Shrinkage Cracks in Sediments Without Exposure to the Atmosphere; Abs., Bull. Geol. Soc. Amer., vol. 34, p. 64.
- 1926: Treatise on Sedimentation; The Williams & Wilkins Co., Baltimore.

Twenhofel, W.H., and MacClintock, P.

- 1940: Surface of Newfoundland; Bull. Geol. Soc. Amer., vol. 51, pp. 1665-1728.

Utting, J.

- 1965: Geology of the Codroy Valley, Southwestern Newfoundland, Including Results of a Preliminary Palynological investigation; M.Sc. Thesis, Memorial University of Newfoundland, 89 pp.

van de Poil, H.W.

- 1967: Carboniferous Volcanic and Sedimentary Rocks of the Mount Pleasant Area, New Brunswick; Report Investigation No. 3, Min. Res. Branch, New Brunswick.

Van Houten, F.B.

- 1962: Cyclic Sedimentation and the Origin of Analcime-Rich Upper Triassic Lockatong Formation, West-Central New Jersey and Adjacent Pennsylvania; Amer. J. Sci., vol. 260, pp. 561-576.
- 1965: Composition of Triassic Lockatong and Associated Formations of Newark Group, Central New Jersey and Adjacent Pennsylvania Amer. J. Sci., vol. 263, pp. 825-863.

Vause, J.E.

- 1959: Underwater Geology and Analysis of Recent Sediments Off the Northwest Florida Coast; J. Sed. Pet., vol. 29, pp. 555-563.

Walker, C.T.

- 1968: Evaluation of Boron as a Paleosalinity Indicator and its Application to Offshore Prospects; Bull. Amer. Assoc. Petrol. Geol., vol. 52, pp. 751-766.

Wallace, R.E.

- 1949: Structure of a Portion of the San Andreas Rift in Southern California; Bull. Geol. Soc. Amer., vol. 60, pp. 781-806.

Walthier, T.N.

- 1949: Geology and Mineral Deposits of the Area Between Corner Brook and Stephenville, Western Newfoundland, Part I; Geology and Mineral Deposits of the Area Between Lewis Hills and Bay St. George, Western Newfoundland, Part II; Geol. Surv., Newfoundland, Bull. 35, 87 pp.

Webb, G. W.

- 1963: Occurrence and Exploration Significance of Strike-Slip Faults in Southern New Brunswick, Canada; Bull. Amer. Assoc. Petrol Geol., vol. 47, pp. 1904-1927.
- 1967: Paleozoic Wrench Faults in the Canadian Appalachians; Abs., Gander Conf., Gander, Newfoundland, pp. 29-30.

Webb, G.W. (cont.)

- 1968: Palinspastic Restoration Suggesting Late Paleozoic North Atlantic Rifting; Sci., vol. 159, pp. 875-878.

Werner, H.J.

- 1955: The Geology of the Humber Valley, Newfoundland; Report for the Newkirk Mining Corp., Toronto, Canada. Report on file, Dept. of Mines, Agriculture and Resources, Mineral Resources Branch, St. John's Newfoundland, 116 pp.

Williams, H.

- 1964: The Appalachians in Northeastern Newfoundland-- A Two-Sided Symmetrical System; Amer. J. Sci., vol. 262, pp. 1137-1158.

- 1967: Compiler, Geology, Island of Newfoundland; Map No. 1231A; Geol. Surv., Canada, Ottawa.

Willis, B.

- 1938: San Andreas Rift, California; J. Geol., vol. 6, pp. 793-827.

Wilson, J.T.

- 1962: Cabot Fault, An Appalachian Equivalent of the San Andreas and Great Glen Faults and Some Implications for Continental Displacement; Nature, vol. 195, p. 135.

Wright, W.J.

- 1922: Geology of the Moncton Map-Area, New Brunswick, Canada; Geol. Surv., Canada, Mem. 129.

Wulf, G.R.

- 1963: Bars, Spits, and Ripple Marks in a Michigan Lake; Bull. Amer. Assoc. Petrol. Geol., vol. 47, pp. 691-695.

Zen, E-An, White, W.S., and Hadley, J.B.

- 1968: Studies in Appalachian Geology, Northern and Maritime; Wiley, New York.

APPENDIX

1. The orientation of each feature was corrected for bedding inclination by rotation about the tectonic strike (Bucher, 1944; Potter and Pettijohn, 1963).

2. Either the azimuths of individual readings, or the vector mean direction for grouped similar features at any one outcrop, were plotted on base maps at their proper locations. A preliminary overall view of dispersal patterns was thus provided.

3. Primary features of any one type were grouped together within subregions, the limits of which are based upon stratigraphic considerations.

4. Vector mean azimuths and standard deviations from the means were calculated for groupings of each type of feature (within subregions), using a CDC 6400 computer and a program written by Dr. J.M. Parks. Calculations were based on individual readings, not grouped data.

5. For any one subregion, the vector mean and all individual readings of a single type of directional feature were plotted on the periphery of a polar co-ordinate graph. This showed the general distribution of readings and tended to disclose polymodality, if present.

6. Since current orientation may change according to location within a basin, each grouping (rose diagram) of directional data is thought of and treated as belonging to a new population of normally distributed directional features.

The assumption of normality seems warranted at least for unimodal data (Potter and Pettijohn, 1963, p. 226).

The sector size (e.g., 15° , 30° , 45°) for each rose diagram was then chosen such that, (a) it be evenly divisible into 360° , (b) the limits of the modal class encompass a large proportion or distinct clustering of the readings, and (c) if possible, the vector mean fall near the center of the modal sector. In this way natural groupings are enclosed within a single sector rather than possibly being split through use of a pre-set arbitrary sector size (e.g., with point of origin at zero). Thus, the size of the modal sector will vary among the individual diagrams (though not within a diagram), for it is based upon the distribution of paleocurrent directions for that diagram and not on some predetermined interval which may or may not be appropriate for subsequent sets of readings.

Furthermore, varying the sector size among the diagrams also conveys more accurately the degree of dispersion of the data than does the pre-set method. A number of readings dispersed throughout a quadrant is not shown in the same fashion as an identical number of readings which are tightly clustered within a portion of a quadrant.

7. A correlary to varying the sector size is varying the point of origin. Since current dispersal systems may be oriented in any direction of the compass, there is no valid reason or special significance to choosing the sectors' point

of origin at 0° azimuth (due north) rather than 10° , or $13\frac{1}{2}^\circ$, etc. (Krumbein and Sloss, 1963, p. 115 and Tanner, 1955, p. 2472, establish the class interval point of origin at other than 0° .) A poor choice of point of origin, one splitting a modal class, will give the impression that directional readings are considerably more dispersed than they actually are.

8. The radial scale of the rose diagrams has been varied within limits. That is, the diameter of one based on three to ten readings is 3.9 cm.; 11 to 31 readings is 4.7 cm; 32 to 51 readings is 5.4 cm., more than 51 readings is 6.2 cm. Allen (1960, p. 199) shows one example using this technique.

(a) The significance of few, closely spaced directional readings is exaggerated and undue visual emphasis is given these readings when they are presented in circular graphical form. That is, the "pie-shaped wedge" would be enormous when compared with that of rose diagrams containing greater numbers of readings which, as may be expected, show greater variations.

(b) The size of the rose diagram for few closely spaced readings will depend upon the size and point of origin of the class sector used.

(c) When rose diagrams with large numbers of somewhat dispersed readings are reduced to map size those class sectors containing small numbers of readings virtually disappear.

In order that comparisons among diagrams may still be made, the percentage of total readings in the modal class has been indicated for that sector on the rose diagram. In this way current roses can be returned to the original size by simple comparison with a unit circle.

9. The total number of readings upon which any current rose is based is a most important feature of that diagram. In this thesis the number of readings is indicated in the small central circle of the current rose.

10. The vector mean direction for grouped data is shown as a line (for sense of current movement features) or an arrow (for direction of movement features) extending outward from the margin of the diagram. One standard deviation from the mean is indicated by dashed lines.

11. A rose by any other name is a confusing graph.

VITA

George H. P. Popper was born in the British channel-port of Hythe on November 29, 1939. His youth was spent in uptown New York City where he was first introduced to Geology in the form of the Manhattan Schist and Inwood Marble. He was awarded a New York State Regents Scholarship while attending Stuyvesant High School. His Bachelor of Science Degree in Geology was granted by The City College in 1962. As a graduate teaching assistant, he spent two years at The University of Massachusetts. He received the Master of Science Degree in Geology in 1965. At Lehigh University he held the Chester W. Kingsley Memorial Fellowship for three years.

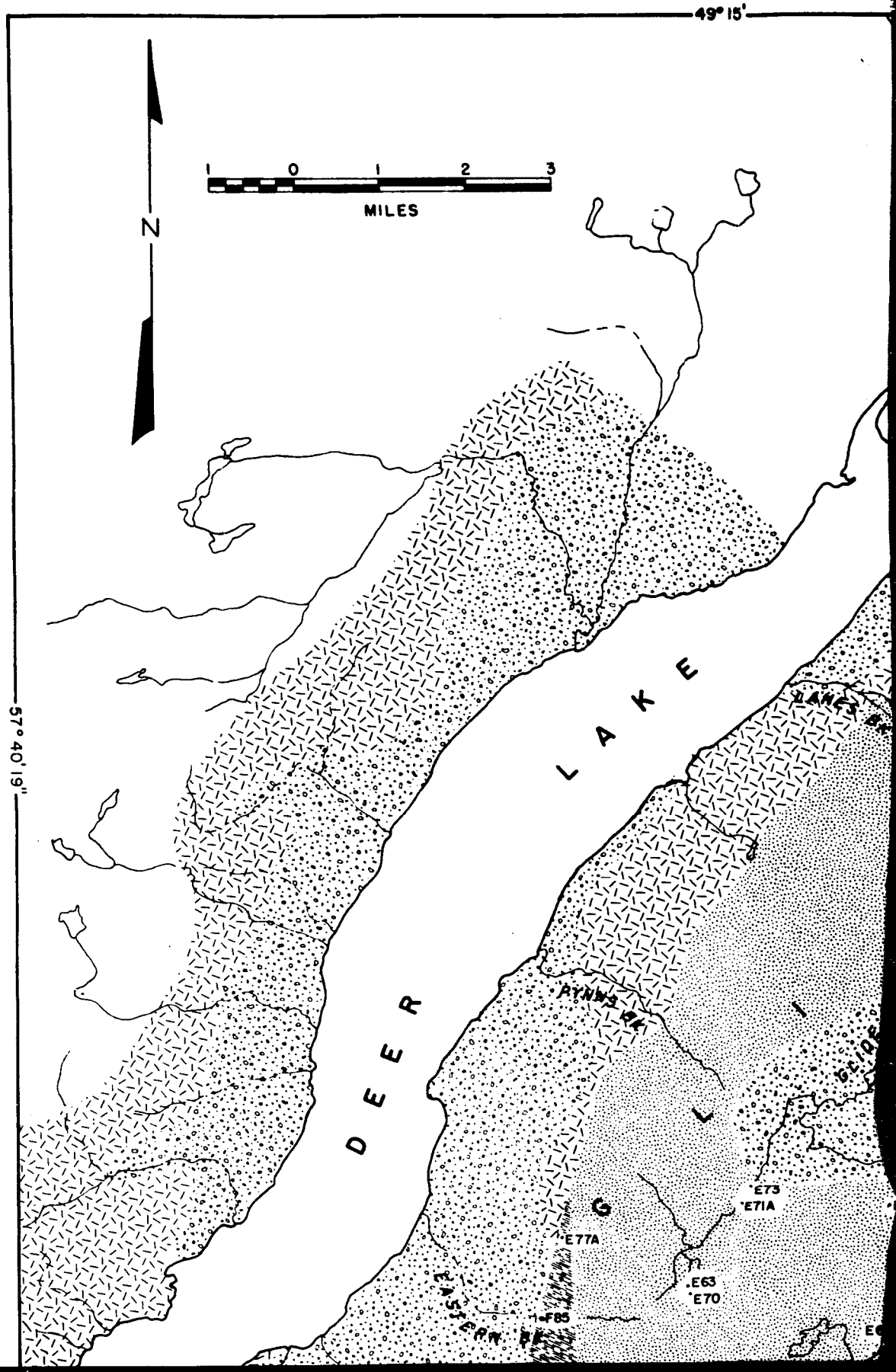
During the fall of 1968 he was an instructor in Geology at Dickinson College, Carlisle, Pennsylvania. He was appointed Assistant Professor of Geology at Eastern Connecticut State College, Willimantic, Connecticut in the fall of 1969.

He is a member of Sigma Xi. He was president of a local chapter of the Honorary Society for the Earth Sciences, Sigma Gamma Epsilon.

His bibliography is: 1) Stratigraphic and Tectonic History of the Memramcook Terrestrial Redbeds of New Brunswick, Canada; Unpublished M.S. Thesis, Univ. of Mass. (1965), and

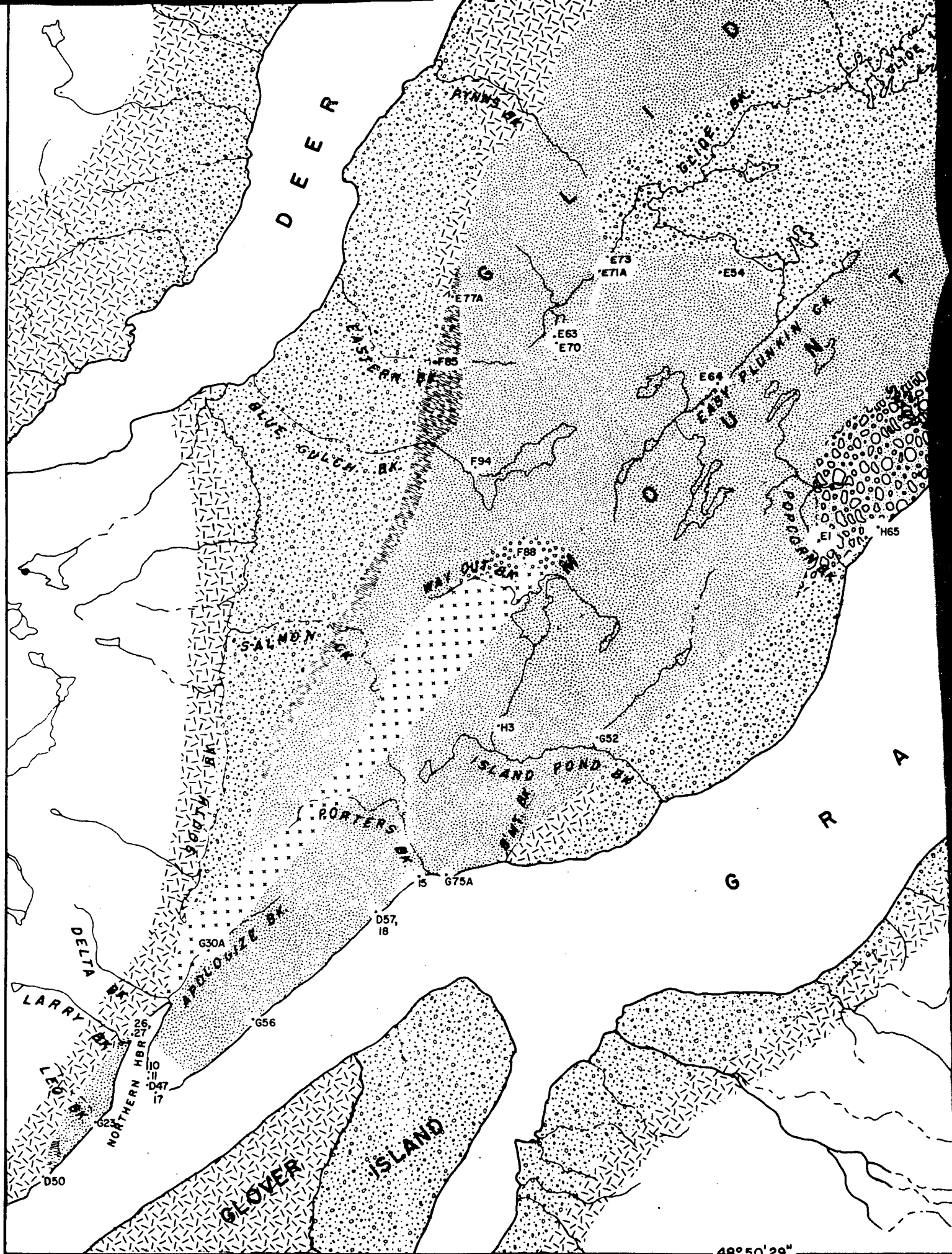
2) Paper presented at Northeast Section GSA Meetings, Washington, D.C. (Spring, 1968): "Tectonic Framework of Carboniferous Deformation in West-Central Newfoundland" (Abstract in Program 1968 Ann. Meeting, p. 47).

Plate 1 Figure and Sample Locations









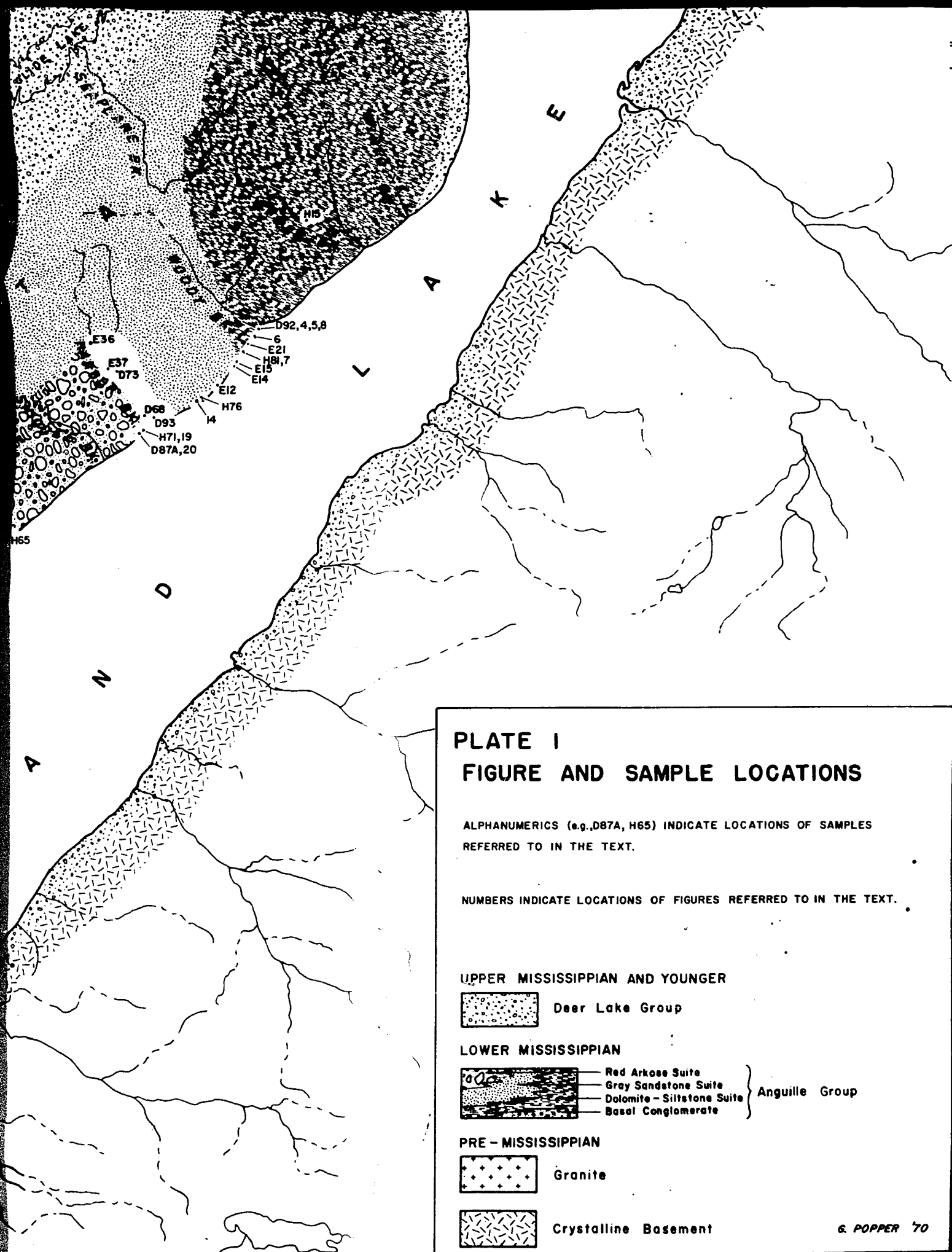


PLATE I
FIGURE AND SAMPLE LOCATIONS

ALPHANUMERICS (e.g.,D87A, H65) INDICATE LOCATIONS OF SAMPLES REFERRED TO IN THE TEXT.

NUMBERS INDICATE LOCATIONS OF FIGURES REFERRED TO IN THE TEXT.

UPPER MISSISSIPPIAN AND YOUNGER

 Deer Lake Group

LOWER MISSISSIPPIAN

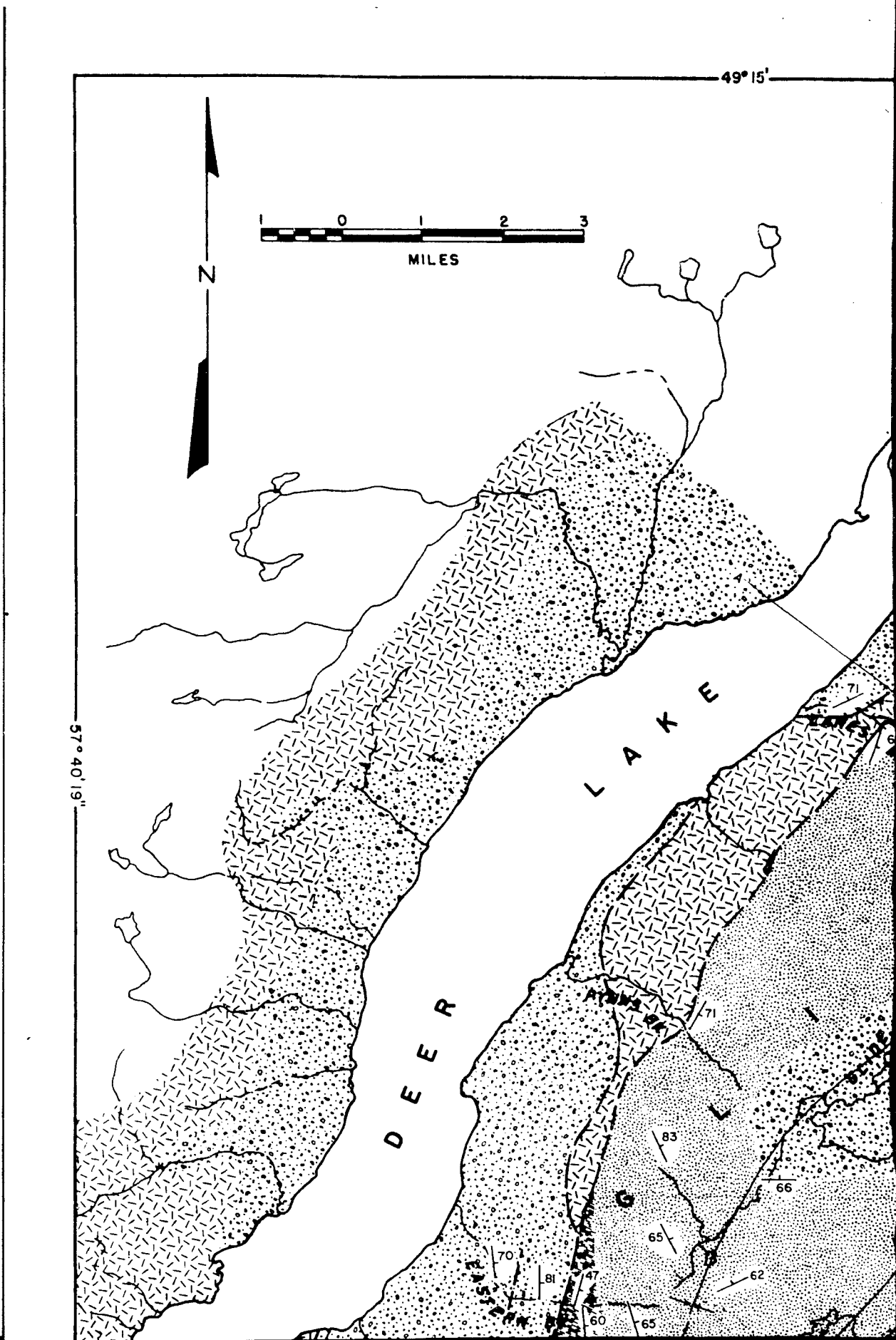
 Red Arkose Suite
 Gray Sandstone Suite
 Dolomite - Siltstone Suite
 Basal Conglomerate } Anguille Group

PRE - MISSISSIPPIAN

 Granite

 Crystalline Basement

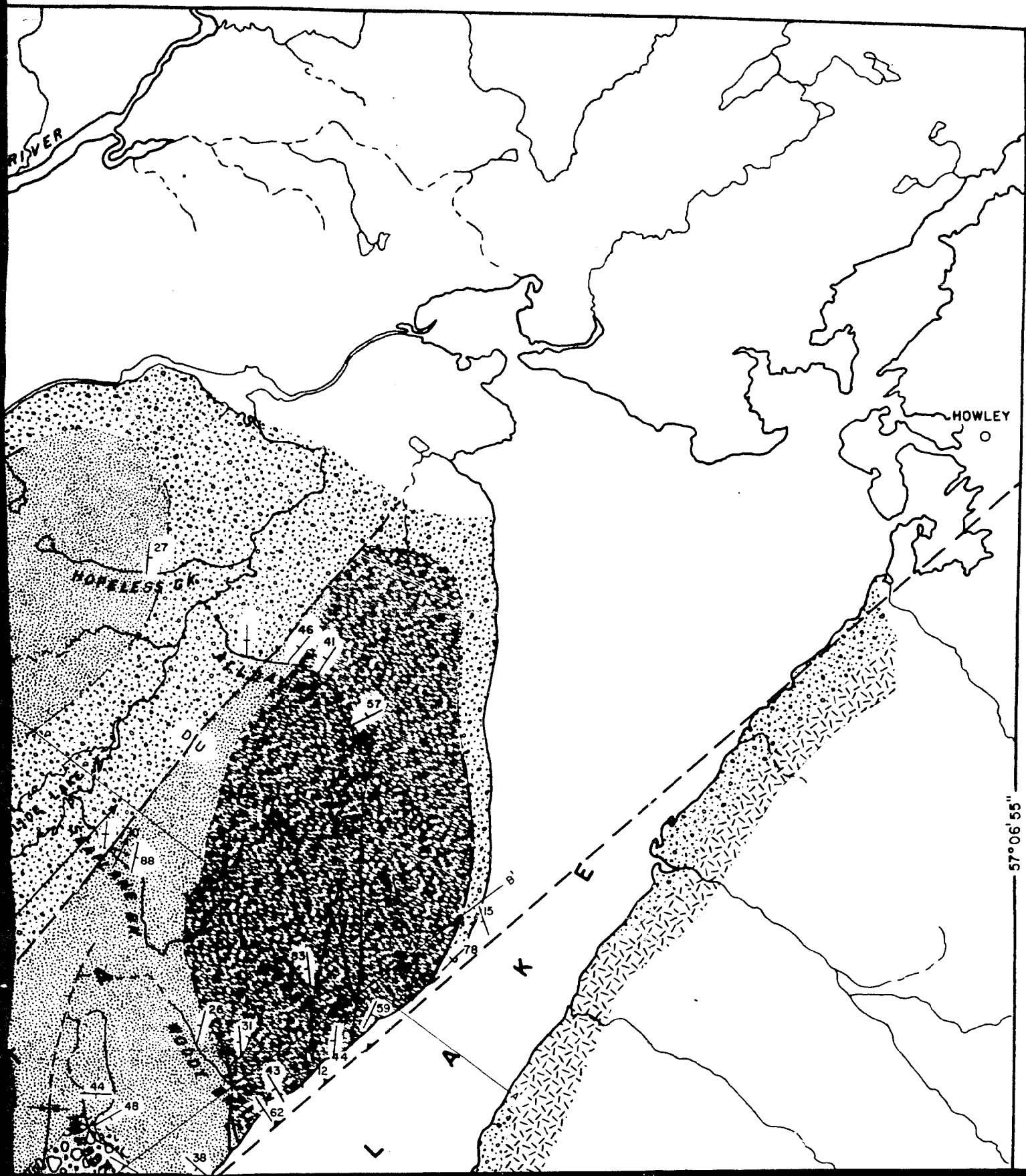
Plate 2 Geologic Map of the Glide Mountains,
West-Central Newfoundland

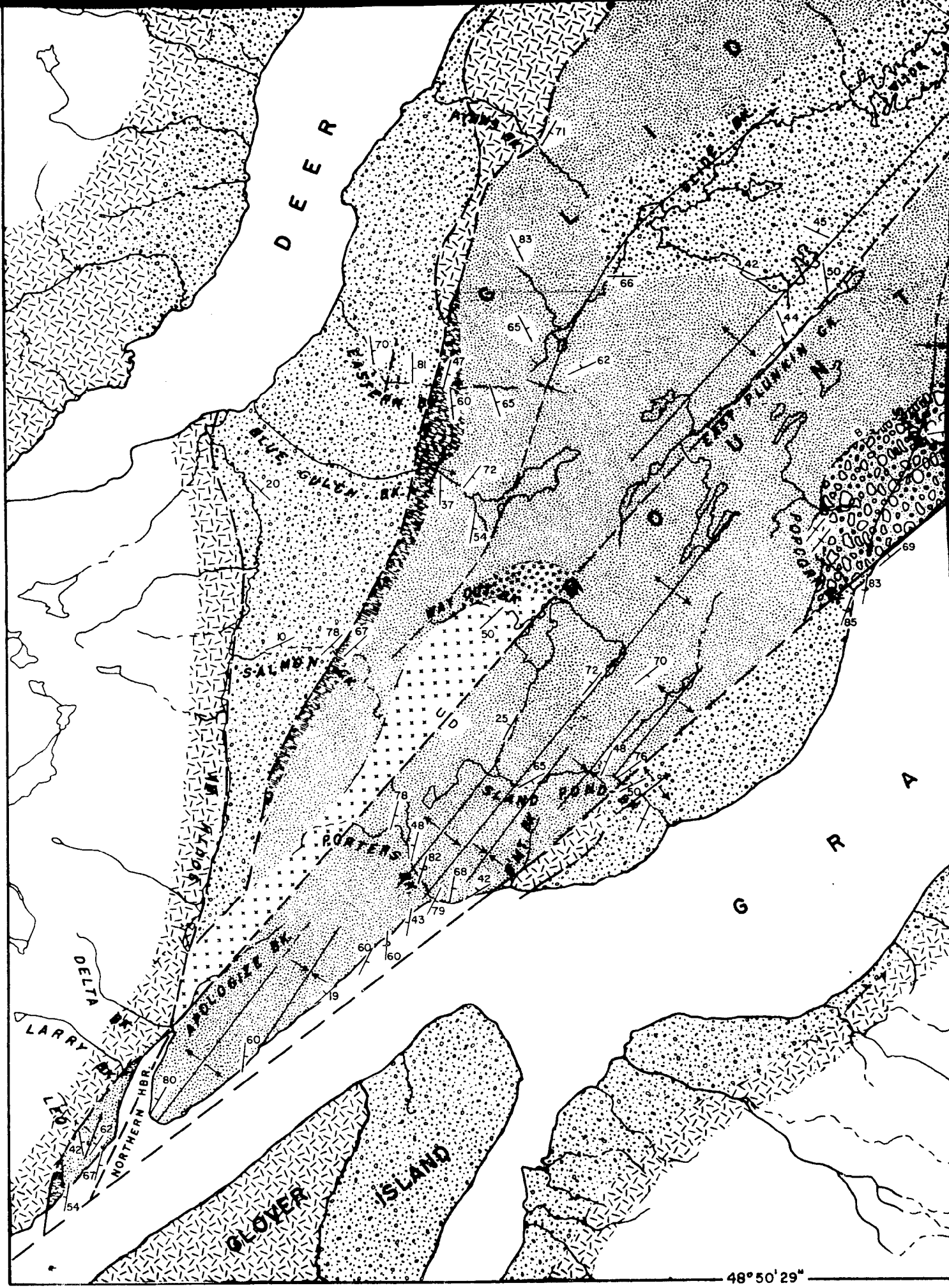


S,

49° 15'







48° 50' 29"

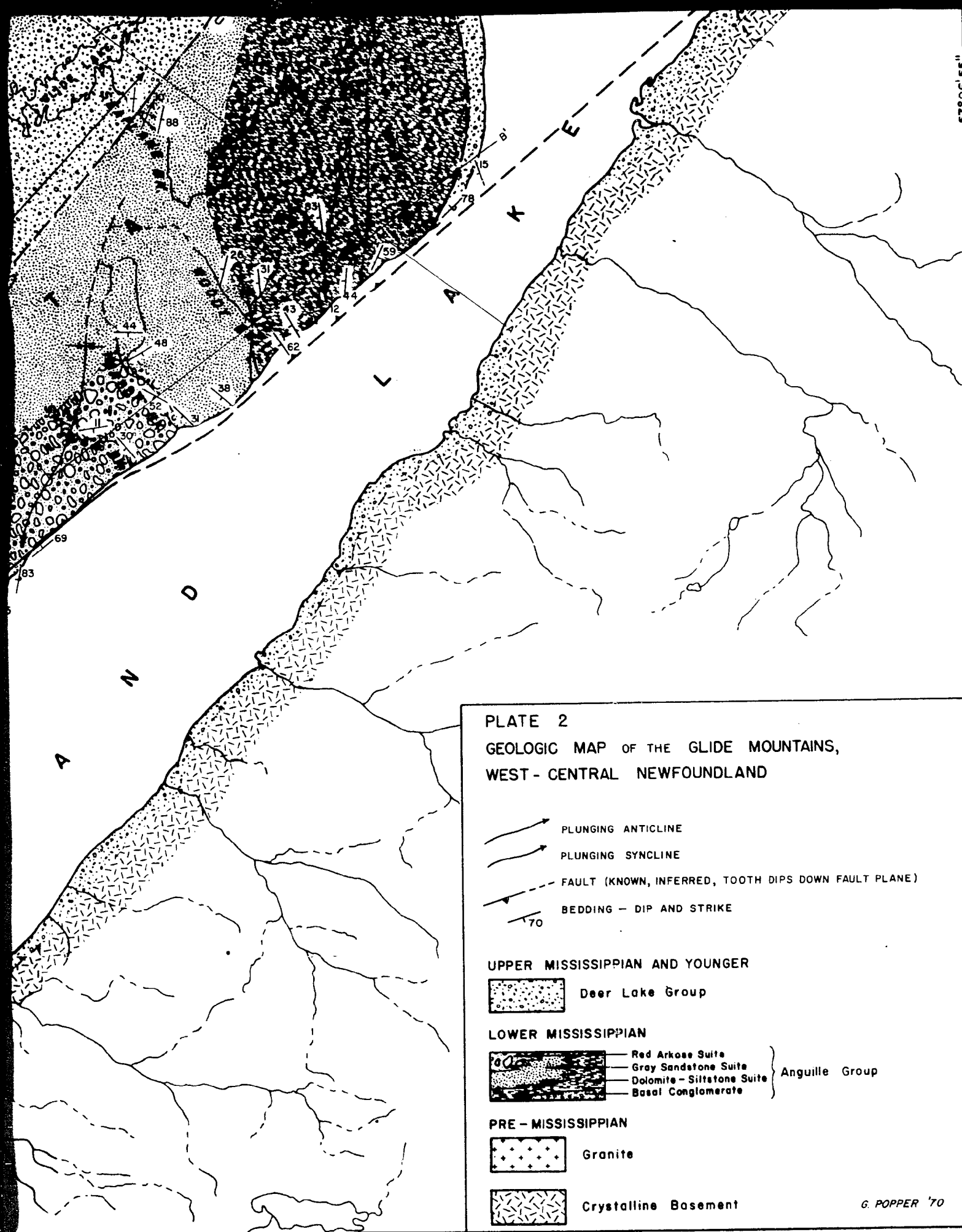


PLATE 2
GEOLOGIC MAP OF THE GLIDE MOUNTAINS,
WEST-CENTRAL NEWFOUNDLAND

- PLUNGING ANTICLINE
- PLUNGING SYNCLINE
- FAULT (KNOWN, INFERRED, TOOTH DIPS DOWN FAULT PLANE)
- BEDDING - DIP AND STRIKE

UPPER MISSISSIPPIAN AND YOUNGER

Deer Lake Group

LOWER MISSISSIPPIAN

} Anguille Group

- Red Arkose Suite
- Gray Sandstone Suite
- Dolomite - Siltstone Suite
- Basal Conglomerate

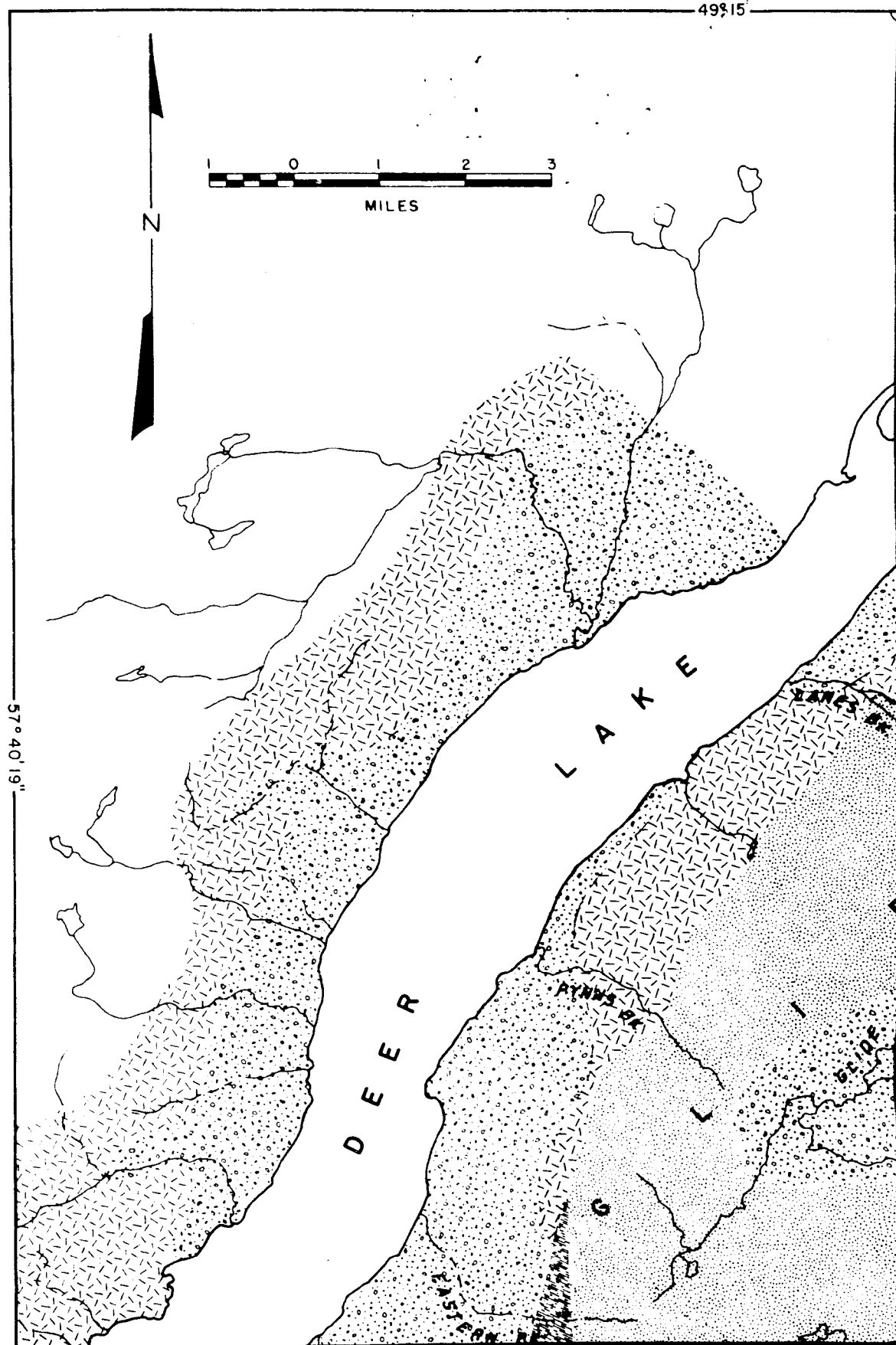
PRE - MISSISSIPPIAN

Granite

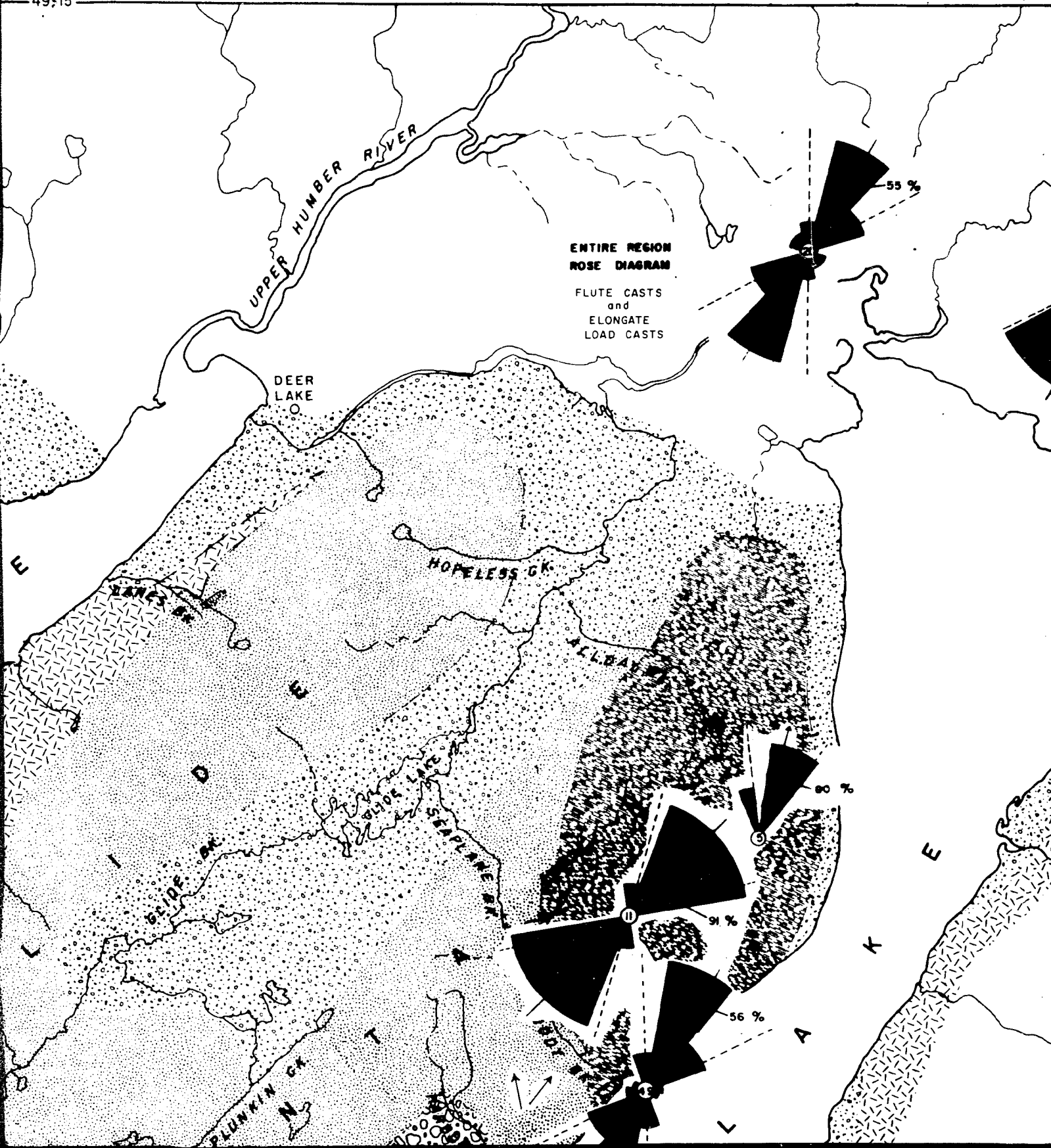
Crystalline Basement

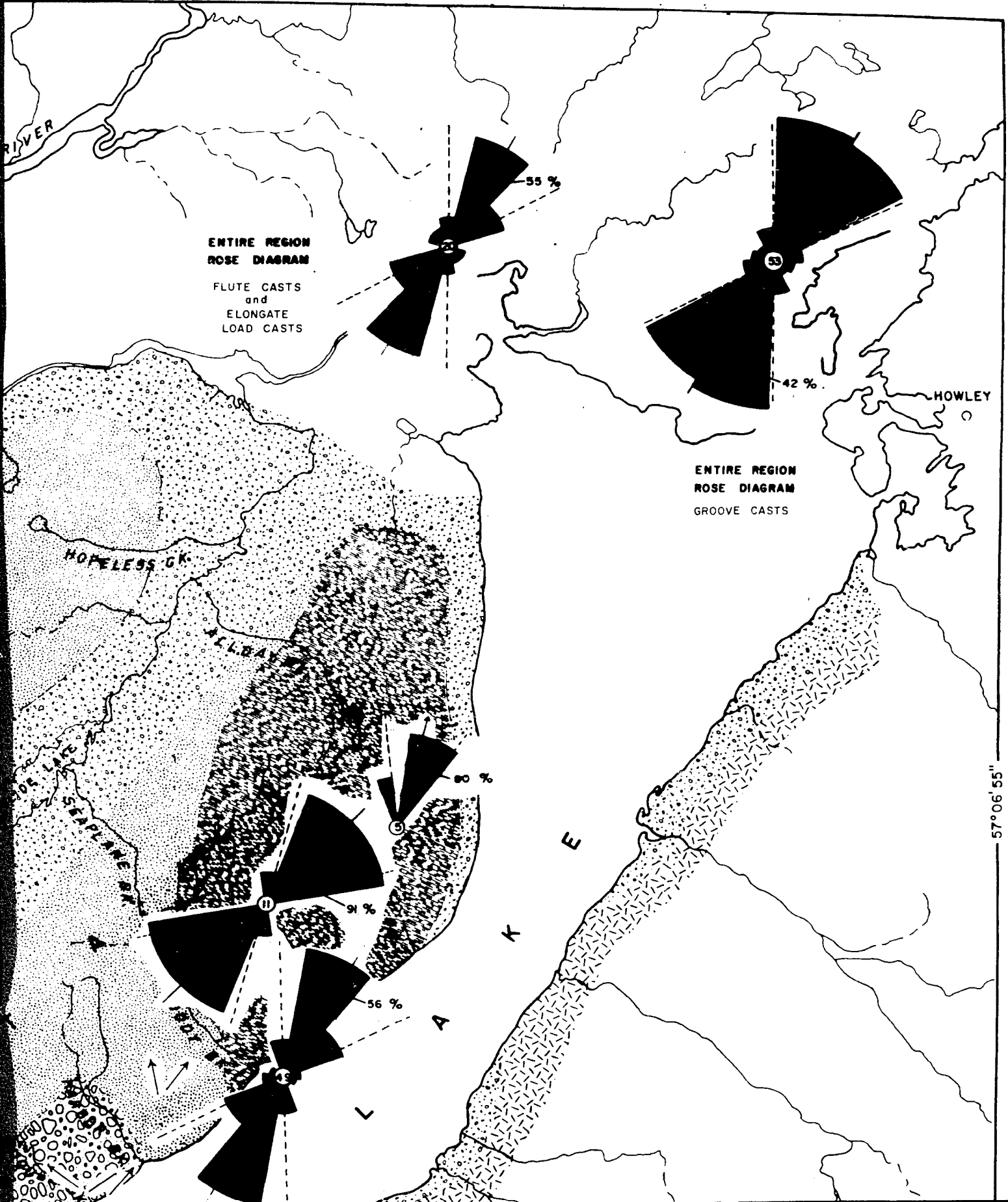
G. POPPER '70

Plate 3 Groove Casts and Flute Casts of the Anguille Group, West-Central Newfoundland



49°15'

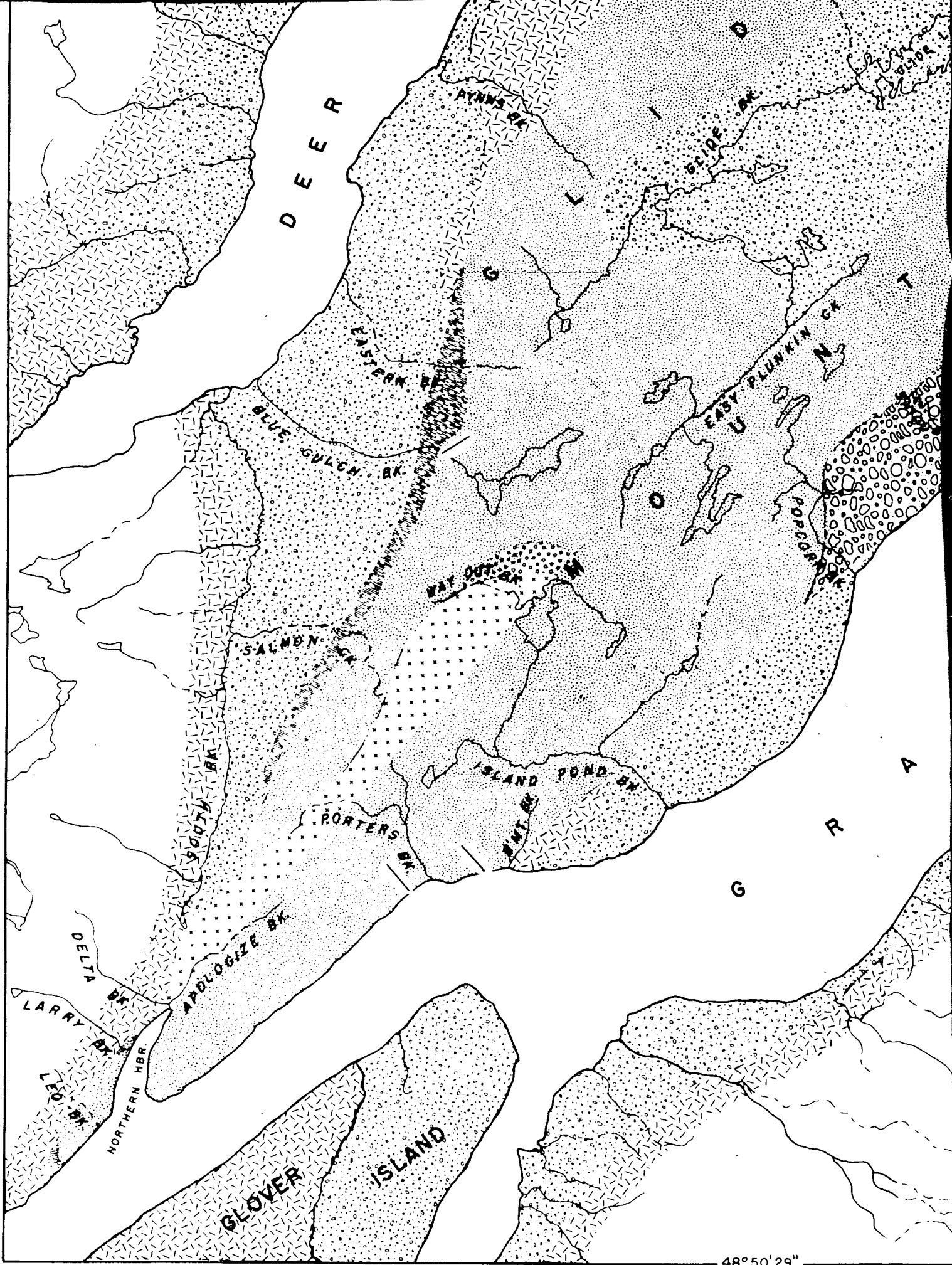




ENTIRE REGION
ROSE DIAGRAM

FLUTE CASTS
and
ELONGATE
LOAD CASTS

ENTIRE REGION
ROSE DIAGRAM
GROOVE CASTS



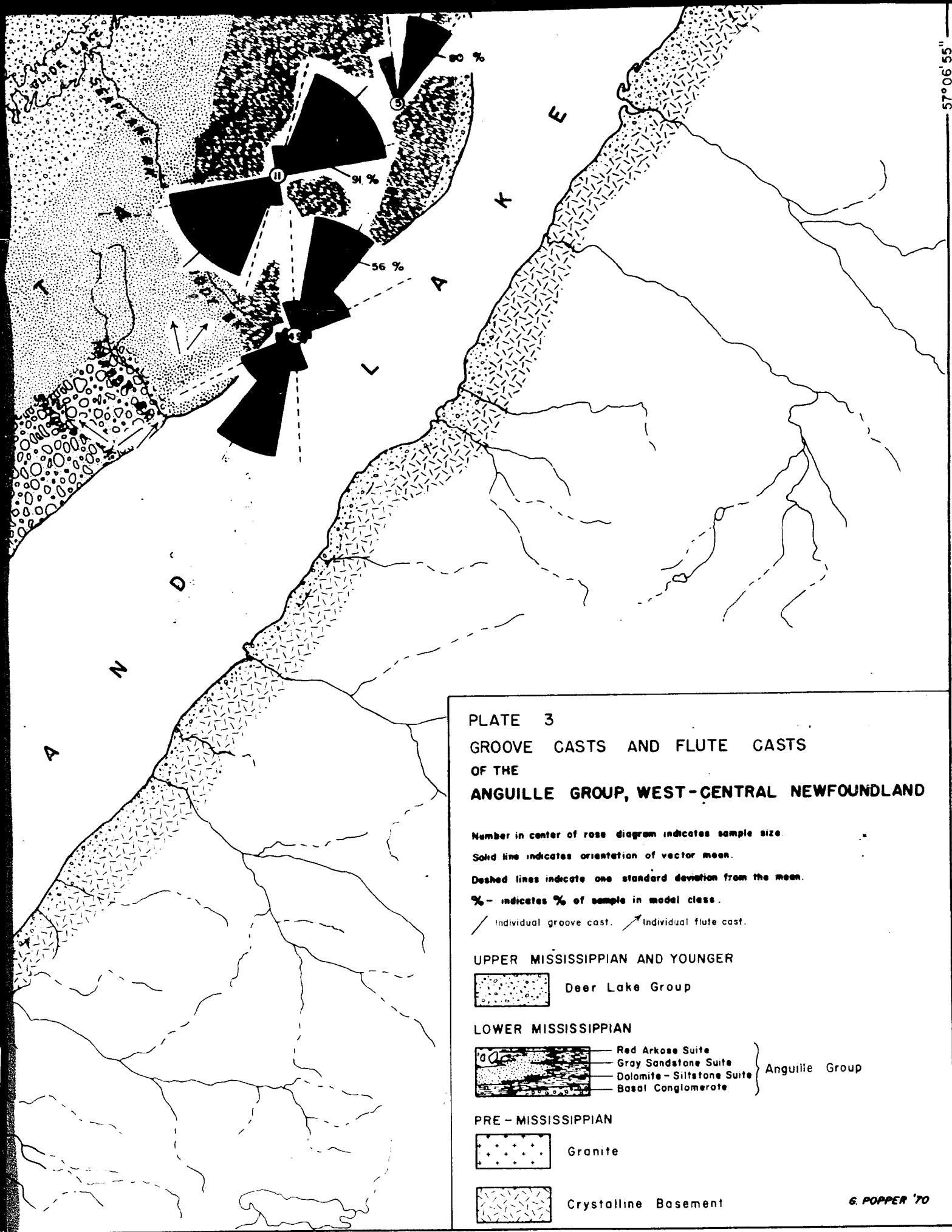


PLATE 3
GROOVE CASTS AND FLUTE CASTS
OF THE
ANGUILLE GROUP, WEST-CENTRAL NEWFOUNDLAND

Number in center of rose diagram indicates sample size.
 Solid line indicates orientation of vector mean.
 Dashed lines indicate one standard deviation from the mean.
 % - indicates % of sample in modal class.
 / Individual groove cast. \ Individual flute cast.

UPPER MISSISSIPPIAN AND YOUNGER

 Deer Lake Group

LOWER MISSISSIPPIAN

 Red Arkose Suite
 Gray Sandstone Suite
 Dolomite-Siltstone Suite
 Basal Conglomerate } Anguille Group

PRE - MISSISSIPPIAN



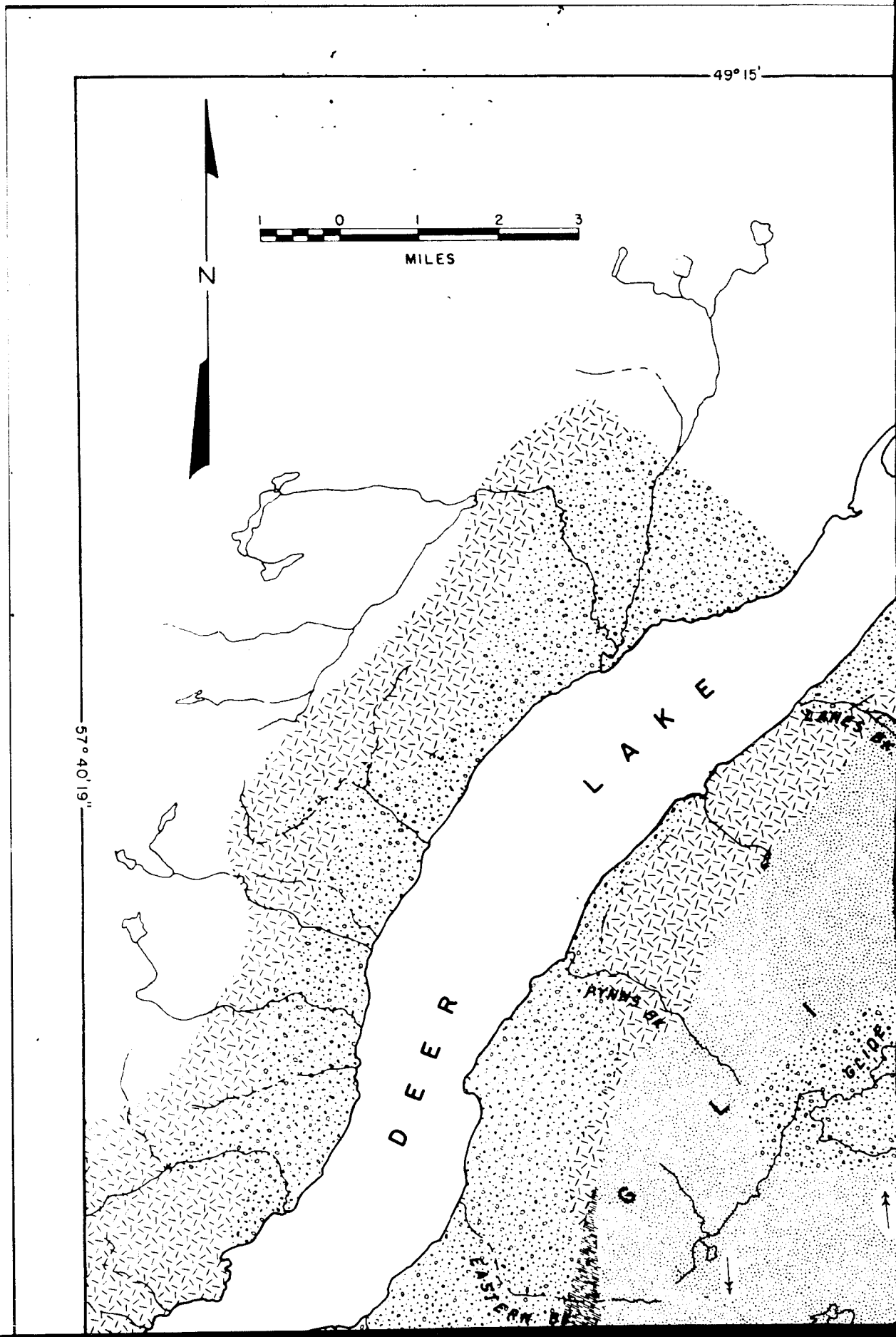
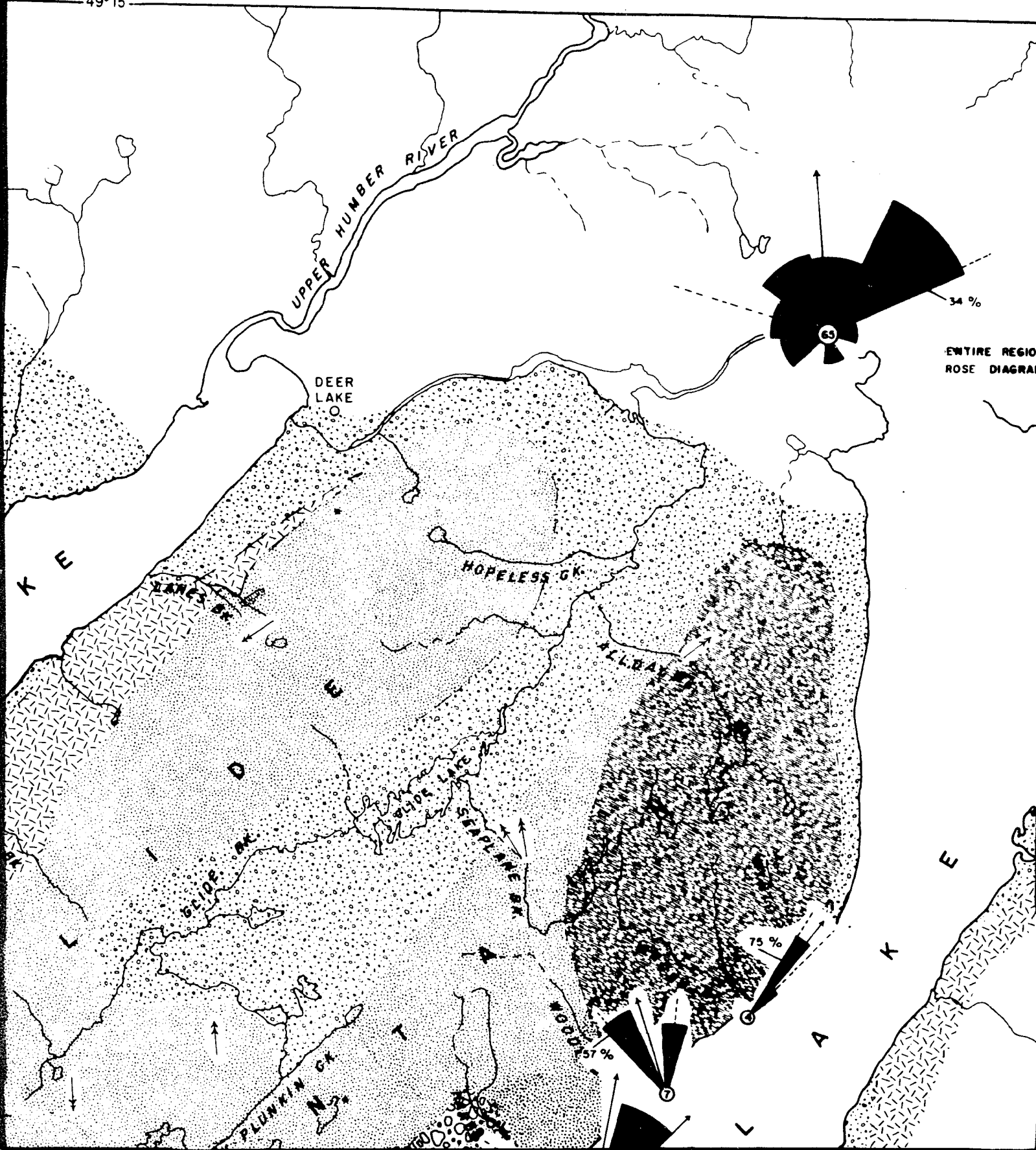
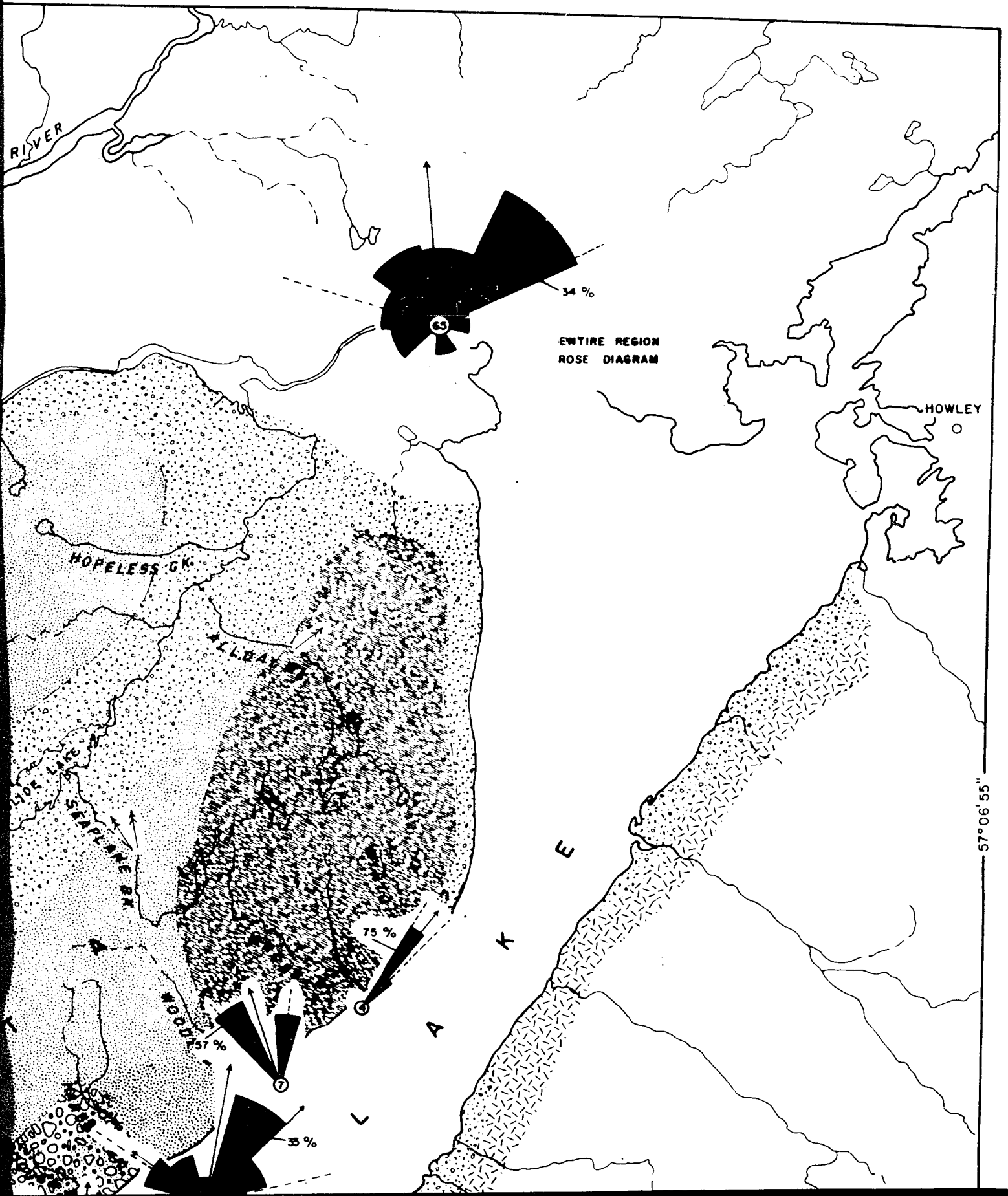
 Granite
 Crystalline Basement

Plate 4 Cross-Beds of the Anguille Group,
West-Central Newfoundland



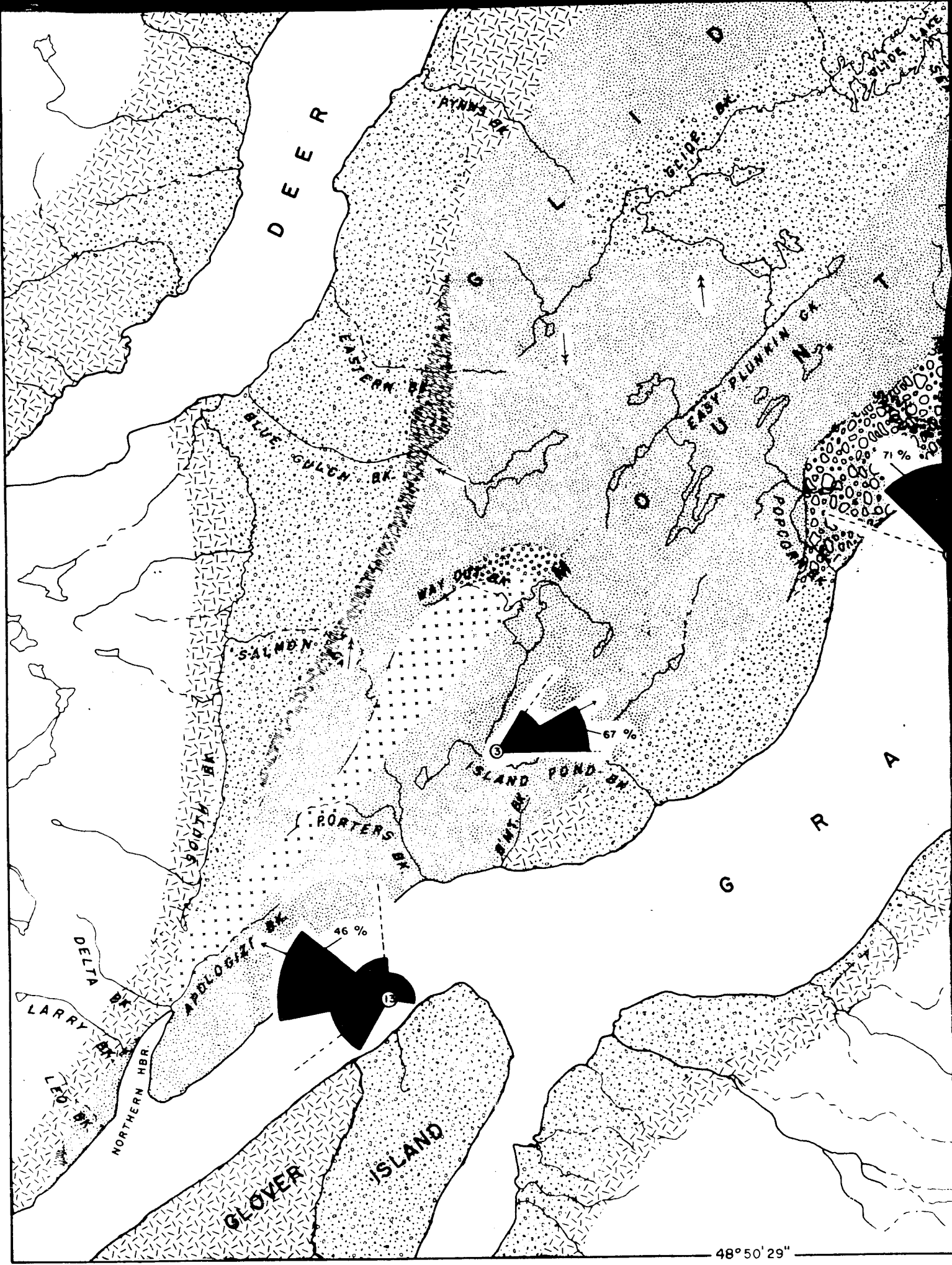
49° 15'





ENTIRE REGION
ROSE DIAGRAM

57° 06' 55"



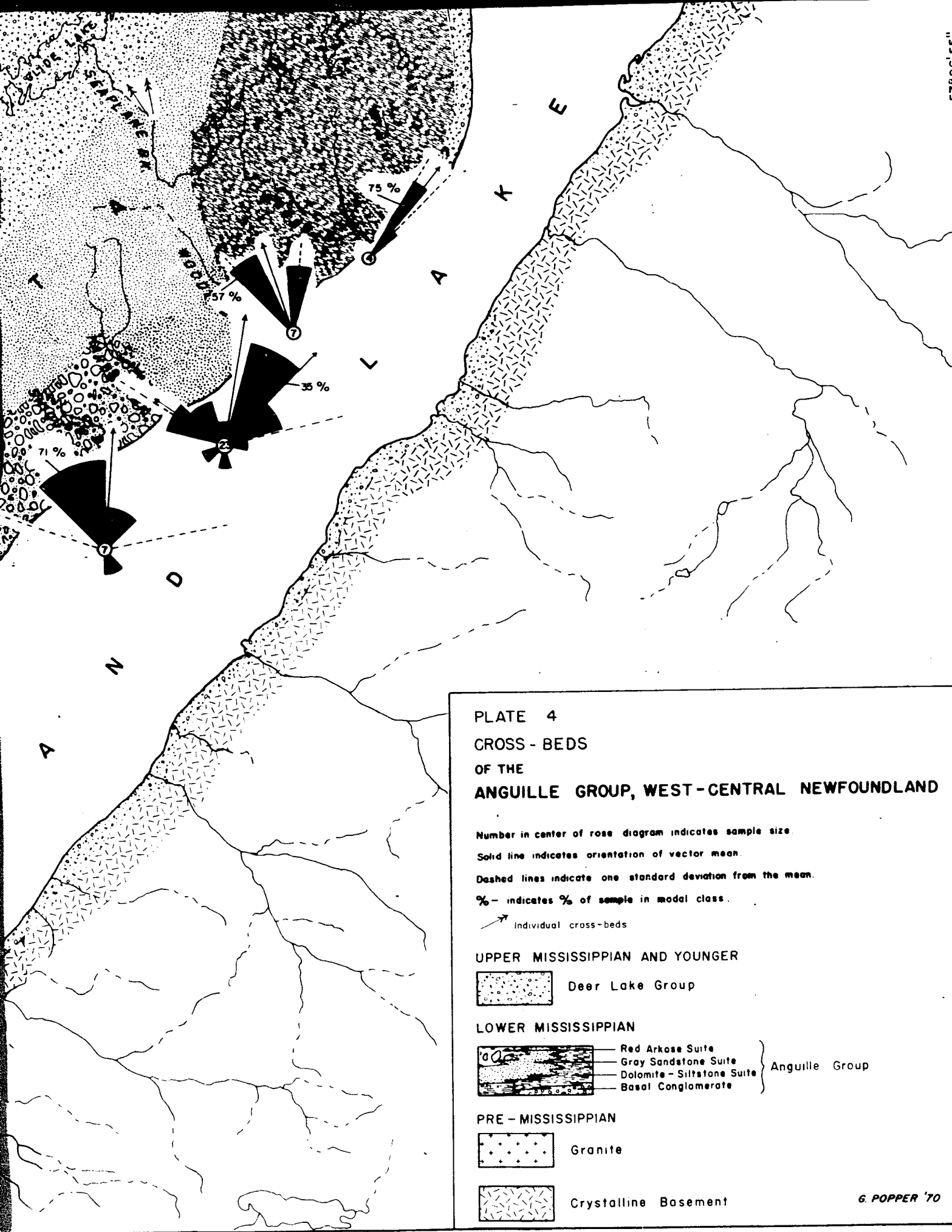






PLATE 4
CROSS - BEDS
OF THE
ANGUILLE GROUP, WEST-CENTRAL NEWFOUNDLAND

Number in center of rose diagram indicates sample size.
 Solid line indicates orientation of vector mean.
 Dashed lines indicate one standard deviation from the mean.
 % - indicates % of sample in modal class.
 ↗ Individual cross-beds

UPPER MISSISSIPPIAN AND YOUNGER

 Deer Lake Group

LOWER MISSISSIPPIAN

 Red Arkose Suite
 Gray Sandstone Suite
 Dolomite - Siltstone Suite
 Basal Conglomerate
 } Anguille Group

PRE - MISSISSIPPIAN

 Granite

 Crystalline Basement

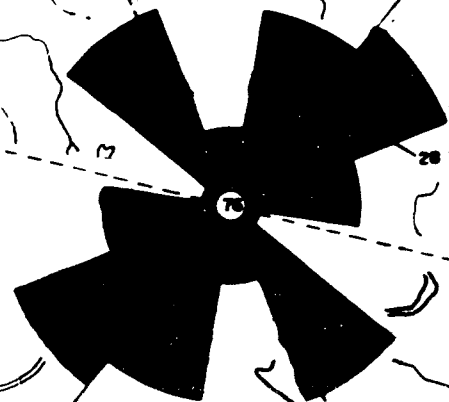
Plate 5 Parting Lineations of the Anguille Group, West-Central Newfoundland



49°15'

UPPER HUMBER RIVER

ENTIRE REGION ROSE DIAGRAM



DEER LAKE

HOPELESS GK

LANCE BK

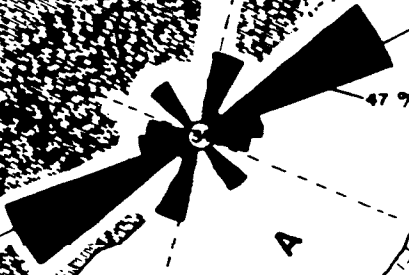
ALBANY

SLIDE BK

SEAPLANE BK

EAST PLUNKIN GK

MOODY



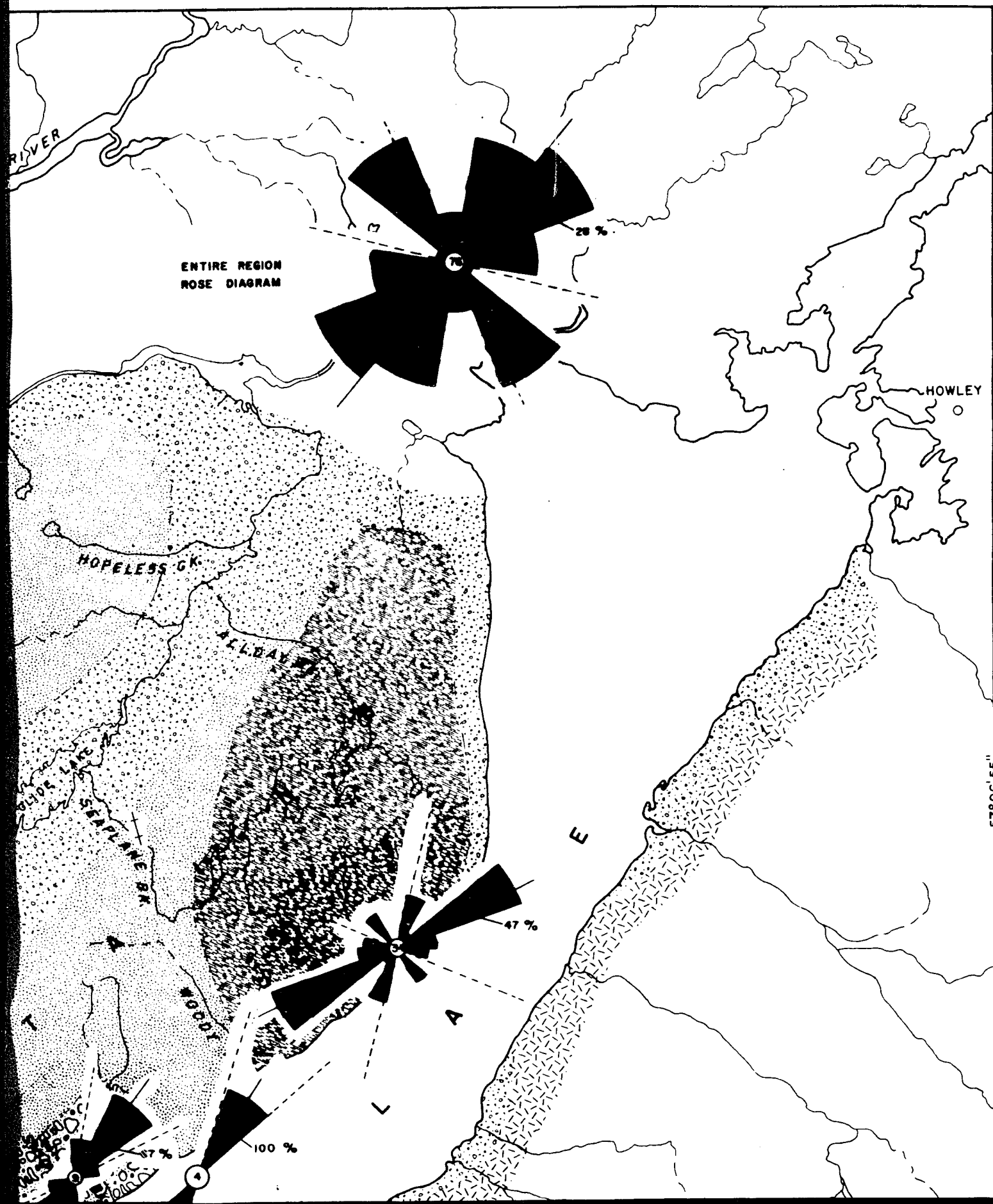
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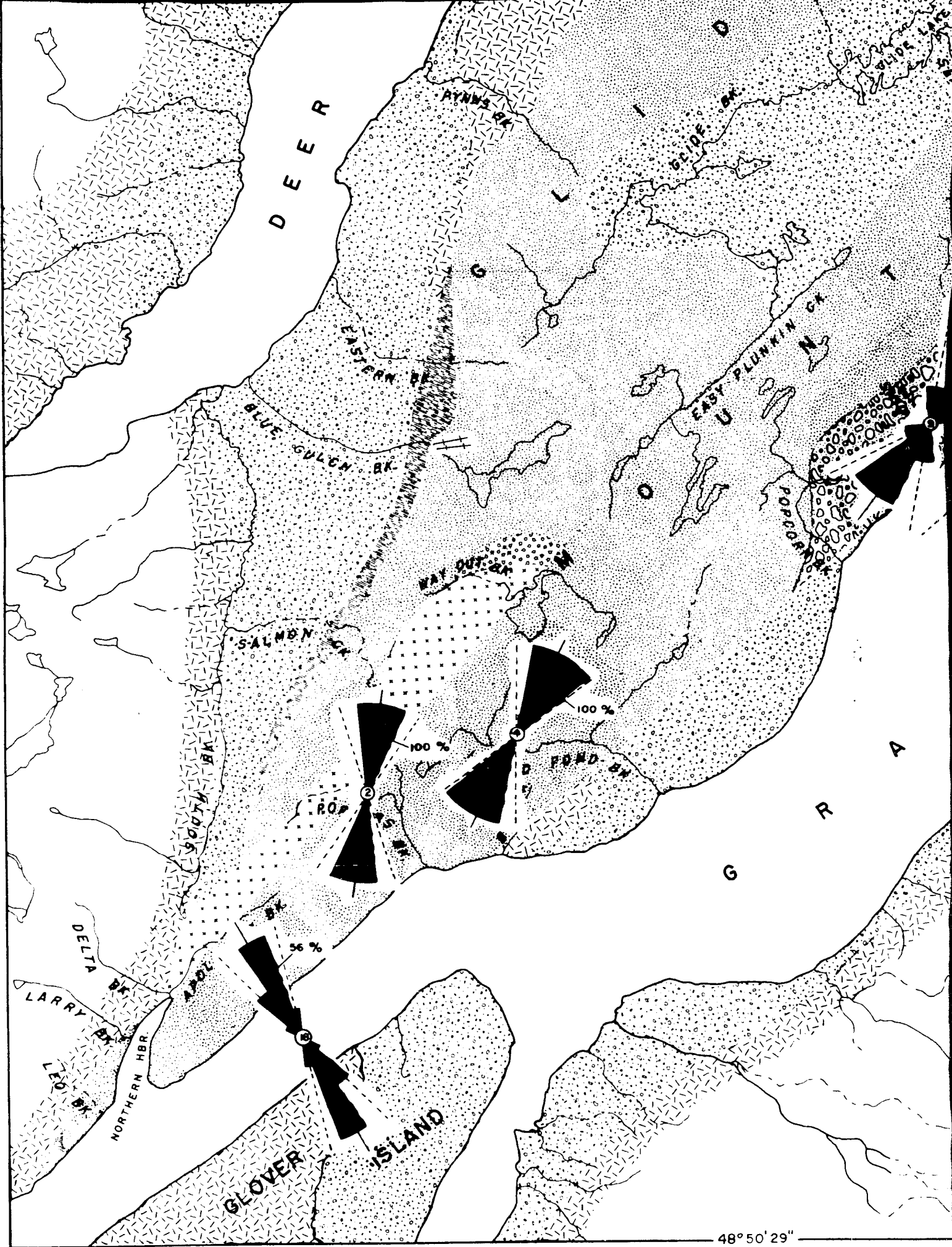
E

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57°06'55"



48° 50' 29"

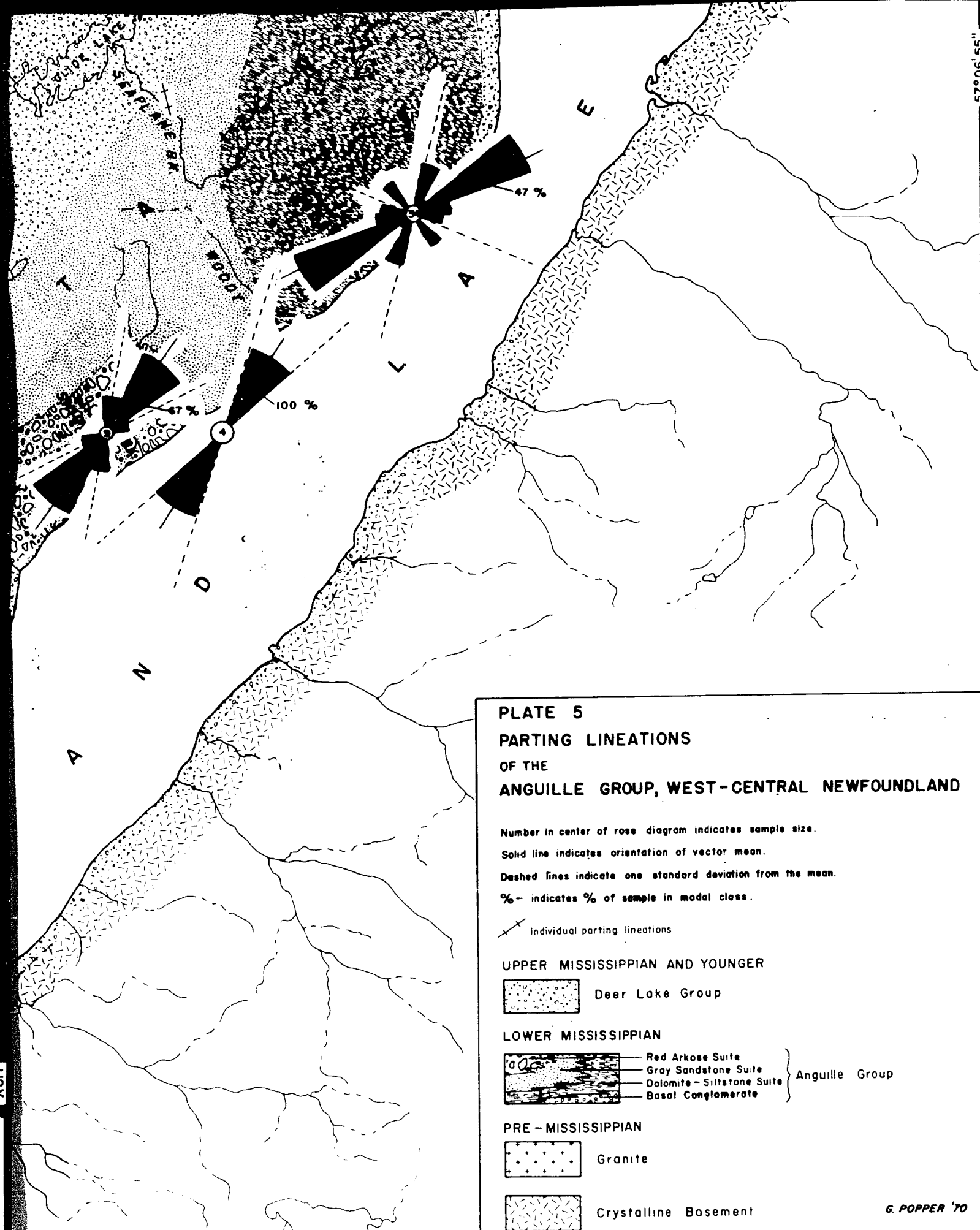
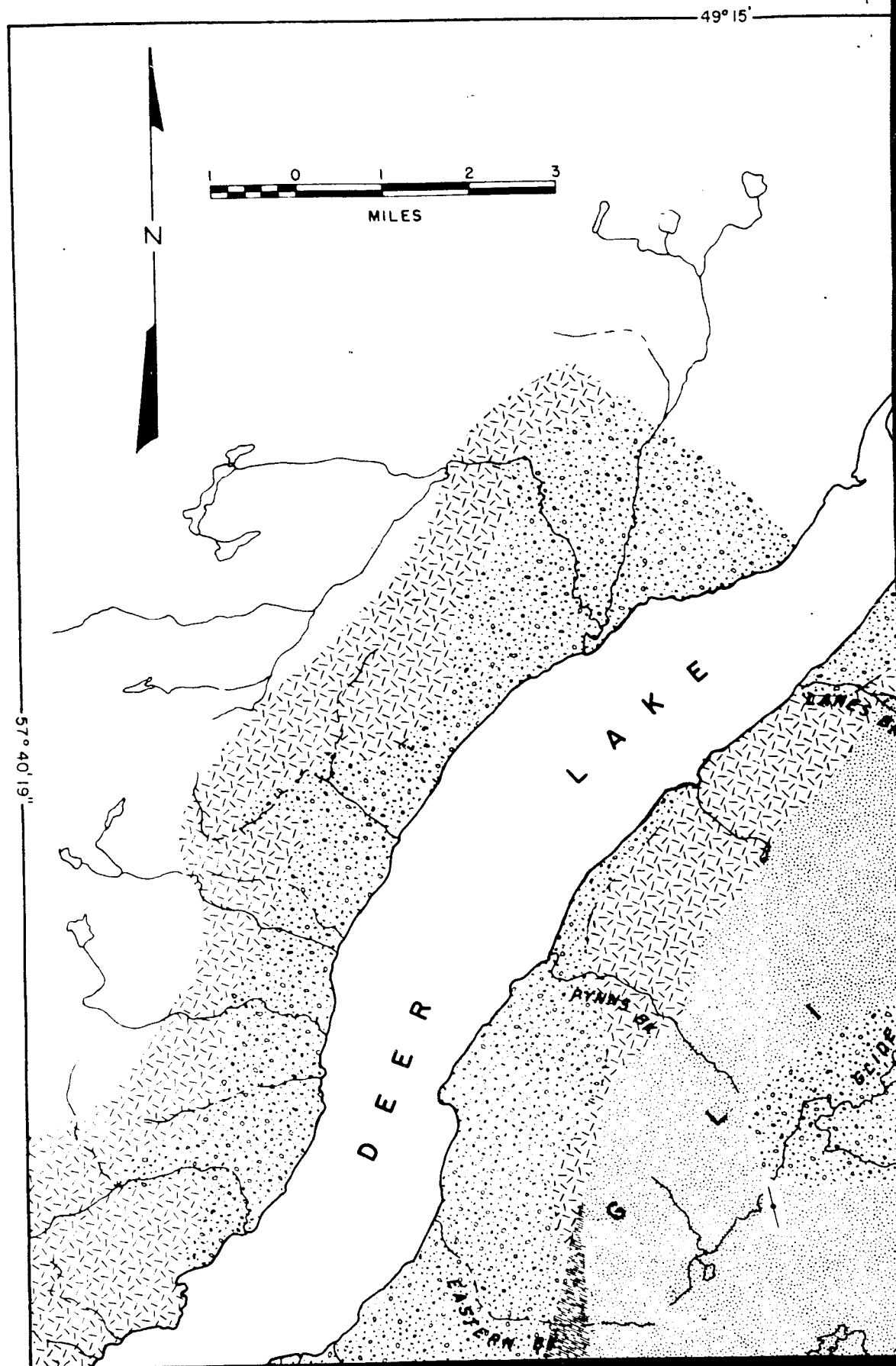


PLATE 5
PARTING LINEATIONS
OF THE
ANGUILLE GROUP, WEST-CENTRAL NEWFOUNDLAND

Number in center of rose diagram indicates sample size.
 Solid line indicates orientation of vector mean.
 Dashed lines indicate one standard deviation from the mean.
 % - indicates % of sample in modal class.
 - Individual parting lineations

- UPPER MISSISSIPPIAN AND YOUNGER**
 Deer Lake Group
- LOWER MISSISSIPPIAN**
 Red Arkose Suite
 Gray Sandstone Suite
 Dolomite - Siltstone Suite
 Basal Conglomerate } Anguille Group
- PRE - MISSISSIPPIAN**
 Granite
 Crystalline Basement

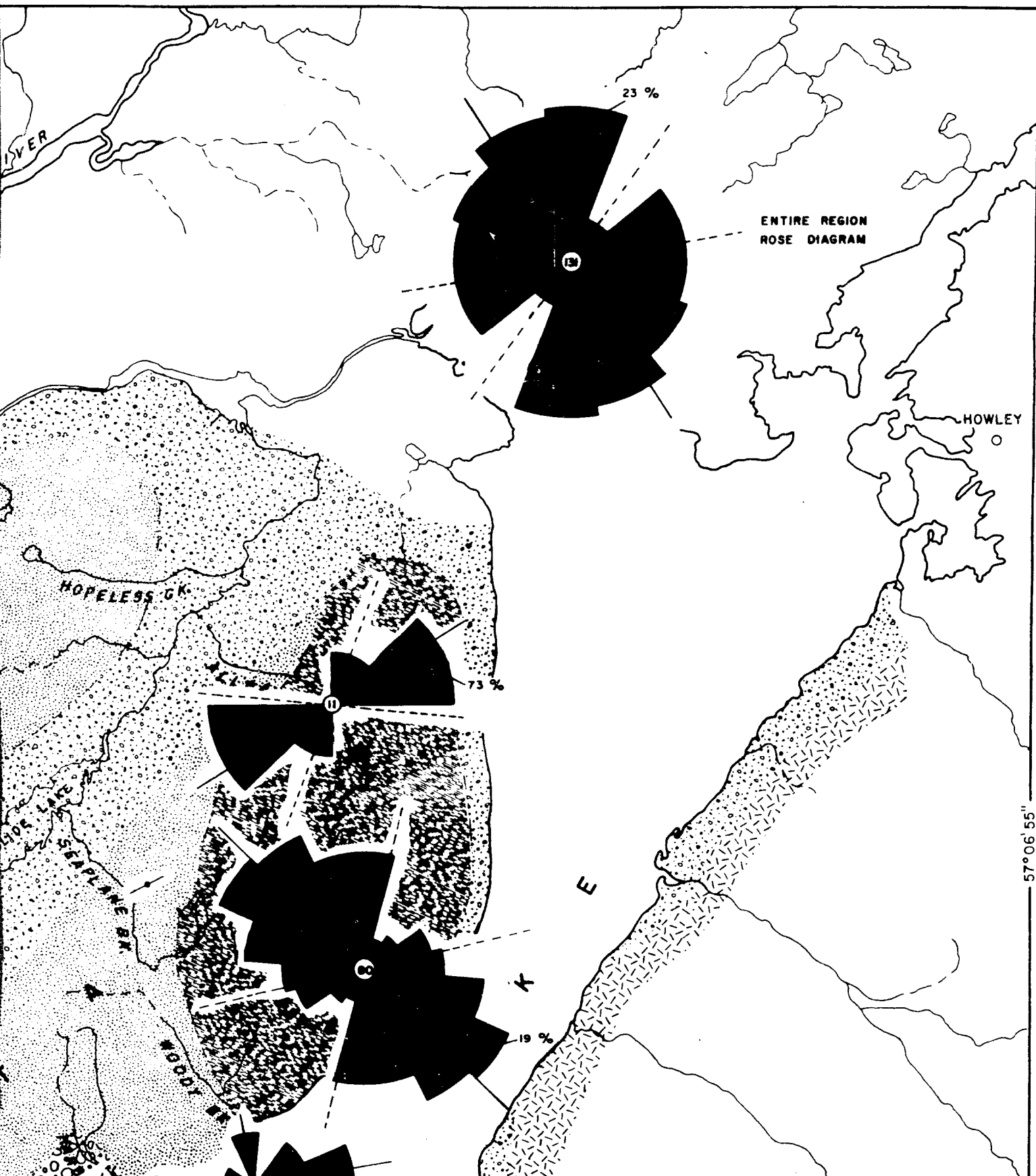
Plate 6 Ripple Marks of the Anguille Group,
West-Central Newfoundland



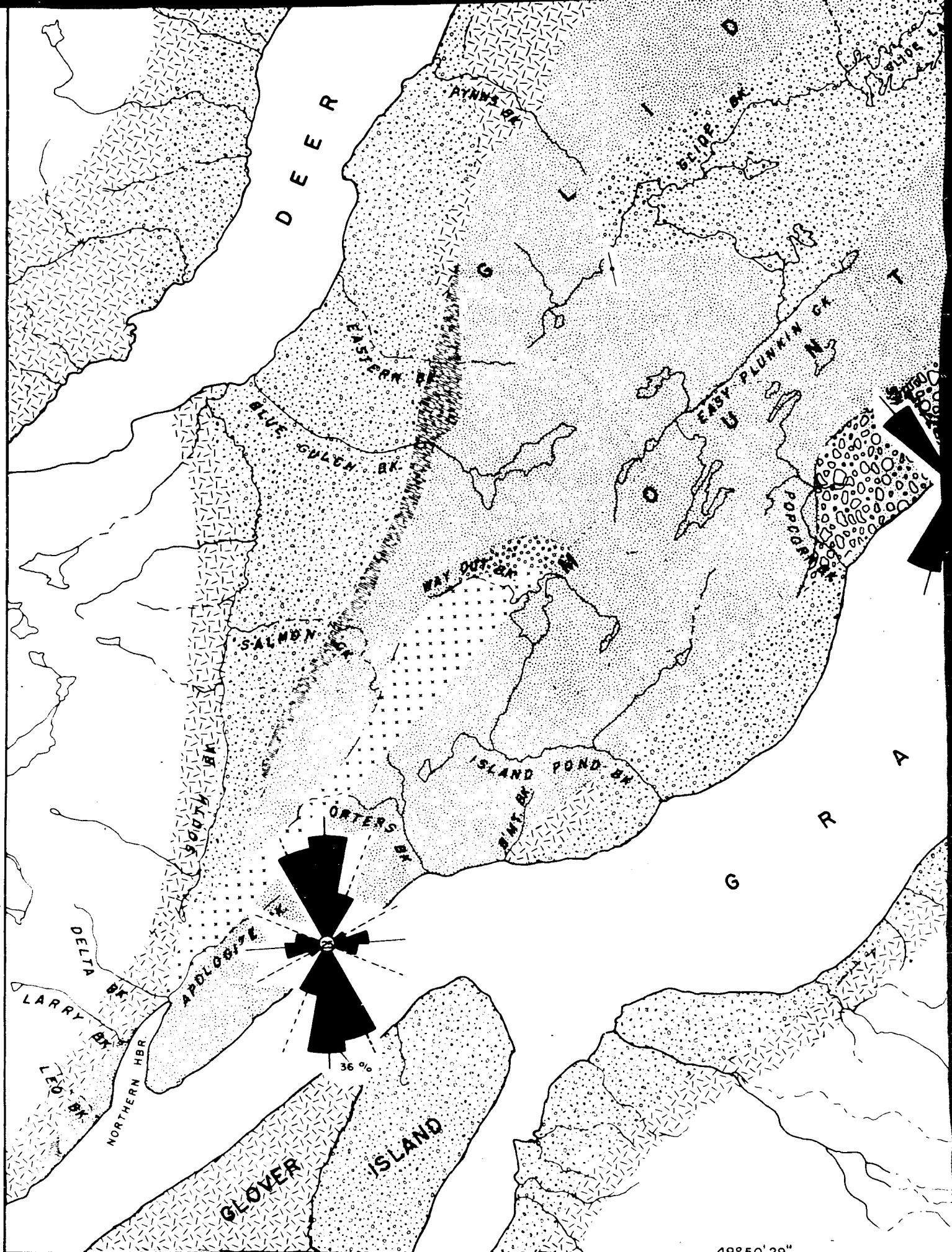
roup,

49° 15'





57°06' 55"



48° 50' 29"

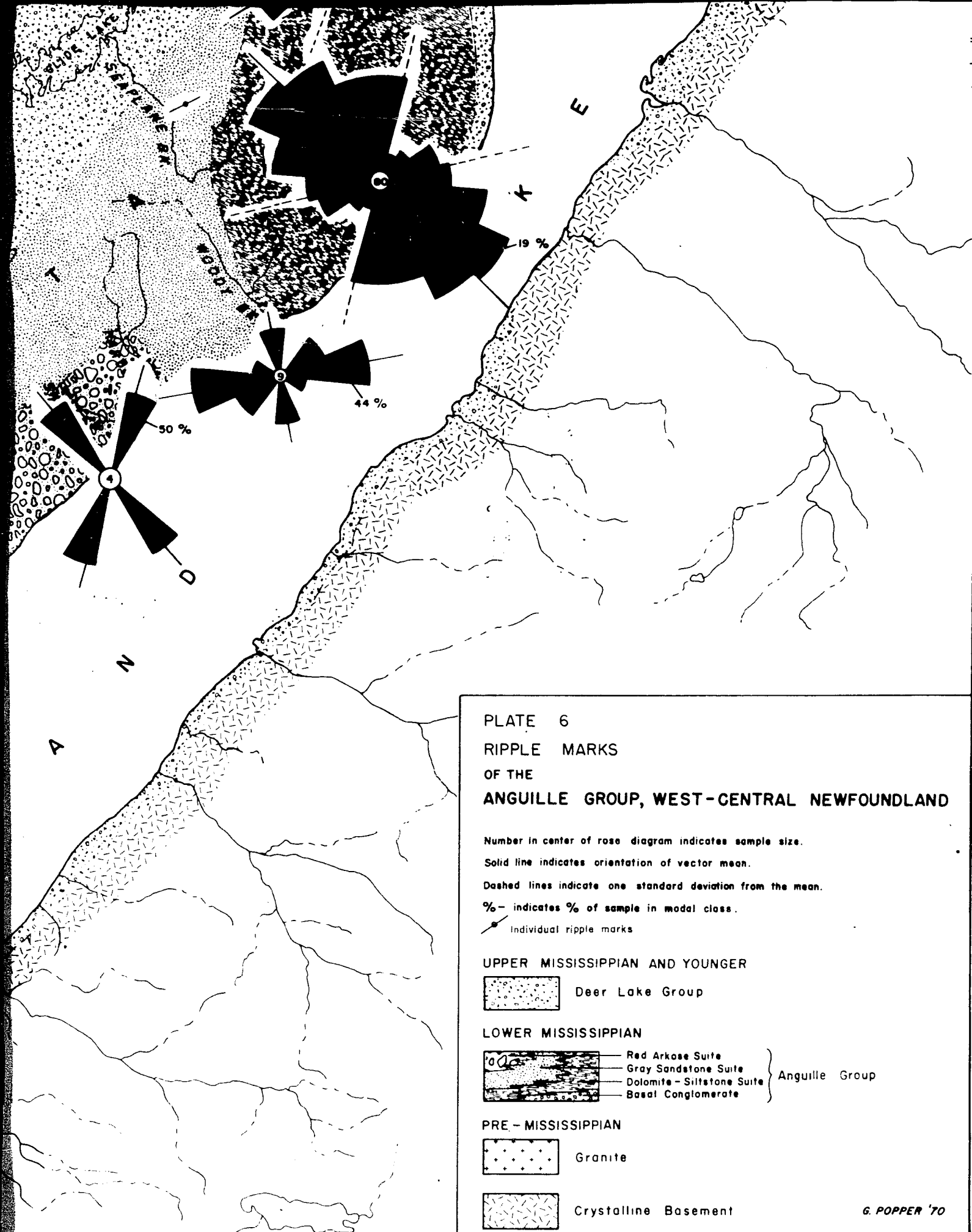


PLATE 6
RIPPLE MARKS
OF THE
ANGUILLE GROUP, WEST-CENTRAL NEWFOUNDLAND

Number in center of rose diagram indicates sample size.
 Solid line indicates orientation of vector mean.
 Dashed lines indicate one standard deviation from the mean.
 %- indicates % of sample in modal class.
 Individual ripple marks

UPPER MISSISSIPPIAN AND YOUNGER

 Deer Lake Group

LOWER MISSISSIPPIAN

 Red Arkose Suite
 Gray Sandstone Suite
 Dolomite - Siltstone Suite
 Basal Conglomerate
 } Anguille Group

PRE - MISSISSIPPIAN



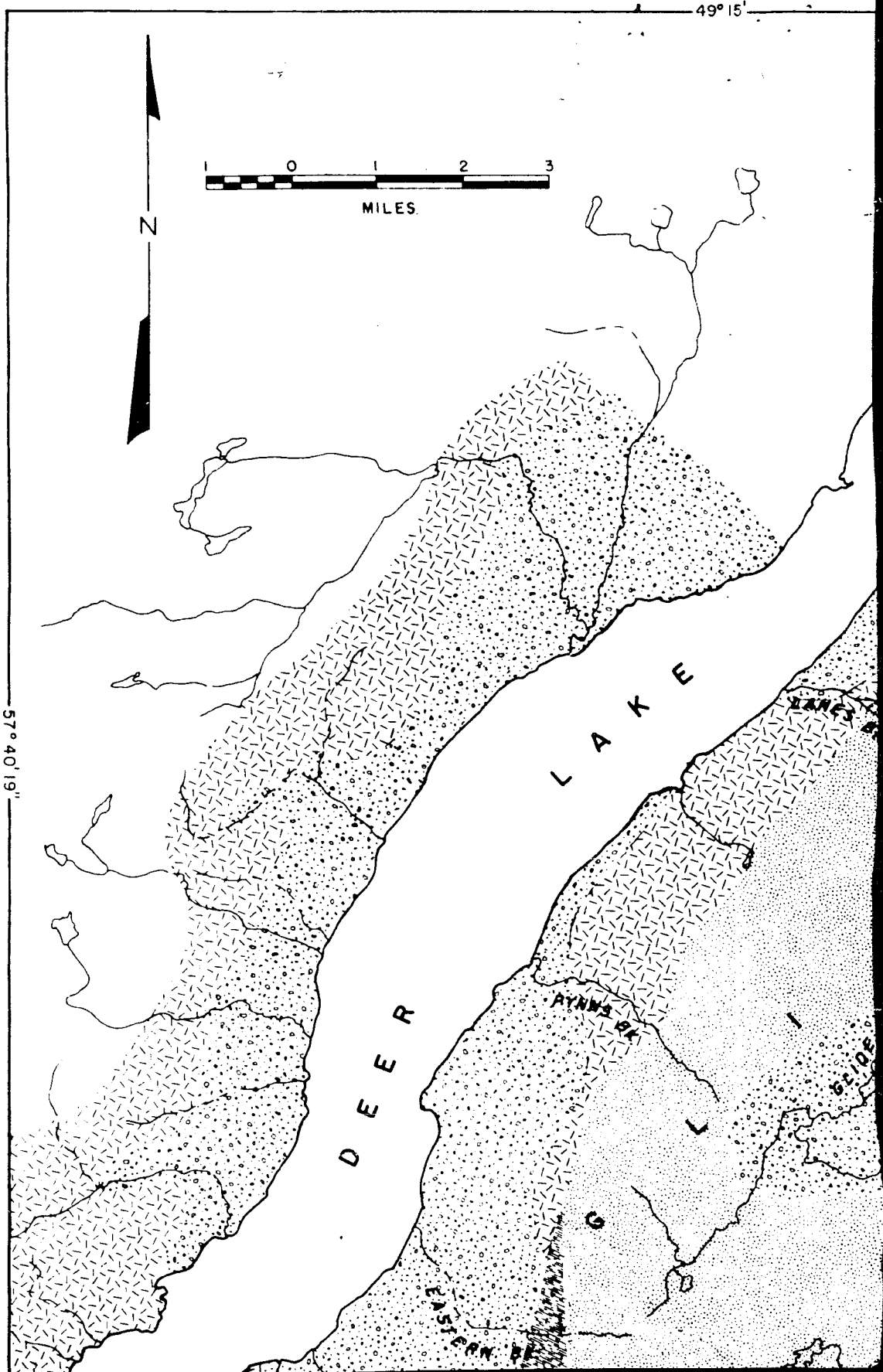
 Granite
 Crystalline Basement

Plate 7 Plant Fragments and Channels of the Anguille Group, West-Central Newfoundland



49° 15'



UPPER HUMBER RIVER

DEER LAKE

HOPELESS CR.

JAMES CR.

WILDCAT CR.

SLIDE CR.

SEAPLANE CR.

PLUNKIN CR.

WOOD CR.

33%

K E

W

D

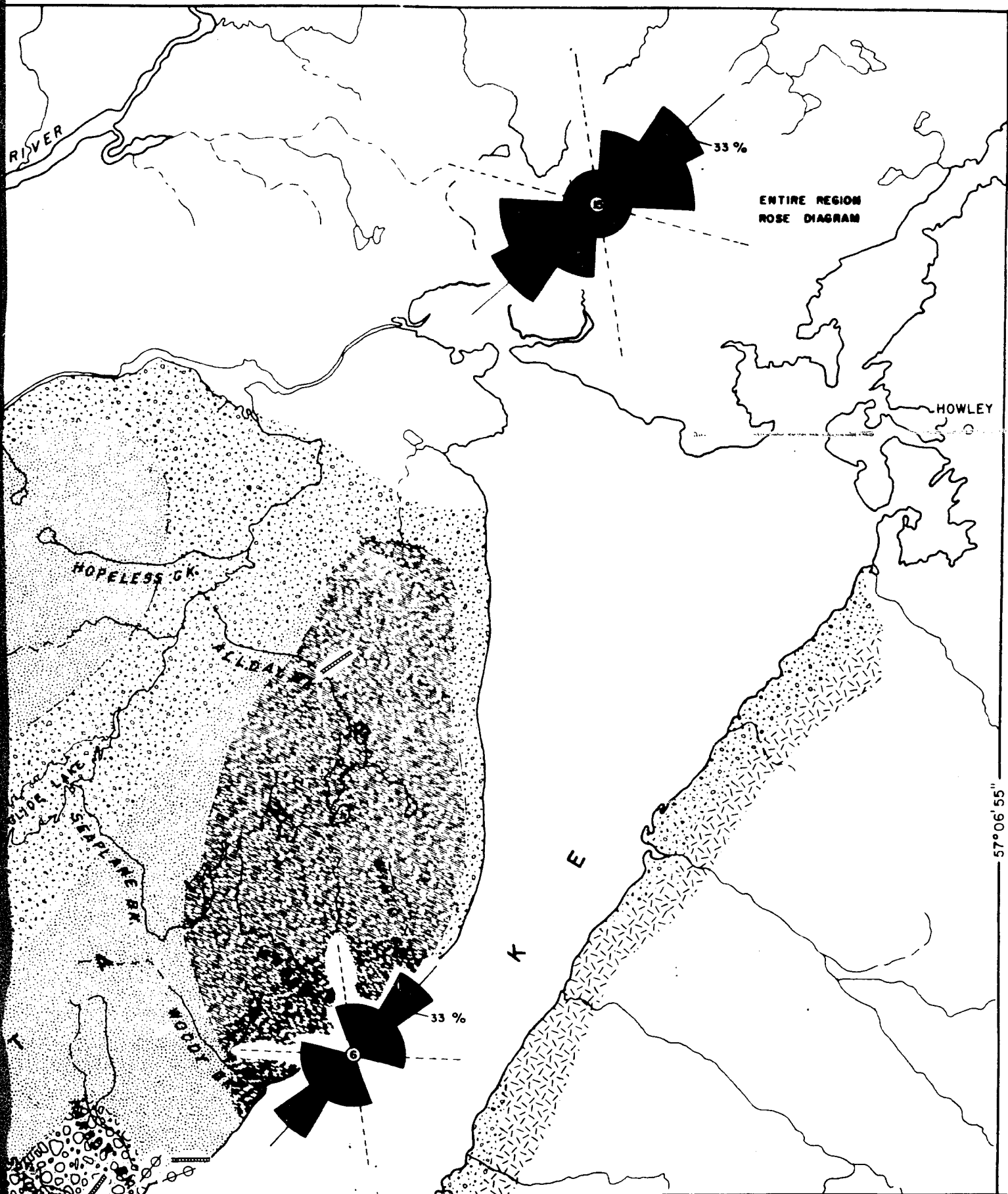
T

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RIVER

33 %

ENTIRE REGION
ROSE DIAGRAM

HOWLEY

HOPELESS CR.

ALDAY CR.

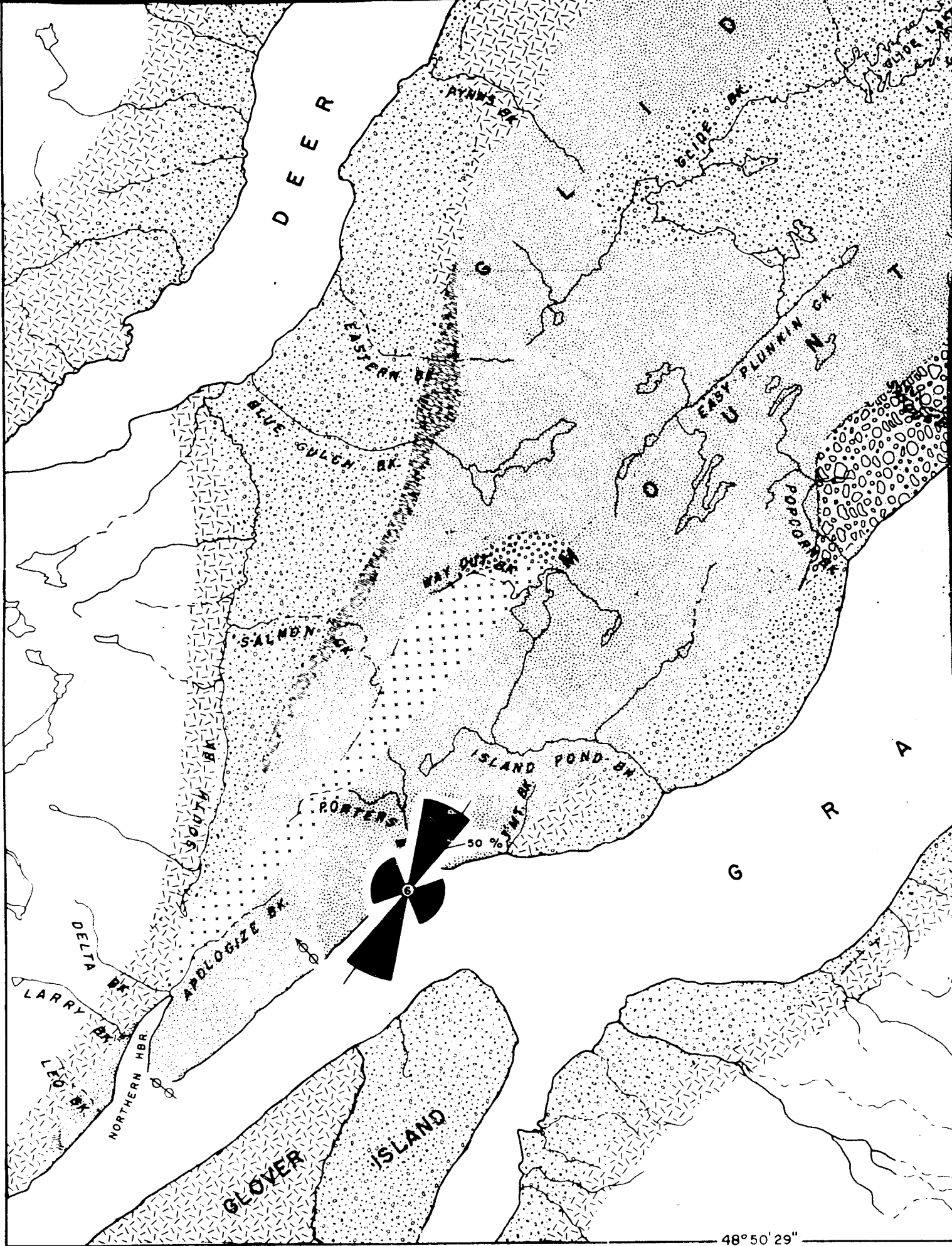
SLIDE LAKE N.
SEAPLANE BK.

FOON

33 %

K
E

57° 06' 55"



48° 50' 29"

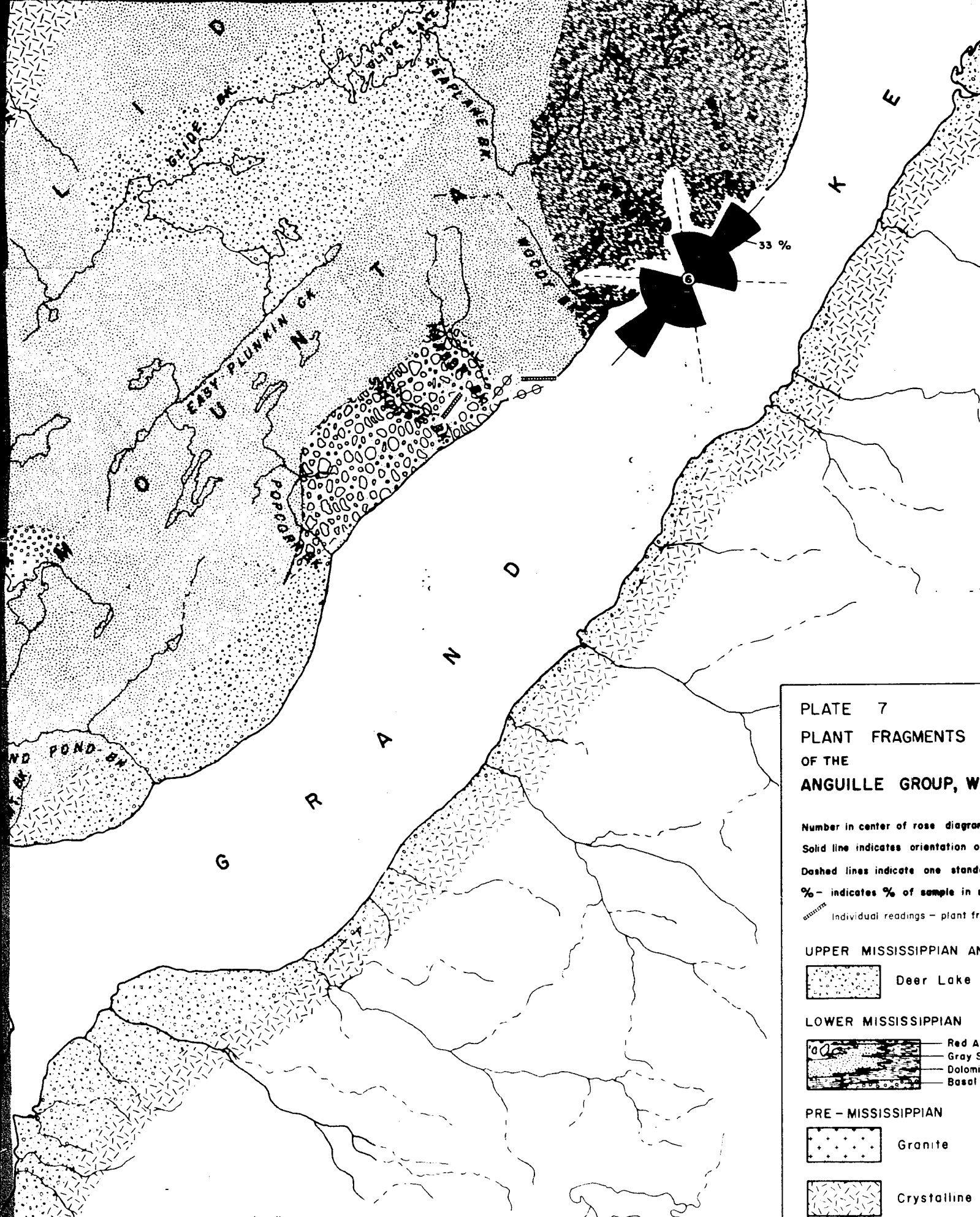
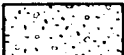


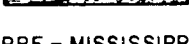
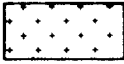



PLATE 7
PLANT FRAGMENTS
OF THE
ANGUILLE GROUP, WISCONSIN

Number in center of rose diagram
 Solid line indicates orientation of
 Dashed lines indicate one standard
 % - indicates % of sample in
 Individual readings - plant fragments

- UPPER MISSISSIPPIAN AND LOWER MISSISSIPPIAN**
-  Deer Lake
 -  Red Ar
Gray S
 -  Dolomite
 -  Basalt
- PRE - MISSISSIPPIAN**
-  Granite
 -  Crystalline

48° 50' 29"

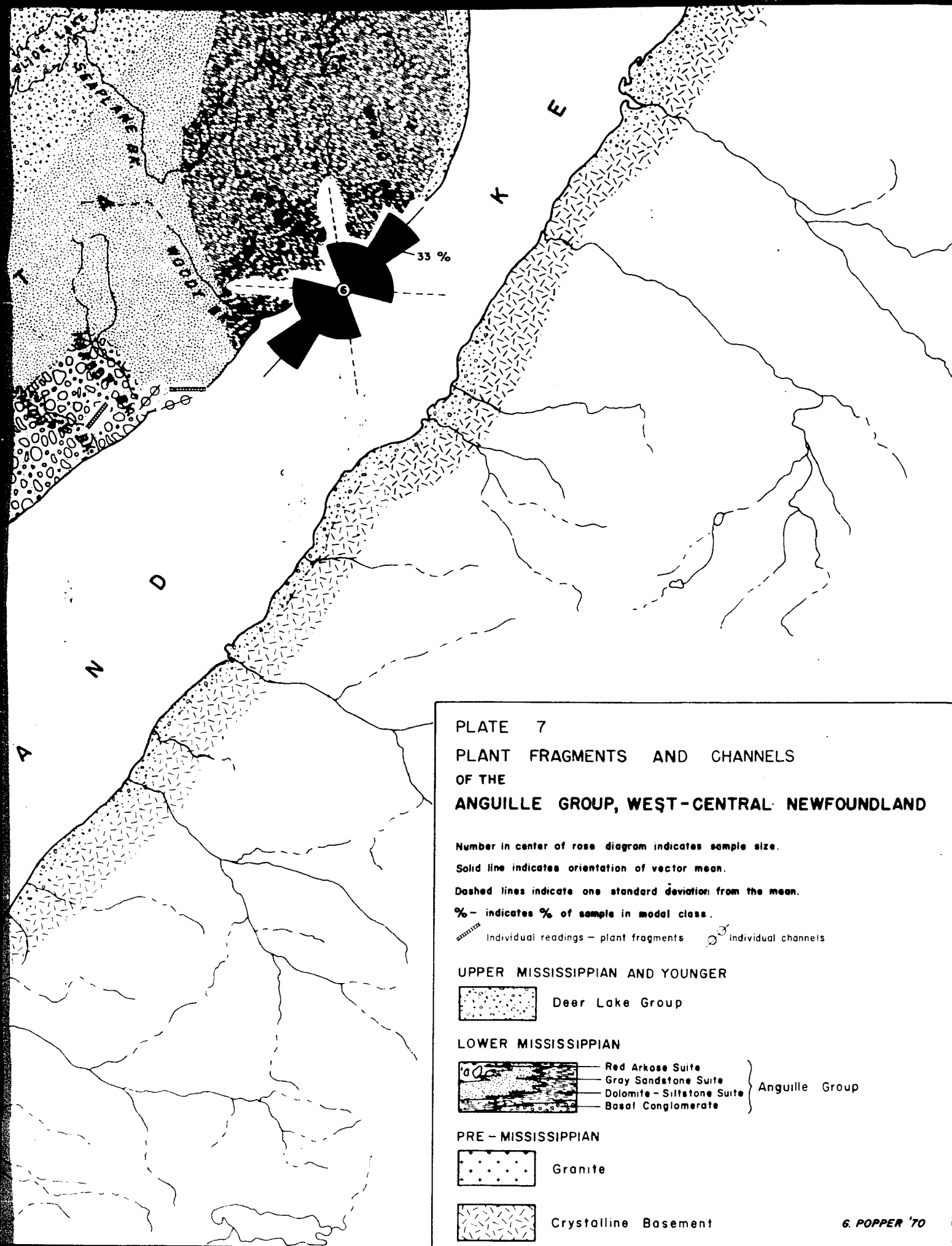











PLATE 7
PLANT FRAGMENTS AND CHANNELS
OF THE
ANGUILLE GROUP, WEST-CENTRAL NEWFOUNDLAND

Number in center of rose diagram indicates sample size.
 Solid line indicates orientation of vector mean.
 Dashed lines indicate one standard deviation from the mean.
 % - indicates % of sample in modal class.

 Individual readings - plant fragments  Individual channels

UPPER MISSISSIPPIAN AND YOUNGER
 Deer Lake Group

LOWER MISSISSIPPIAN
 Red Arkose Suite
 Gray Sandstone Suite
 Dolomite - Siltstone Suite
 Basal Conglomerate } Anguille Group

PRE - MISSISSIPPIAN
 Granite
 Crystalline Basement

G. POPPER '70

Plate 8 Cross-Section B-B', Glide Mountains,
West-Central Newfoundland

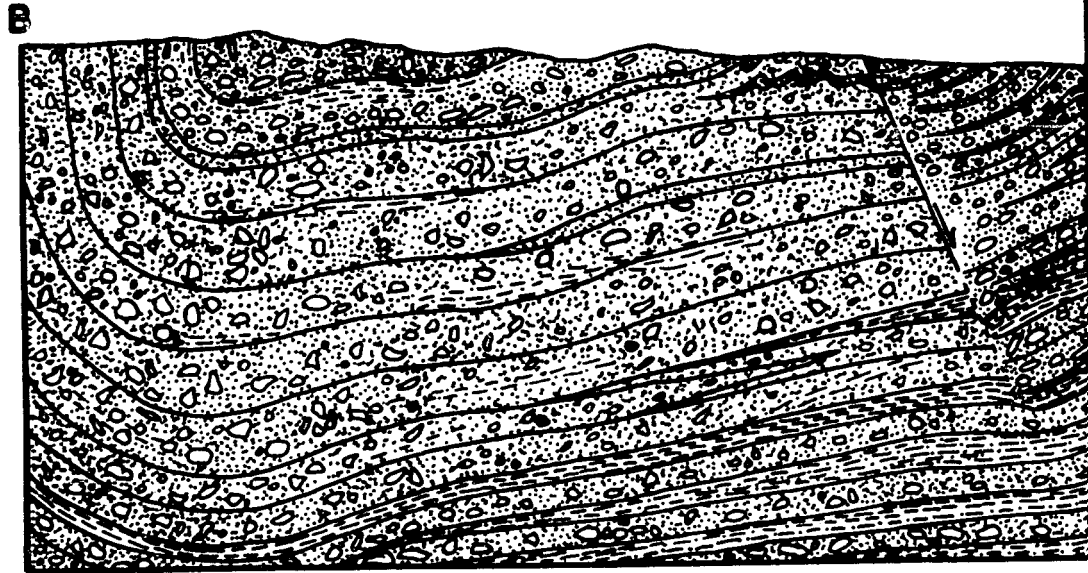
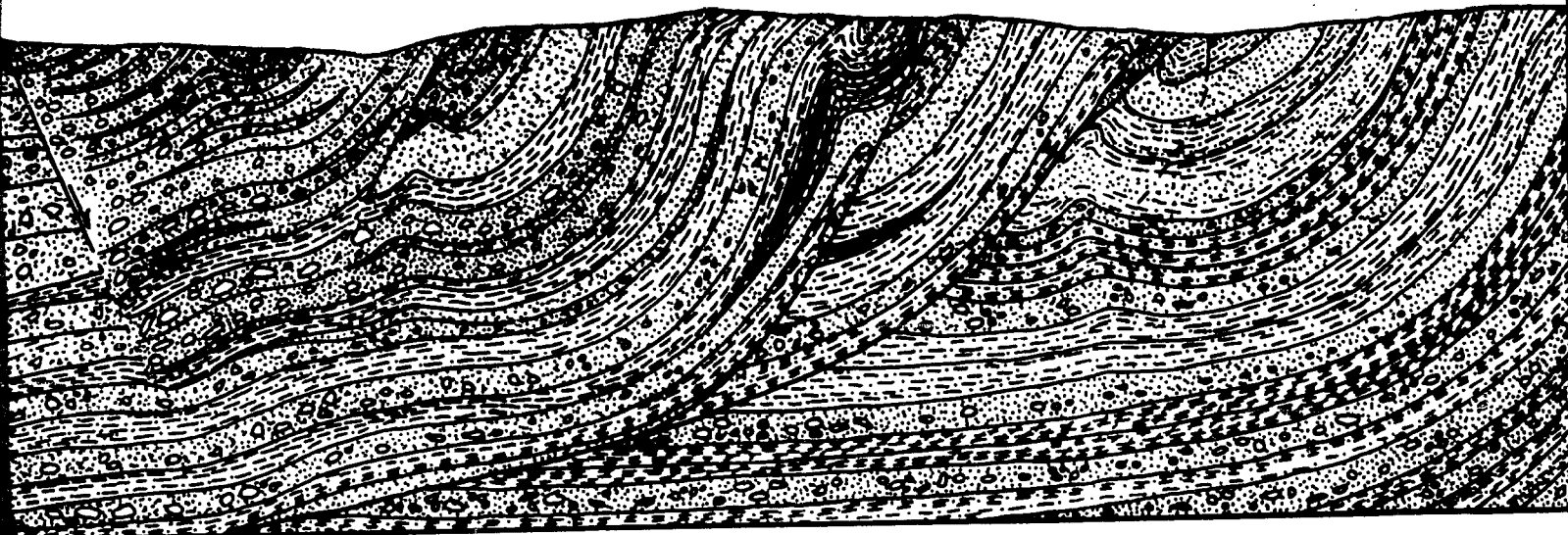


PLATE 8
CROSS-SECTION B-B', GU
WEST-CENTRAL NEW

————— N 52° E —————



ONE MILE

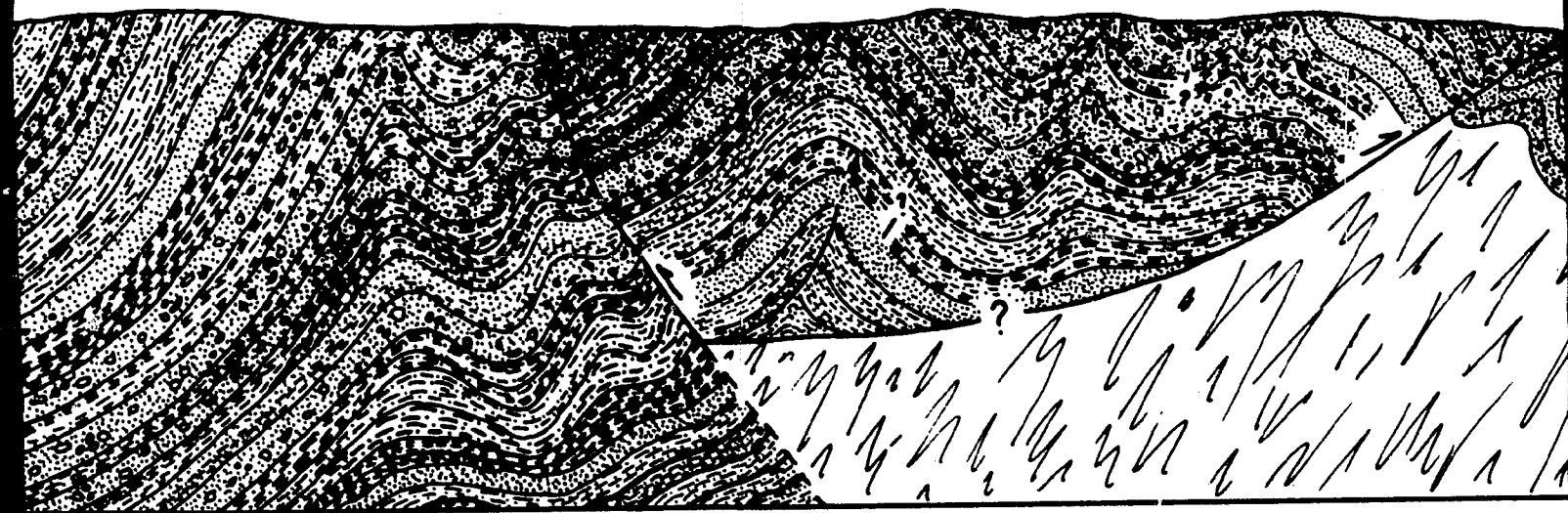
NO VERTICAL EXAGGERATION

PLATE 8

B-B', GLIDE MOUNTAINS,

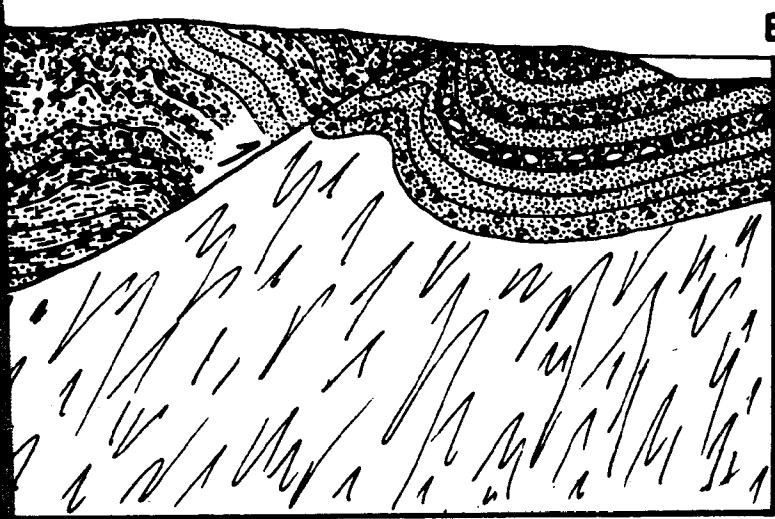
AL NEWFOUNDLAND

2°E →



—

TION



B'

UPPER MISSISSIPPIAN AND YOUNGER



CONGLOMERATE AND SANDSTONE

LOWER MISSISSIPPIAN



CONGLOMERATE, COARSE (ARKOSE)



SANDSTONE - ARKOSE, GRAYWACKE



SILTSTONE



LAMINATED DOLOMITE AND SILTSTONE



SHALE



LIMESTONE

PRE - MISSISSIPPIAN



CRYSTALLINE BASEMENT

G. POPPER '70



UPPER MISSISSIPPIAN AND YOUNGER



CONGLOMERATE AND SANDSTONE of the DEER LAKE GROUP

LOWER MISSISSIPPIAN



CONGLOMERATE, COARSE (ARKOSIC) SANDSTONE, PEBBLY SANDSTONES



SANDSTONE - ARKOSE, GRAYWACKE



SILTSTONE



LAMINATED DOLOMITE AND SILTSTONE



SHALE



LIMESTONE

PRE - MISSISSIPPIAN



CRYSTALLINE BASEMENT

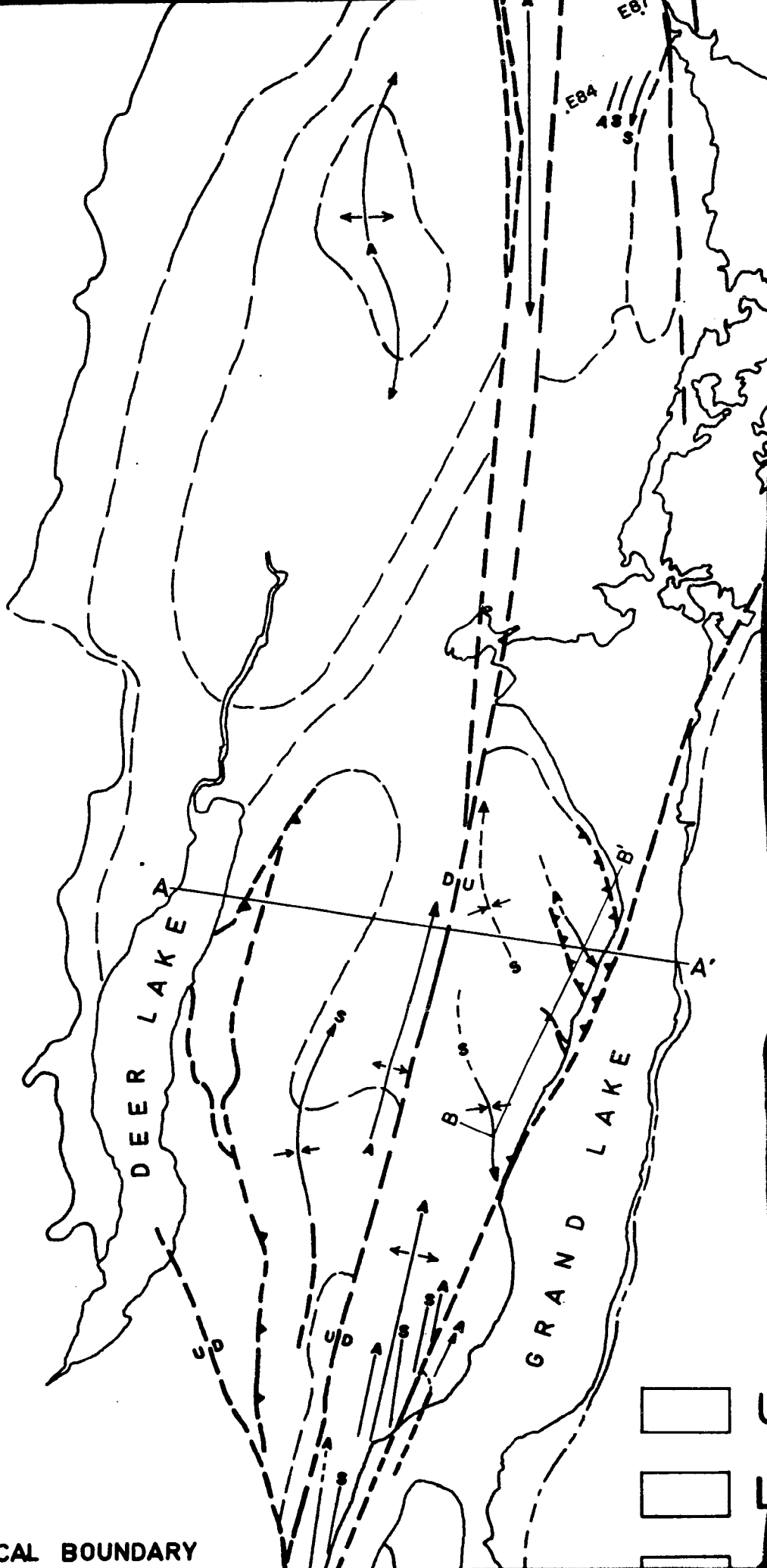
Plate 9 Generalized Geologic Map of Grand Lake-
White Bay Region, West-Central Newfoundland



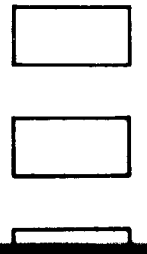


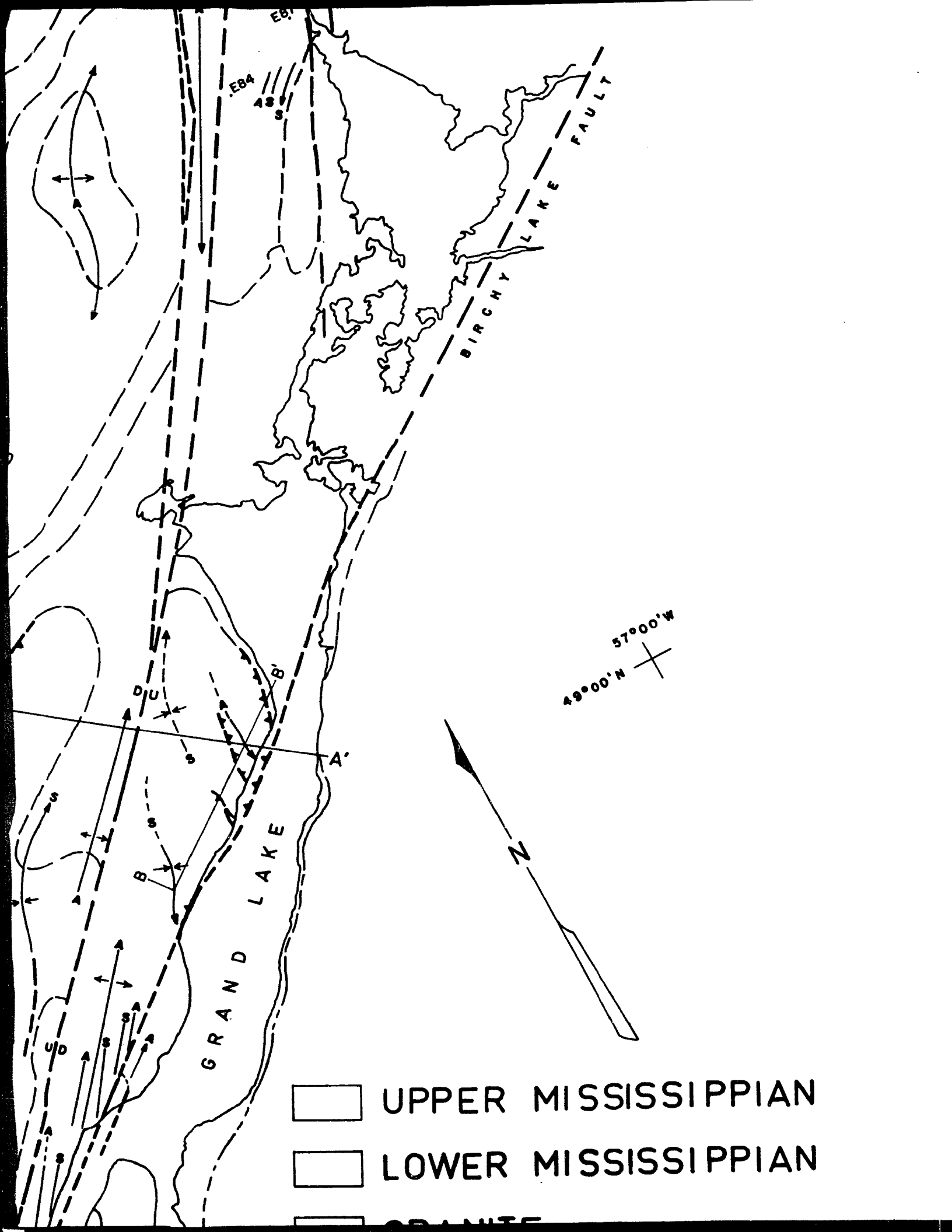
PLATE 9 -

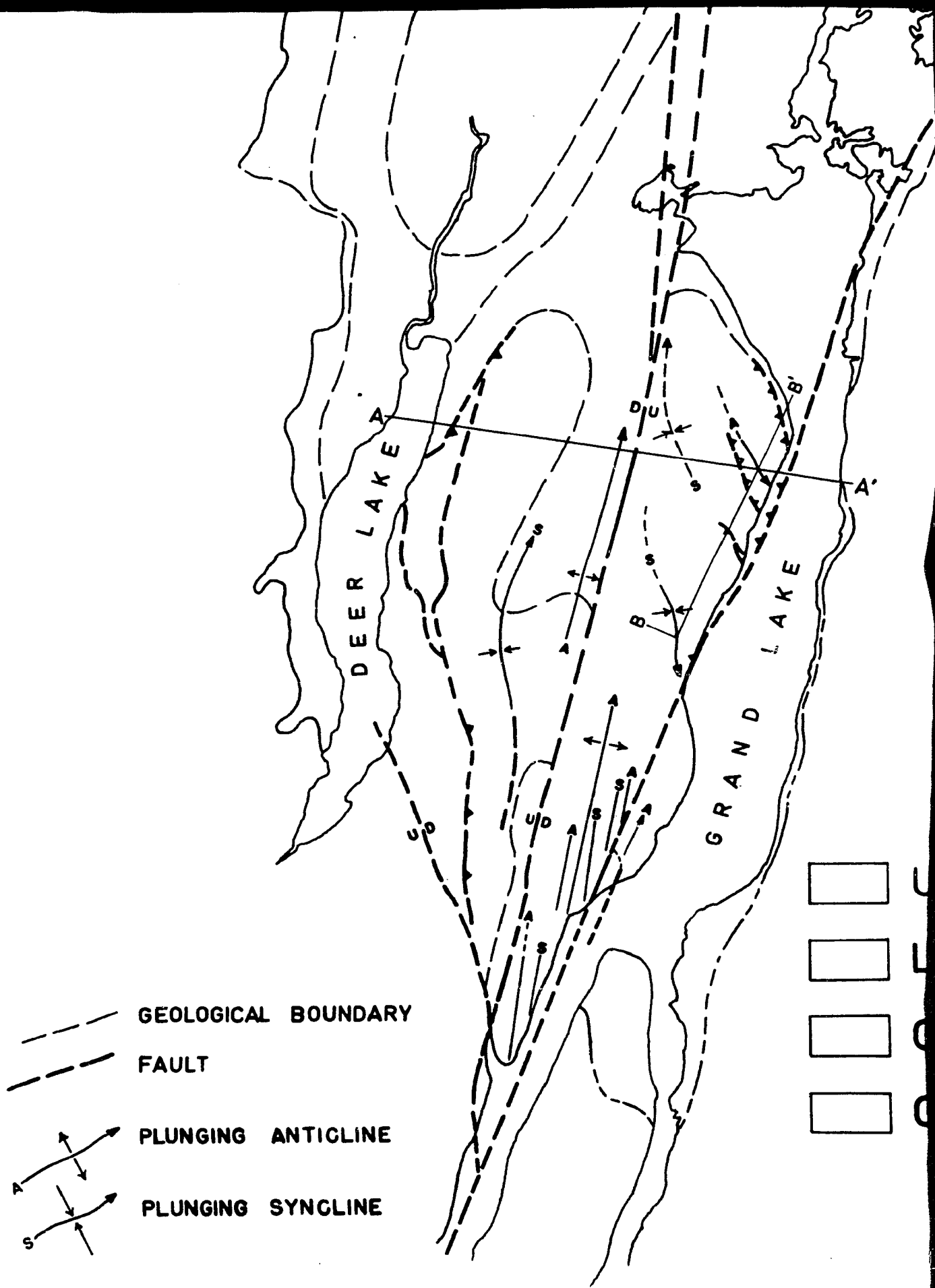
GENERALIZED GEOLOGIC MAP OF THE
 GRAND LAKE - WHITE BAY REGION,
 WEST-CENTRAL NEWFOUNDLAND

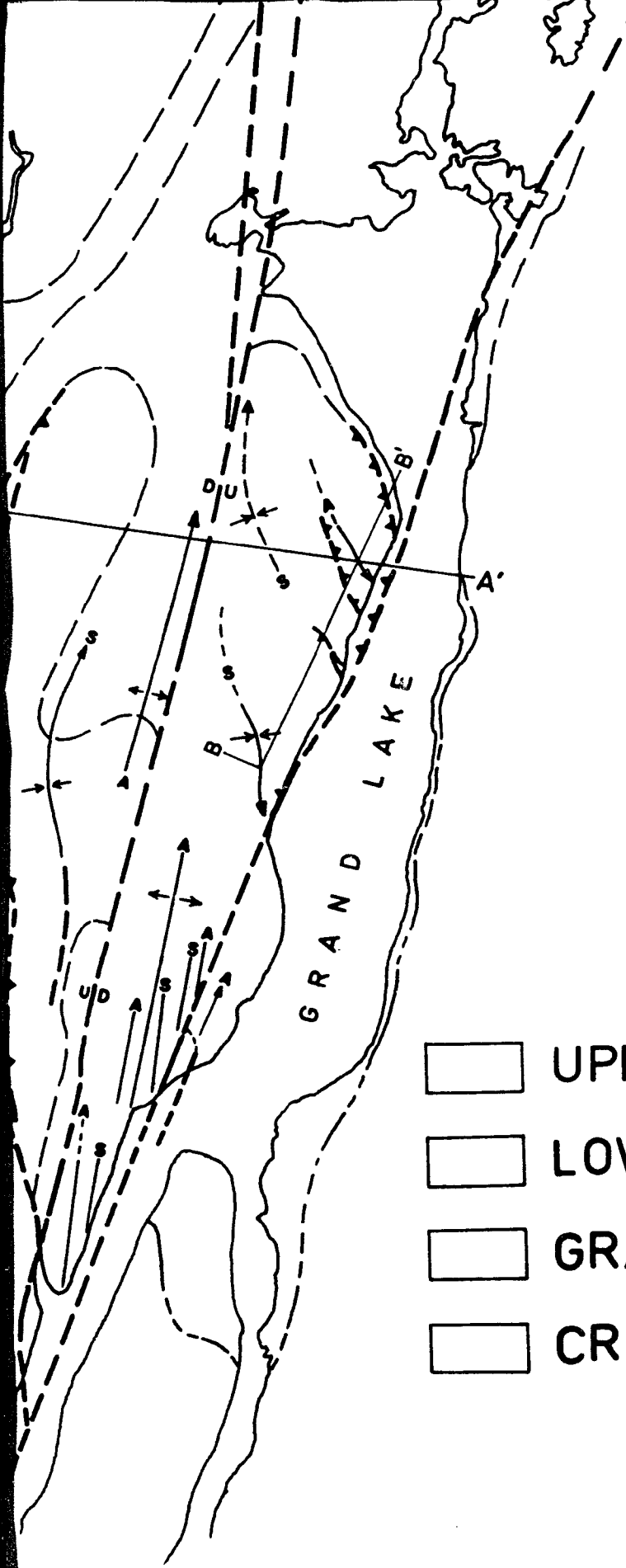


--- GEOLOGICAL BOUNDARY

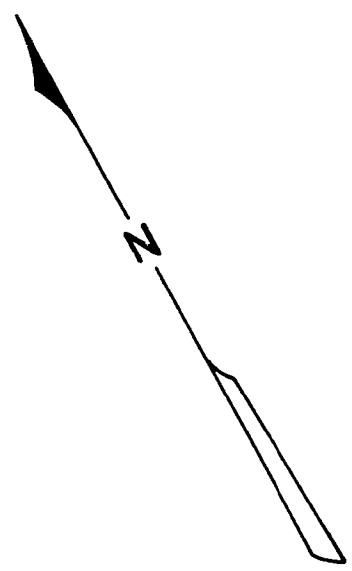




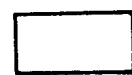
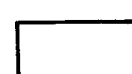


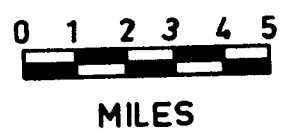




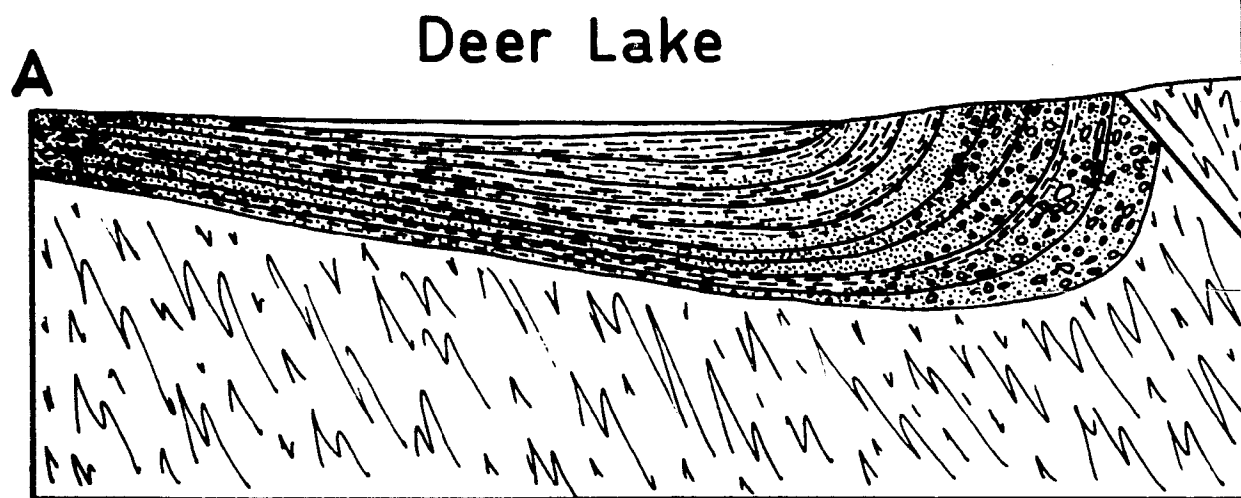
49°00'N
57°00'W



-  UPPER MISSISSIPPIAN
-  LOWER MISSISSIPPIAN
-  GRANITE
-  CRYSTALLINE BASEMENT



XUM



6

□ UPPER MISSISSIPPIAN

□ LOWER MISSISSIPPIAN

▣ GRANITE

▣ CRYSTALLINE BASEMENT

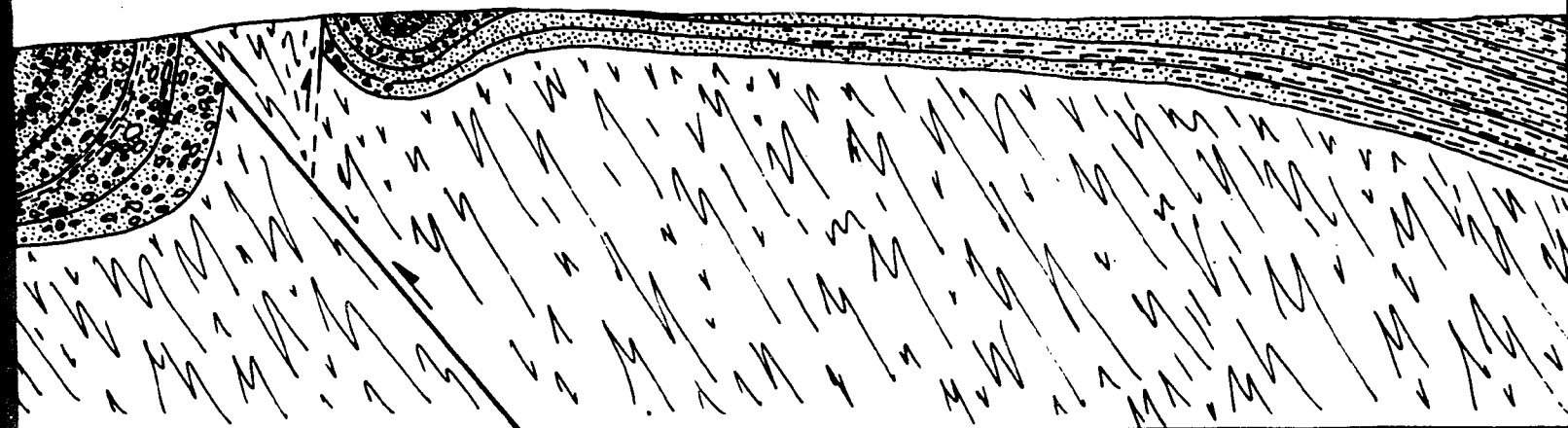
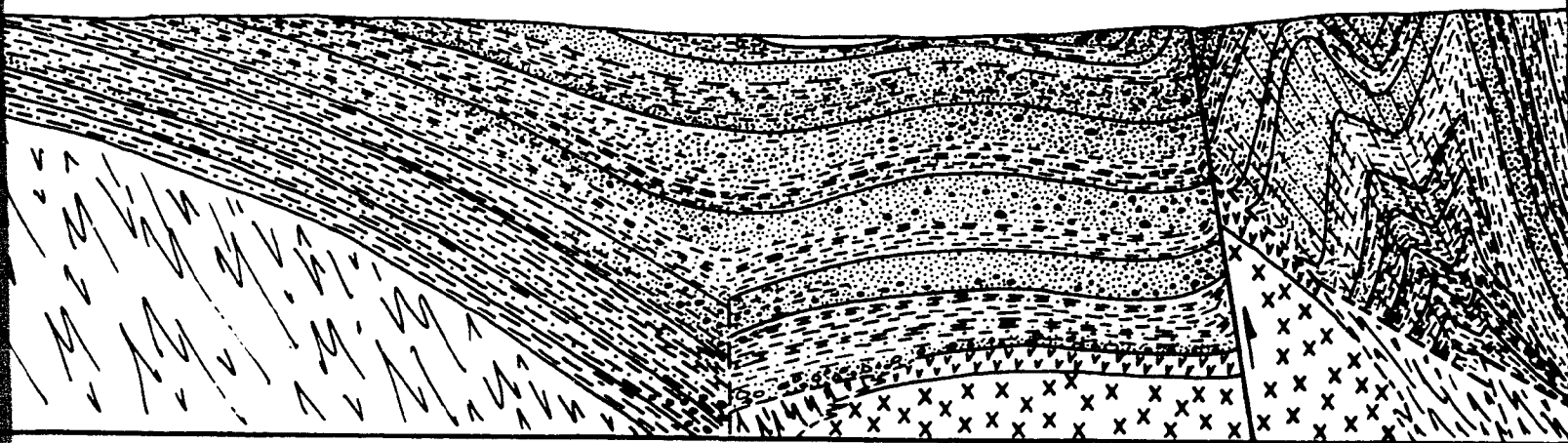


PLATE
CROSS-SECTION A-A', G
WEST-CENTRAL NEW

T

← N 53° W →



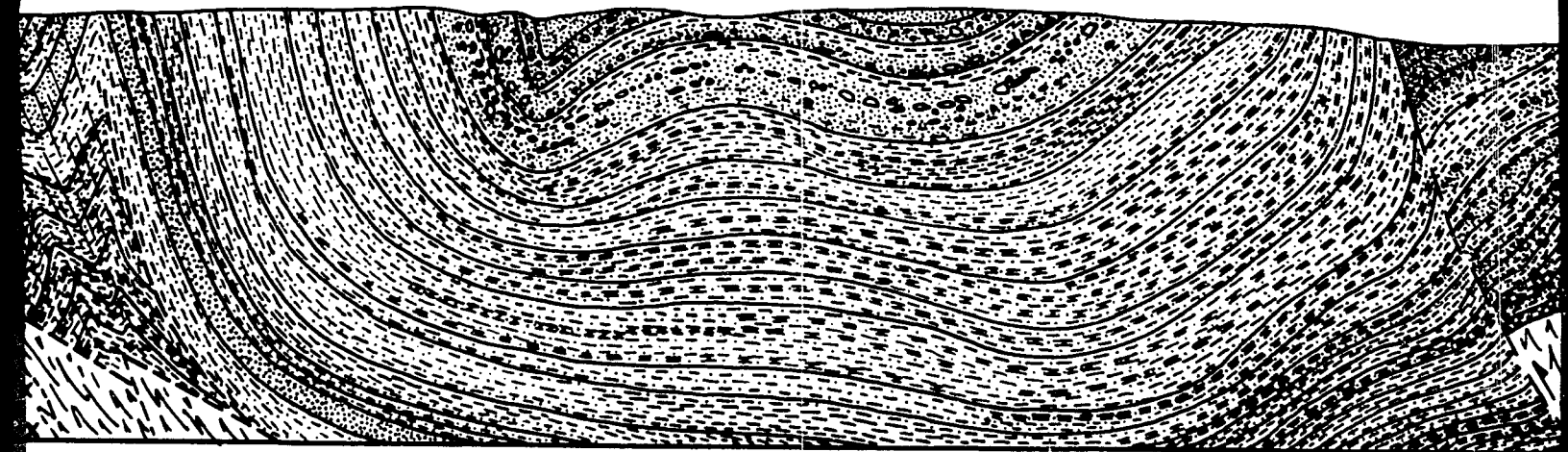
ONE MILE

NO VERTICAL EXAGGERATION

PLATE 10

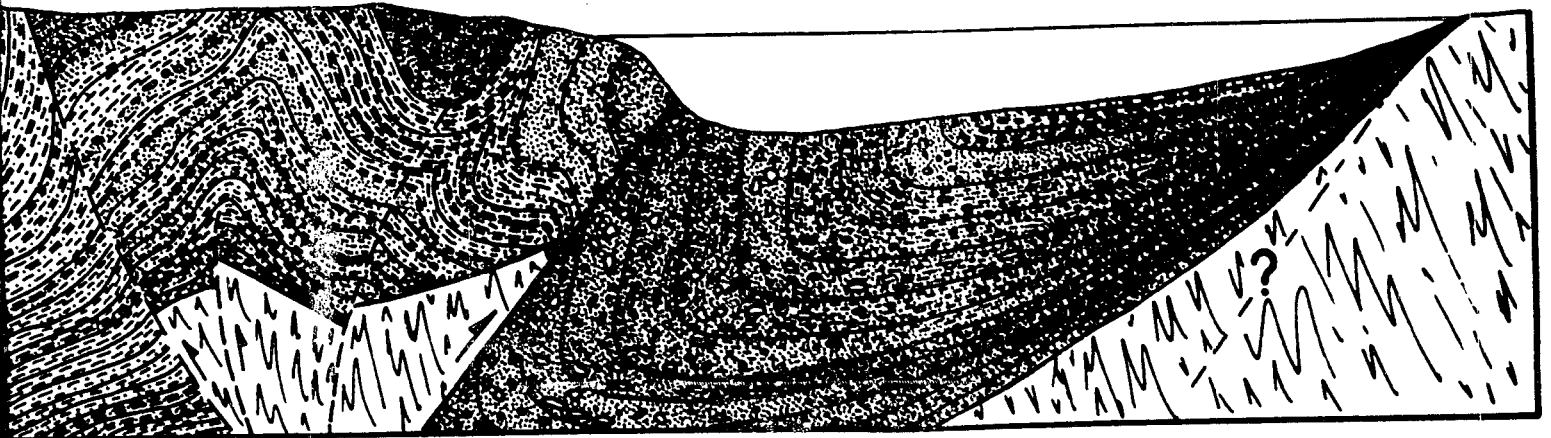
A-A', GLIDE MOUNTAINS,

AL NEWFOUNDLAND



Grand Lake

A'



G. POPPER '70