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GEOLOGY AND PETROGRAPHY OF ORDOVICIAN VOLCANIC ROCKS, BATHURST–NEWCASTLE DISTRICT, NEW BRUNSWICK.

University of Cincinnati, Ph.D., 1964
Geology

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# GEOLOGY AND PETROGRAPHY OF ORDOVICIAN VOLCANIC ROCKS, BATHURST-NEWCASTLE DISTRICT, NEW BRUNSWICK

A dissertation submitted to

The Graduate School

of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

1964

by

Robert A. Jones
B.Sc. University of New Brunswick 1957
M.Sc. University of New Brunswick 1960

# UNIVERSITY OF CINCINNATI

June 15, *19* 64

*I hereby recommend that the thesis prepared under my supervision by* Robert Alan Jones

*entitled* Geology and Petrography of Ordovician Volcanic Rocks, Bathurst-Newcastle District, New Brunswick

*be accepted as fulfilling this part of the requirements for the degree of* Doctor of Philosophy

*Approved by:*

William F. Jenks

Edward H. Larsen

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Geology and Petrography of Ordovician Volcanic Rocks, Bathurst-Newcastle District, New Brunswick
by Robert A. Jones



ABSTRACT

The Bathurst-Newcastle Mining District is in the eugeosynclinal part of the northern Appalachian geocyncline. In the present study an area of about 200 square miles across the center of the district was mapped. The purposes of the study were (1) to map the geology and determine all possible geological relationships during the three summers available, and (2) to study the metamorphism of the acid metavolcanic rocks, with particular emphasis on the development of augen schists and quartz-mica schists. The present work is the first comprehensive regional study of these acid metavolcanics.

The region has low relief and dense forest cover. Much of the area is covered by a veneer of glacial drift. These factors combined with a complex structure, lack of marker horizons, and moderate but variable degrees of metamorphism necessitates mapping on a lithologic basis mainly.

Gross stratigraphic relations were established for the Ordovician complex. The oldest of these units consist of rhyolite flows and tuffs and form the central part of a domal structure approximately 25 miles in radius. This core is rimmed by quartz and feldspar augen schist with assorted metasedimentary rocks. The youngest of these units form an outer rim of dominantly intermediate

volcanic rocks with thick sequences of metasedimentary units.

The principal period of deformation, the Acadian orogeny (late Devonian), has produced pronounced structural features that trend northeast-southwest. Major folds are prominent with axes plunging steeply northeast and southwest. Minor folds appear to be associated with shearing along major fault zones. Acadian structures have been superimposed on northwest-southeast striking Taconic (late Ordovician) structures.

Two directions of faulting have been recognized, one northeast-southwest and a second northwest-southeast. Displacements are not apparent from the data available and only relative movements can be indicated. Although in the past there has been a tendency to explain structures in the area by folding alone, the present work suggests that faulting may be equally important.

Metavolcanic and metasedimentary rocks display a prominent schistosity which has developed as bedding plane foliations apparently through compaction and later dynamic metamorphism.

Granitic intrusive rocks occurred during the Acadian orogeny, but no Ordovician granites have been recognized in the area. Massive rhyolite porphyry bodies in the central part of the structure are here interpreted as remnant cores of Ordovician volcanoes; however, gabbroic rocks intruded during the Taconic and Acadian orogenies have been recognized. Other narrow diabase dykes may be of Triassic Age.

Regional metamorphism associated with the Taconic and Acadian orogenies has been largely of a dynamic nature in the greenschist facies. Equilibrium was not established so that subfacies cannot be recognized, but it is possible to observe varying metamorphic intensities. On a local scale increase in metamorphic intensity can be related to shear, and on a regional scale it can be related to rock type. In this respect there appears to be an increase in intensity from southeast to northwest.

Metamorphism has locally destroyed most of the original features of the rocks. However, available textural and mineralogical evidence indicates the augen schists have been derived largely from tuffs by dynamic metamorphism. Present variations in chemistry and physical appearance of the augen schists are accounted for by variation of depositional environments, weathering and varying degrees of dynamic metamorphism. Augen schists resulting from the metamorphism of flows and pyroclastics have also been recognized.

Massive intrusive rhyolites and flows represent the least metamorphosed rocks of the acid volcanic series. Associated tuffs have reacted more rapidly to dynamic metamorphism. Increase in shear is evident in more pronounced schistosity and production of small augen from the quartz and feldspar phenocrysts of the original rock. Where shearing is extreme the augen schists are converted to quartz-mica schists.

Deformation in response to shear has been both brittle and plastic. Phenocrysts tend to be destroyed by crushing with resultant alteration effects. The matrix has been recrystallized and is indicative of failure by plastic means. There appears to have been no appreciable addition of material during metamorphism.

Mineralogically, the acid volcanic rocks are simple. They are composed predominantly of quartz and low temperature forms of K-feldspar and Na-plagioclase. Various features of the minerals are indicative of igneous origin. In the series massive rhyolites - augen schists, sericite forms at the expense of K-feldspar. In the more highly reconstituted rocks secondary albite and biotite also become prominent. The appearance of biotite porphyroblasts and garnet in increased amounts in some rocks may indicate increasing grade of metamorphism or only compositional variations. Rocks of the dacite group have been altered through propylitization and epidote is a major product.

## ACKNOWLEDGEMENTS

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The writer also wishes to express his gratitude to his able and conscientious field assistants: Mssrs. D. Davis, H. Bowen, R. Prakash, H. Smith, W. Reksalegora, D. Lawson, P. Hickey, W. Pollock, T. Mersereau, G. Ross, and G. Ingersoll.

Thanks are extended to the entire faculty and graduate student body of the Department of Geology at the University of Cincinnati for many helpful suggestions, criticisms and assistance in laboratory proceedures.

Finally, special thanks are accorded to my wife for her invaluable assistance in the preparation of the maps and manuscript.

# C H A P T E R

# O N E

# INTRODUCTION

## Purpose and Scope of the Investigation

The purpose of this report is twofold; first, to present the geology of a part of the Bathurst-Newcastle mining district in northern New Brunswick, and second, to present the results of a detailed field and laboratory study of certain acid volcanic rocks which occur in this area. These porphyritic rocks are of particular interest because of their close spatial relationship to the massive, stratigraphically controlled, sulphide deposits of the area. It has been contended, since the discovery of the first sulphide deposits, that this rock sequence bears some genetic relationship to the emplacement of the massive sulphides.

The writer has spent five summers in the Bathurst-Newcastle district, mapping certain areas as part of a detailed program being carried out by the New Brunswick Mines Branch. Through the summers of 1960, 1961 and 1962 the writer was engaged in mapping the N - 6, O - 7, and the O - 8 "quarter-mile" sheets (Plate I). These three maps constitute areas of primary economic interest within the mining district and have been published by the New Brunswick Mines Branch on the scale of 4 inches to the mile (Jones, 1961, 1963, 1964). Each sheet encompasses 12 minutes of longitude and 6 minutes of latitude, or a total area of approximately 60 square miles. Together they (Plate I and Plate VII) traverse a section across the whole of the mining district in a northwest-southeast direction and include all the major lithologic units in the district.

These three maps are fundamental to the understanding of the geology of the district, show the contributions to the geology of the writer, and form the framework for a study of the acid volcanic units.

The summer of 1963 was spent in the field studying the acid volcanics on a regional scale, collecting samples, and studying the lithologic variations in the porphyritic units.

Laboratory studies involved mineralogical and textural study of numerous rock samples of the acid volcanic types. The work entailed the preparation and study of two hundred thin sections, heavy mineral separations, identification of minerals by x-ray diffraction and chemical analysis by flame-photometry. Feldspar mineralogy was in special cases determined by the use of Rittman zone methods, utilizing the universal stage.

## Previous Work

This study represents the first attempt at a regional study of the acid volcanic sequence in the Bathurst-Newcastle area. Earlier work on this rock unit by Sawyer (1957), Loudon (1960), and Pearce (1963) dealt with specific areas. Sawyer (1957) made a petrographic study of rock samples from drill core at the Brunswick Number 6 and Number 12 sulphide zones. Loudon (1960) described the "porphyries" and related rocks on the Devils Elbow mining property of the American Metal Company (Plate VII). Pearce's (1963) work entailed a study of "porphyritic" units from the Brunswick Number 6 property and areas immediately east of there.

There are several earlier papers on the general geology of the Bathurst-Newcastle area. Skinner (1956) mapped the Tetagouche Group for the Canadian Geological Survey, and his study summarizes the general geology with special attention to the porphyritic units. Smith (1957) compiled the latest and most complete map of the general geology. This map, which has been reproduced as Plate I from Roy (1961), has been the standard reference since its publication. Earlier work on the geology of northern New Brunswick was conducted by Ells (1881-1883), Young (1911), and by Alcock (1941).

Since 1955 the New Brunswick Mines Branch has conducted a mapping program in areas of economic interest (Plate I) in the Bathurst-Newcastle district. The results of this work have been published as a series of maps on the scale of 4 inches to the mile.

## TOPOGRAPHY

The Bathurst-Newcastle mining district is situated in the Central Highlands of New Brunswick. This region is composed of rolling hills and wide valleys. Heavy glaciation accounts for the rounded nature of the hills. Although the region is an extension of the Appalachian mountain chain, there are scarcely any hills which reach the proportions of mountains. The highest elevation, Mount Carleton (2690'), is west of the headwaters of the Nepisiquit River, not far beyond the west border of Plate I. Other elevations above 2000 feet are common. The highest hills are in the western part of the region. Figure 1 (Plate V) shows a view west and northwest from the summit of Little Bald Mountain (N - 8). Mount Carleton is visible on the south side of the photo. It is notable that the majority of high hills in the western extremity of the area are underlain by granitic batholiths of Devonian age.

From Little Bald Mountain elevations decrease northeastward toward the Bay of Chaleur. This area, according to Young (1911), may be considered as a tilted plain, rising out of the Bay of Chaleur and attaining higher altitudes to the west.

Figure 2 (Plate V) is a view north from the summit of Little Bald Mountain, looking across the wide expanse of the Nepisiquit River Valley. Mt. Fronsac (elevation 2100 feet), on the N - 7 sheet, is visible on the horizon north of the Nepisiquit River. The topographic expression is caused primarily by rhyolitic rocks, which are typical for the district, and the youthful character of the tributary streams to the Nepisiquit system.

Figure 3 (Plate VI) is a view east over the tilted plain towards Bathurst, from the Tetagouche fire tower in the south-east corner of the O - 5 map. The topography is nearly featureless and is an expression of glaciation and underlying bedrock, which consists of softer sedimentary and basic volcanic rocks.

Figure 4 (Plate VI) is a view southwest onto the N - 6 map from the same locality as above. Again the topography appears featureless.

The mining district is drained by two major water systems (Plate I), the Nepisiquit and the Miramichi Rivers. The former has been adversely affected by the

PLATE V : TOPOGRAPHY OF THE BATHURST - NEWCASTLE DISTRICT.

Figure 1 . View west from Little Bald Mountain, south-west corner of N - 8. Rugged topography is characterized by granite batholiths.

Figure 2 . View north from Little Bald Mountain. Ne-pisiquit River valley runs east-west across the photo behind first range of hills. Western edge of map sheet O - 8 is visible in east side of photo.

# PLATE V

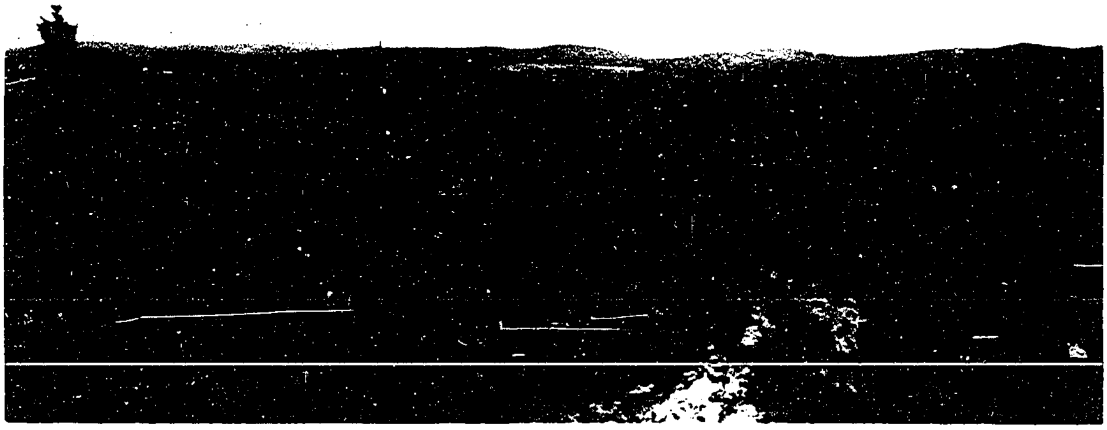


Figure 1

Figure 2

PLATE VI : TOPOGRAPHY OF THE BATHURST - NEWCASTLE DISTRICT

Figure 3. View east from Tetagouche fire tower, southwest corner of O - 5 map sheet. Topography relatively flat.

Figure 4. View southwest from Tetagouche fire tower over the N - 6 map area. Topography relatively flat.

# PLATE VI

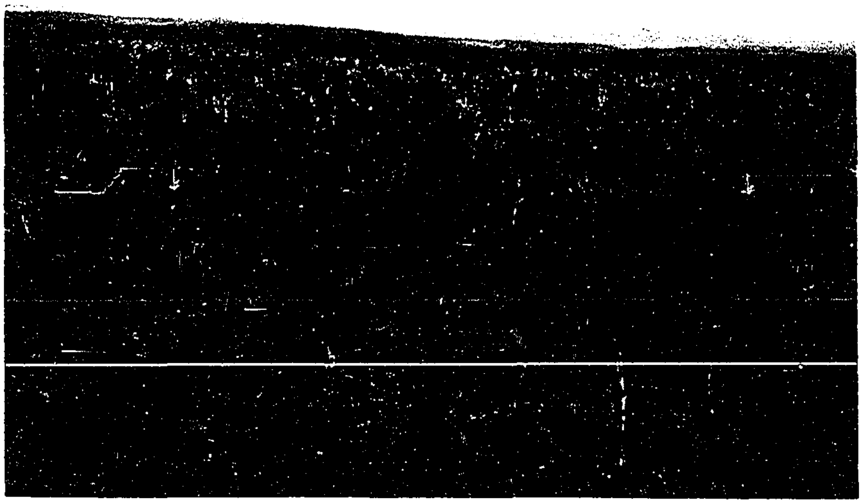


Figure 3

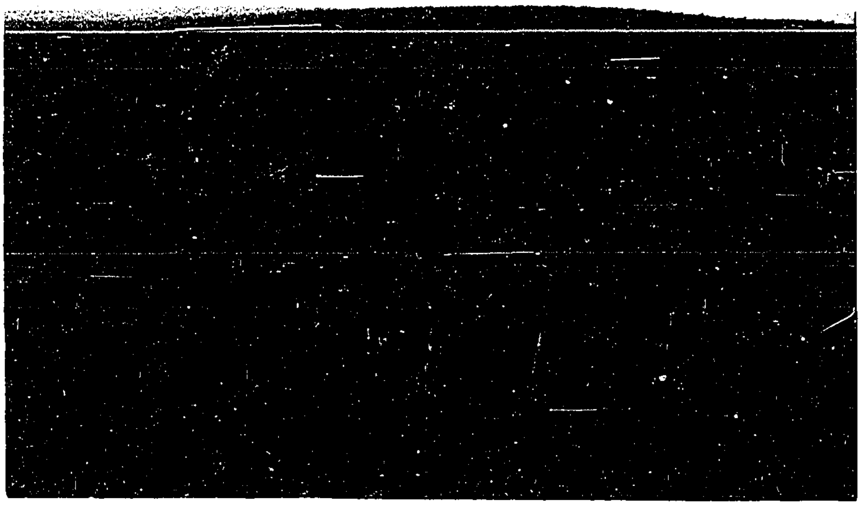


Figure 4

glacial period and shows many characteristics of a youthful stream flowing in a mature valley. The Miramichi River has reached a higher state of equilibrium and approaches the stage of maturity.

## HISTORY OF THE BATHURST-NEWCASTLE MINING DISTRICT

The history of mining development in the Bathurst-Newcastle area of New Brunswick is relatively short, although mineral occurrences have been known for over one hundred years. Two factors combined to restrain the early discovery and development of mineral deposits in this area. The region is covered not only by a dense forest cover, but also by a relatively thin, uniform layer of glacial drift. Prior to the advent of geophysical instruments and their use as exploration tools, the only means of exploration and discovery was through direct surface outcropping or through the tracing of mineralized glacial float.

The earliest date of mineral discovery is listed as 1837 (Gesner, 1947) when the Gloucester Mining Association gained rights from the Provincial Government to explore and mine a copper deposit on the Nepisiquit River south of the town of Bathurst. Between 1837 and 1900 government geologists and prospectors explored the area for mineral wealth. A few showings were discovered, but for the most part they were not economical or were not conducive to further work.

The first major mineral discovery in the Bathurst-Newcastle area was made by William Hussey, who in 1902 located a hematite-magnetite deposit seventeen miles south of Bathurst near the junction of Austin Brook and the Nepisiquit River. This iron-rich deposit lies immediately south of, and in contact with, the massive sulphides of the Brunswick Mining and Smelting Number 6 ore zone (Plate I). Between 1907 and 1913 a total of 181,127 tons of ore were shipped from this property to the steel mills in Philadelphia. The property closed down but was reopened during 1942 and 1943 to supply iron ore to the steel mills at Sidney, Nova Scotia.

Prior to 1950 a few base metal occurrences were known, and some development work was completed. However, active prospecting was greatly curtailed by lack of trained personnel and the ineffectiveness of surface prospecting. A few of these early discoveries merit attention as they were forerunners of later discoveries and served to keep prospectors interested in further exploration. Prior to 1900 lead and zinc deposits were known to occur in the Elmtree River area (Mackenzie, 1958), but it was not until 1952 that any extensive work was done on them. At this time the M.J. Boylen interests optioned the Elmtree Group, and, encouraged with the results of a diamond drilling program, Keymet Mines Limited was incorporated to operate the mine. Production began in 1954, and, although it ceased operations in 1956, it was the first mine to produce base metal concentrates in the Province of New Brunswick.

A base metal boulder, discovered in 1860 on Armstrong Brook, aroused periodic interest. However, it was not until 1938 that a large base metal deposit was discovered on Orvan Brook. Tracing of copper-rich float in a boulder train led to the discovery. The ore body is narrow, but it is significant in being over 6000 feet in total length and in being stratigraphically controlled. The sulphide zone is presently held by the Tetagouche Exploration Company Limited (New Calumet Mines Ltd.) which in 1953 outlined 150,000 tons of ore.

Between 1940 and 1952 work was concentrated along the Rocky Brook-Millstream break between the Ordovician and Silurian systems (See Plate I). A number of small ore showings were discovered. One of these is the property presently held by Sturgeon River Mines Limited.

G.S. MacKenzie (1958), writing on the post-war period 1945-1952 states:

> It had long been realized that development of natural resources in New Brunswick was hampered by a lack of information. The provincial government took steps in the post-war period to overcome this deficiency .... Adequate base maps for various types of surveys, some of them geological, were a first requisite. A program of aerial photography was instituted and maps soon followed. The photographs themselves, of course, aided greatly in later geological interpretation and provided specific guidance to some discoveries .... (Notably the Anaconda-Caribou deposit on N - 6).
>
> The New Brunswick Resources Development Board was instrumental in securing an aeromagnetic survey of much of northern and central New Brunswick in 1950 and 1951 ..... The first maps appeared in 1951. The aeromagnetic survey helped to overcome the problem of the overburden, greatly aided geological interpretation and gave guidance to exploration.

In 1951 Brudon Enterprises Limited of Montreal received a concession covering the area of the Drummond Iron Mine at Austin Brook. The main interest was a source of sulphur, and in 1952 the M.J. Boylen organization optioned the property to investigate the occurrence of base metals in association with pyrite on the footwall of the iron mine. The company conducted an electromagnetic survey further north, and the testing of anomalies by diamond drilling led to the discovery of the Brunswick Mining and Smelting Number 6 zone, the largest massive base metal occurrence to this time. The Boylen organization quietly staked a large area of ground and incorporated a number of companies to explore it. So successful was this enterprise that it was not until January of 1953 that word of the initial discovery leaked out. A larger discovery by the same company followed closely and was again the result of a geophysical survey. This deposit is located six miles northwest of the former and is known as the Brunswick Mining and Smelting Number 12 ore zone. At the present time this body is being developed, plans are complete for production, and a smelter is being built north of Bathurst, primarily to handle the ore from this mine.

The announcement of sulphide discoveries in the Bathurst area set off a staking rush in northern New Brunswick which surpassed any ever witnessed in Canada. Whereas most mining regions were primitive wastelands at the outset, the Bathurst-Newcastle region supplied ample accessibility routes and local access to needed supplies.

After the initial rush in the winter of 1953 several new properties were discovered, and development work was carried out on the more promising. Among these were the New Larder "U" property (No. 12, Plate I) and the Nigadoo Mine (No. 2, Plate I) both discovered in 1953. During the summer of 1953 a broad systematic airborne electromagnetic survey of northern New Brunswick was conducted by the American Metal Company Limited. Immediate ground study of airborne anomalies led to the discovery of the huge Little River ore-bodies in 1954 (No. 15, 16, 17, Plate I). The Middle River Mining Company Limited and Conwest Exploration Company Limited discovered base metal orebodies in 1955 near the head of the Northwest Miramichi River (No.13, Plate I). In late 1955 the Anaconda Company (Canada) Limited discovered the large Caribou deposit on the headwaters of Forty Mile Brook (No. 6, Plate I).

Since 1956 exploration has continued on a diminished basis. The Anaconda Company continued its study outward from Caribou and discovered two deposits in the same belt of rocks, one near the head of Armstrong Brook (No. 7, Plate I) and a second near Rocky Turn (Map O - 5) on the Tetagouche River. Other discoveries include two by the American Metal Company, one near Forty Mile Brook and the other north of Devils Elbow on the Nepisiquit River (Plate VII); two by Kennco Exploration, one on Eighteen-mile Brook (No. 18, Plate I) and the other along the middle course of the Nepisiquit River, and the Consolidated Mining and Smelting Wedge (No. 10, Plate I), west of Forty Mile Brook. To date the Wedge Mine is the only one actively producing lead-zinc-copper concentrates. Later discoveries include the New Jersey Zinc property near Portage Lakes (No. 5, Plate I) and a nickel-bearing meta-norite staked by Noranda Mines Limited near Goodwin Lake on sheet N - 9.

During the early phases of the mining rush a detailed geologic picture of the district was beginning to emerge. Since that time company, federal and provincial geologists have combined to present a fairly comprehensive picture of the geology.

## REGIONAL GEOLOGY AND TECTONIC HISTORY

The Maritime Provinces form the northerly extension of the major physiographic division termed the Appalachian Mountains in the United States. Young (1911) states:

> The Appalachian mountains extend from Alabama northeastward into New York state. Farther northward they are continued by the Green mountains of Vermont, the White Mountains of New Hampshire, and the mountainous country of the State of Maine. In Canada they are represented by the Notre Dame mountains in the Eastern Townships of Quebec, and by the Shickshock mountains of Gaspé peninsula. In New Brunswick and Nova Scotia, on the other hand, though much of the two provinces are much broken and relatively elevated, they can scarcely be termed mountainous, and the propriety of including the Maritime Provinces within the Appalachian region is to be justified by the general northeasterly trend of the major physiographical features, and the general geological structure and history of the two provinces.

Locally, the Bathurst-Newcastle district lies in an area of highly deformed rocks of the early Paleozoic which Skinner (1953) placed within the Tetagouche Group of Ordovician age. This belt of early Paleozoic rocks has been regionally metamorphosed and intruded by granitic batholiths. The linear trend of granites and folded Paleozoic rocks compose the Central Highlands, which traverse the province in a northeast-southwest direction from Bathurst to the Maine border. This feature is illustrated in figure 5, from Neale, Beland, Potter and Poole (1961).

The Central Highlands of New Brunswick are flanked to the northwest by the Northwest Plateau consisting of less-folded and less-metamorphosed rocks of Silurian-Devonian and Ordovician age. To the east the area is flanked by the flat, sedimentary rocks of the Carboniferous Basin.

In reference to figure 5, from Neale, Beland, Potter and Poole (1961), it is seen that Ordovician, Silurian and Devonian rocks are common in the northern Appalachians. According to Neale, et al., the rocks in the central part of New Brunswick can be correlated with beds in the New England States, which occur in the inner deformed zone of the Appalachians, and which appear east of the Green Mountain axis in Vermont. The rocks of this sequence are largely of eugeosynclinal type. The northern Appalachians differ from the southern Appalachians in that they contain abundant eugeosynclinal rocks, whereas the rocks of the southern Appalachians are mainly miogeosynclinal. The rocks in the central deformed zone of the Northern Appalachians probably are also eugeosynclinal.

King (1954), in discussing the northern Appalachians in the Vermont and New Hampshire regions states that as one proceeds southwest across the structure the complexity increases through increase in metamorphism and that relationships between rock units become obscure. The rocks in the northern areas of New Brunswick have not been as highly metamorphosed and deformed as those of New England. Correlation with rocks in the New England states is difficult because of the lack of fossil evidence and marker horizons.

In some areas of the northern Appalachians three periods of orogenic movement have been recognized. In northern New Brunswick, on the other hand, only two major orogenies occurred during Paleozoic time (figure 6). The first, in late Ordovician time, is referred to as the Taconic revolution. The effects of the Taconic orogeny are most evident in the northwestern extremity of the chain where the rocks, for a large part, have not been

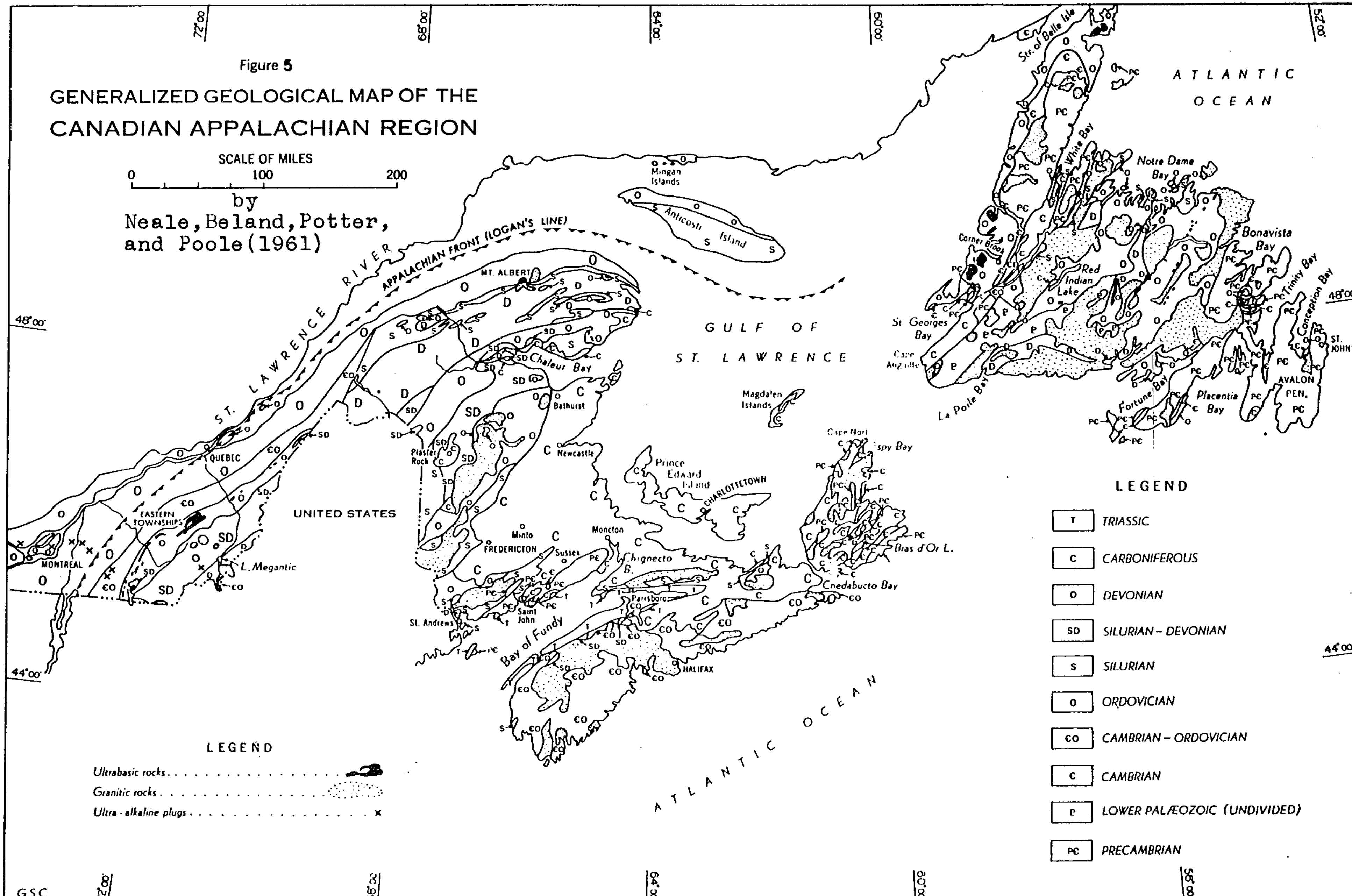


Figure 5
GENERALIZED GEOLOGICAL MAP OF THE
CANADIAN APPALACHIAN REGION
SCALE OF MILES
0 100 200
by
Neale, Beland, Potter, and Poole (1961)
ATLANTIC OCEAN
GULF OF ST. LAWRENCE
ST. LAWRENCE RIVER
APPALACHIAN FRONT (LOGAN'S LINE)
UNITED STATES
Anticosti Island
Mingan Islands
Magdalen Islands
Prince Edward Island
CHARLOTTETOWN
QUEBEC
MONTREAL
EASTERN TOWNSHIPS
L. Megantic
MT. ALBERT
Chaleur Bay
Bathurst
Newcastle
Plaster Rock
Minto
FREDERICTON
Moncton
Sussex
Saint John
St. Andrews
Bay of Fundy
Chignecto B.
Parrsboro
HALIFAX
Chedabucto Bay
Bras d'Or L.
Corner Brook
Red Indian Lake
White Bay
Notre Dame Bay
Bonavista Bay
Trinity Bay
Conception Bay
ST. JOHN'S
AVALON PEN.
Placentia Bay
Fortune Bay
La Poile Bay
St Georges Bay
Str. of Belle Isle
LEGEND
Ultrabasic rocks
Granitic rocks
Ultra-alkaline plugs
LEGEND
T TRIASSIC
C CARBONIFEROUS
D DEVONIAN
SD SILURIAN – DEVONIAN
S SILURIAN
O ORDOVICIAN
CO CAMBRIAN – ORDOVICIAN
C CAMBRIAN
P LOWER PALÆOZOIC (UNDIVIDED)
PC PRECAMBRIAN
GSC

affected by later orogenies. By reference to Figue 6 (Neale, *et al.*, 1961), it can be seen that the Taconic orogeny affected the rocks of the Bathurst-Newcastle area, but that the orogeny is more clearly indicated in the rocks south of the St. Lawrence River. This far western zone of the Canadian Appalachians can be traced southwestward into western Vermont and eastern New York state. Toward the central part of the Canadian Appalachians the effects of the Taconic orogeny are largely overshadowed by the succeeding Acadian orogeny, but results of the first orogeny are evident. For example, Smith and Skinner (1958) indicate that there have been two major periods of deformation in the Bathurst-Newcastle area and that the first period of folding (Taconic) is responsible for the structures which display a northwest trend.

Neale, *et al.* show that in the Canadian Appalachians the Taconic zone affects the broad area from the St. Lawrence River southeastward to the Bay of Fundy. The assemblage of rocks in the middle Taconic zone (Bathurst-Newcastle area) are indicative of deep water deposits with an abundance of intermediate pillow lavas, greenstones, cherts, greywackes, argillites, and graptolitic slates. Neale, *et al.* state:

> No typical calc-alkaline granitic rocks of undisputed Ordovician age are known in the Canadian Appalachian region, whereas Ordovician granites have been recognized in New Hampshire and Maine.

The appearance of Ordovician granites to the southwest, in the northern Appalachians, apparently contributed to the higher degree of metamorphism and complexity of the region towards the Central Appalachians.

The whole New Brunswick region was affected by the Acadian orogeny which culminated in the middle or late Devonian time. It is the effects of this orogeny which are most evident in the central area of the province. Smith and Skinner (1958) state that the second phase of orogenic development produced the dominant northeast trend in the structure. Large granitic intrusives accompanied the orogenic period and can be traced southwest into the New England States.

King (1954) states:

> Deformation is least toward the northeast, in Gaspé and northern New Brunswick. In Gaspé only one large granitic intrusive, that of Tabletop Mountain, is present. The Silurian and Devonian rocks, in contrast to those of the Quebec Ordovician sequence which underlie them to the north, are thrown into broad open folds assymetrical toward the northwest. Sharp folding and cleavage occurs only locally (Alcock, 1936).
>
> Southwestward along the strike, into New England, the rocks of the central belt become progressively more and more meta-

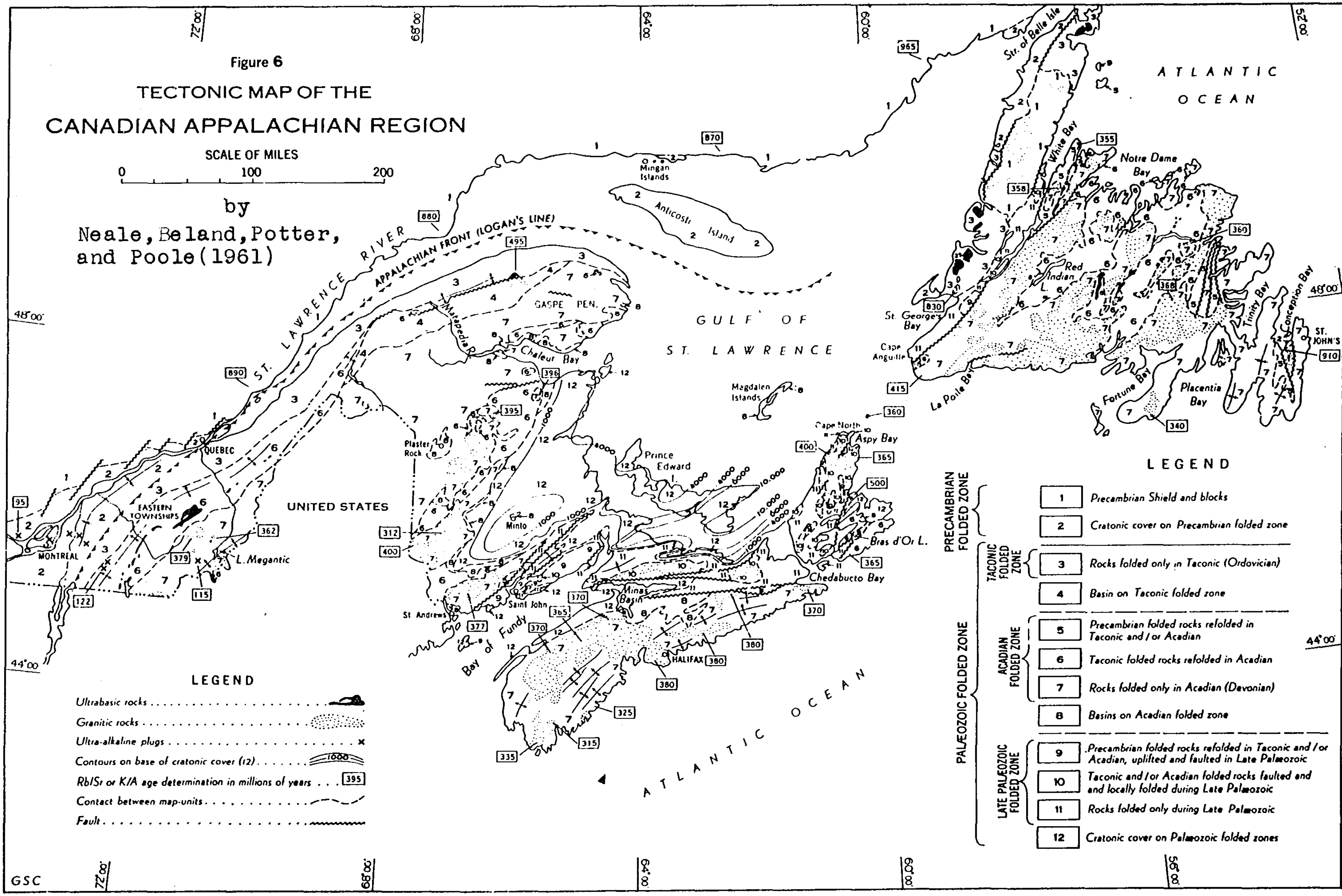


Figure 6
TECTONIC MAP OF THE
CANADIAN APPALACHIAN REGION
SCALE OF MILES
0
100
200
by
Neale, Beland, Potter, and Poole (1961)
ST. LAWRENCE RIVER
APPALACHIAN FRONT (LOGAN'S LINE)
GASPE PEN.
Chaleur Bay
Matapedia
QUEBEC
MONTREAL
EASTERN TOWNSHIPS
L. Megantic
UNITED STATES
Plaster Rock
Minto
Saint John
St Andrews
Bay of Fundy
Minas Basin
HALIFAX
Prince Edward
Mingan Islands
Anticosti Island
GULF OF ST. LAWRENCE
Magdalen Islands
Cape North
Aspy Bay
Bras d'Or L.
Chedabucto Bay
ATLANTIC OCEAN
Str. of Belle Isle
White Bay
Notre Dame Bay
Red Indian L.
St. George's Bay
Cape Anguille
La Poile Bay
Fortune Bay
Placentia Bay
Trinity Bay
Conception Bay
ST. JOHN'S
72°00'
68°00'
64°00'
60°00'
56°00'
52°00'
48°00'
44°00'
GSC
LEGEND
Ultrabasic rocks
Granitic rocks
Ultra-alkaline plugs
Contours on base of cratonic cover (12)
RbISr or K/A age determination in millions of years
Contact between map-units
Fault
LEGEND
PRECAMBRIAN FOLDED ZONE
1 Precambrian Shield and blocks
2 Cratonic cover on Precambrian folded zone
PALÆOZOIC FOLDED ZONE
TACONIC FOLDED ZONE
3 Rocks folded only in Taconic (Ordovician)
4 Basin on Taconic folded zone
ACADIAN FOLDED ZONE
5 Precambrian folded rocks refolded in Taconic and / or Acadian
6 Taconic folded rocks refolded in Acadian
7 Rocks folded only in Acadian (Devonian)
8 Basins on Acadian folded zone
LATE PALÆOZOIC FOLDED ZONE
9 Precambrian folded rocks refolded in Taconic and / or Acadian, uplifted and faulted in Late Palæozoic
10 Taconic and / or Acadian folded rocks faulted and and locally folded during Late Palæozoic
11 Rocks folded only during Late Palæozoic
12 Cratonic cover on Palæozoic folded zones

> morphosed, and from New Hampshire southward they include middle-rank to high-rank schists containing garnet, staurolite, sillimanite, andalusite, and other metamorphic minerals. With the increase in metamorphic rank, fossils become poorly preserved and more and more difficult to discover. Fossils are abundant at some localities in Maine, a few have been found in New Hampshire and Massachusetts, and none are known in Connecticut.
>
> .....the southward increase in degree of metamorphism expresses an increase in this direction of both dynamic and plutonic activity; that is, an increase in the amount of deformation, an abundance of igneous rocks, and the spread of hydrothermal solutions through the country rock.

This was the last great orogeny to affect the Bathurst-Newcastle area. Later orogenic movements at the end of the Paleozoic period affected the rocks in southern New Brunswick, as well as parts of Nova Scotia and Newfoundland. This period of uplift, the Appalachian Revolution, was responsible for the formation of the southern Appalachian mountains.

In summary, the following sequence of events occurred in the Bathurst-Newcastle area. The first major occurrence was the deposition of great thicknesses of sedimentary and volcanic rocks in an eugeosynclinal environment. The age of this sequence is vague, but the association of volcanics with sediments indicates that deposition was probably going on at the start of the Taconic orogeny. After, or during, the deposition of acid volcanics the whole area was sinking and the metasedimentary rocks of the middle unit, along with the associated acid tuffs and flows, were deposited in an environment that featured a rugged volcanic coastline (McAllister, 1960). A variety of depositional conditions existed, ranging from oxidizing to extreme reducing. It is within this central metasedimentary unit that the massive sulphide deposits may have been deposited in restricted basins along the shoreline. This environment, with sedimentation occurring both above and below water level, could account for pre-metamorphic variations in the augen schists of the district.

Subaqueous conditions were attained with the accumulation of intermediate volcanic units of the outer zone (Plates I and VII). Some of these rocks exhibit pillow structures. The basic volcanic units were probably deposited just prior to the culmination of the Taconic orogeny. The area was uplifted above sea level. During this stage quartzose sedimentary rocks (Unit 1, Plate 1) were deposited as clastics from the erosion of the land surface.

During Silurian time the region was depressed below sea level. Conglomerates, sandstones, limestones and shales were deposited over the region. Devonian sedimentation followed the Silurian with no apparent break in the sequence.

During the Acadian orogeny the area was elevated above sea level, and most of the Devonian and Silurian rocks were stripped off. The Acadian orogeny superimposed prominent northeast trending fold axes on the northwest Taconic structures (Smith, 1957). At the same time, the area was domed by the intrusion of large granitic batholiths. Most of the features of primary deposition, and earlier periods of orogeny were masked by dynamic metamorphism.

After the Acadian orogeny the area was leveled by erosion. It was re-submerged during Pennsylvanian time and partially covered by conglomerates, sandstones and shales of shallow water origin. In deeper parts of the basins, or in restricted zones, evaporite sequences were laid down. At the end of the Paleozoic the region was little affected by the Appalachian orogeny, but was once again elevated above the sea as part of a stable craton. Subsequently, the region has been undergoing erosion.

## GENERAL GEOLOGY OF THE BATHURST-NEWCASTLE DISTRICT

### General Statement

Geological mapping in the Bathurst-Newcastle area has tended to parallel periods of interest in the economic feasibility of iron ores and interest in the search for base metal deposits.

Ells (1881-1883) first described the geology of the Bathurst-Newcastle area. Subsequently, Young (1911), Shaw (1936) and Alcock (1935, 1941) added more to the picture. The Geological Survey of Canada in 1949 initiated a program of mapping on the scale of one inch to the mile. Several maps have been published culminating in those of Smith (1957) and Anderson (1962). The Province of New Brunswick, Mines Branch, has been concentrating since 1954 on geologic mapping at the scale of four inches to the mile. The sheets completed to date are indicated on Plate I.

On a regional scale three structural units can be recognized and described. Plate I shows these units as mapped by Skinner and Smith (1958). The three units are:

1. The Ordovician Folded Belt.
2. The Silurian Folded Belt.
3. The Pennsylvanian Cover.

## The Ordovician Folded Belt

Highly folded metamorphosed volcanic and sedimentary rocks of Ordovician age (Tetagouche group) underlie the central area and form the dominant structure of the Bathurst-Newcastle region. It is within this complex of metamorphic rocks that the large, economic, stratigraphically controlled bodies of massive sulphides occur.

Although the rocks of the siliceous volcanic core have suffered from moderate dynamic metamorphism, as compared to the outer metasedimentary units, there is no apparent orogenic break or apparent age difference between the various horizons, suggesting no major break in the whole Tetagouche Series. The present accepted stratigraphic sequence is indicated in Table I.

Dating of the pre-Silurian rocks has presented a problem which has only been partly solved. Skinner (1953) places the sequence within the Tetagouche Group of the Middle Ordovician period. Age was fixed from the occurrence of graptolites within shale units north of Bathurst along the Tetagouche River. Other fossil localities within the Tetagouche sequence are scarce. Simms (1960) reported a brachiopod occurrence in limestones on the west slope of Camel Back Mountain, which substantiates an Ordovician age. Crinoid stems found in a slate horizon near the Anaconda-Caribou sulphide deposit ( 6, Plate 1) indicate the rocks to be post-Cambrian. These fossil discoveries were both within the metasedimentary rocks. The siliceous volcanic core has not been dated radiometrically. Potassium-argon or strontium-rubidium age determination would be of little value because of the several periods of orogenesis and metamorphism the area has experienced.

Siliceous metasedimentary rocks of unit 1 (Plate I) cover a wide area in the south and southwest. Towards the east and north unit 1 is replaced abruptly by the slate division, unit 5. There is considerable controversy as to the relationship of these two units. Smith (1957) places the siliceous sediments of unit 1 at the bottom of the Tetagouche Group and the slates of unit 5 at the top of the Tetagouche Group. Loudon (1960) points out that the confusion over what are presently mapped as lower and upper members of the Tetagouche Group may be the result of marked sedimentary facies changes. Loudon (1960) also postulates that these rocks may have been silicified by the granites with the development of quartz veins. Although such a development is conceivable, no such bodies of highly silicified rocks have been mapped in the vicinity of the batholith immediately south and west of Bathurst. The writer feels that if a facies relationship exists between these two units it is an original sedimentary feature with the clastic rocks of unit 1 representing deposition in relatively shallow water environments, whereas the graphite schists of unit 5 are the deeper water equivalents. An alternate hypothesis accounting for the sudden change in lithologic character would be the presence of a large northwesterly trending fault separating the two units. Such a fault was postulated by Smith and Skinner (1958), and the writer's own experience north of the Heath Steele property confirms the presence of northwesterly trending fault zones.

Siliceous volcanic rocks of unit 2 appear to underlie the metasedimentary rocks of units 1 and 5. Smith (1957) states:

> The siliceous volcanic rocks (2) are grey to white weathering, blue, green or buff aphanitic rocks. These rocks are generally schistose. In thin sections they are seen to be composed of ragged feldspar phenocrysts with or without embayed, brecciated quartz phenocrysts, in a fine, schistose groundmass of quartz, feldspar, chlorite and sericite. In many places it is difficult to determine whether the schistose acid rocks are sheared flows or tuffs. In some places the phenocrysts in the above rocks are particularly large and abundant and there the rock is mapped as part of the quartz-feldspar porphyry unit (3).

More detailed mapping within this area of dominantly siliceous volcanics show this sequence to be very complex and to consist of rocks ranging from acidic volcanic intrusives to metamorphosed equivalents of flows, tuffs and sediments. Considerable interbedding of acid rock types becomes evident when mapped on the scale of four inches to the mile. This is discussed later in Chapter II, on the geology of the N - 6, O - 7 and O - 8 sheets.

The structural relationship of units 1 and 5 to unit 2 is also incompletely known. In reference to Plate I, Smith (1957) indicates that the metasedimentary units underlie the volcanic sequence (2) in the area along the northwest Miramichi River, south of Heath Steele. Similarly, Smith (1957) points out that the siliceous volcanic rocks (2) underlie and are intercalated with porphyry units (3) south and north of Little Bald Mountain, in the southwest corner of the N - 8 sheet. In the Tetagouche Lake area (N - 6) the writer's experience indicates that the siliceous volcanics (2, of Plate I) are the oldest rocks in the area and that they underlie the younger metasedimentary sequences (Figure 14, Plate XI). In this area (N - 6) the sequence is fairly simple and is confirmed by a major unconformity between the Ordovician rocks and the overlying Silurian sequences. Skinner, as reported by Smith (1957), also agrees that in all cases the rocks of units 1 and 5 are younger than the rocks of the siliceous core (2), and he concludes that the apparent reversed sequence to the south of the structure results from the overturning of the section during one of the major orogenic cycles.

The rocks comprising unit 3, of Plate I, have assumed great importance in the area through their close spatial relationship with all of the major sulphide deposits

TABLE I

Stratigraphic Sequence as Represented in Plate I.

| | | |
|---|---|---|
| Pennsylvanian | 9 | Undivided Sedimentary Rocks - sandstones, shales and conglomerates |
| Devonian | 8 | Mafic Intrusive Rocks - gabbros and diabase. |
| | 7 | Felsic Intrusive Rocks - granites. |
| Silurian | 6 | Undivided Sedimentary and Volcanic Rocks of the Chaleur Bay Group. |
| Ordovician (Tetagouche Series) | 5,1 | Sedimentary Rocks. (5) Graphitic slates in the northeast and eastern regions. (1) Silicious sedimentary rocks in the south and southwest region. |
| | 4 | Greenstones - Andesites, basalts and green felsites. Minor associ-ated green sedimentary rocks. |
| | 3 | Augen Schist Units - Quartz and feldspar augen schist with associ-ated graphite schists and minor volcanics and sedimentary members |
| | 2 | Felsic Volcanic Division - Largely undifferentiated acid volcanic flows and tuffs with scattered intrusive rhyolite masses. |

within the Tetagouche Group. These rocks are mainly porphyritic acid volcanics which are of major importance in any work on the Bathurst-Newcastle area. They have previously been treated by Skinner (1956), Smith and Skinner (1958), Holyk (1957), Loudon (1960) and Sawyer (1957) and form the basis for the present study. Smith (1957) points out that this sequence of porphyritic rocks behaves locally as a series of normal stratigraphic units, but on a regional scale they occur in various stratigraphic positions, either above or below or interbedded with the main body of volcanic rocks of unit 2.

Definition of the term "porphyry" as applied to the rocks of the Bathurst-Newcastle area is dependent to a large degree on the individual using the term. What constitutes a "porphyry" to one familiar with the region may not to one less familiar with the local rock terms. Therefore, it is felt that the use of the term "porphyry" for rocks of this sequence is not justified, and it is probably of greater value to designate these rocks by their mineral constituents and their morphological features.

The type of acid volcanic rock represented by unit 3 of Plate I is a close associate of the rocks of unit 2. Smith (1957) states:

> It is a light grey rock with quartz and/or feldspar phenocrysts up to one-half inch long in a microcrystalline or schistose

> matrix of quartz, feldspar, sericite, and chlorite. As the size and abundance of phenocrysts decrease it grades into 'porphyritic rhyolite'; both rocks having much the same origin.

In the Bathurst-Newcastle district several distinct varieties of acid volcanics can be recognized, and are described in Chapter III.

The acid volcanic rocks of units 2 and 3 are overlain by the greenstones of unit 4, and in several instances the two rock types are interlayered, especially in the northerly areas (N - 6). The rocks of unit 4, as outlined by Smith (1957), consist of brown weathering, dark green, schistose, fine-grained to aphanitic rocks with rare megascopic structures. These rocks are responsible for many of the high magnetic anomalies in the area. The writer found the magnetic anomalies helpful in working out the gross structure on the N - 6, O - 7, and O - 8 maps. When mapping at the scale of four inches to the mile, unit 4 of Smith's (1957) compilation (Plate 1) can be sub-divided into dark green to black basalts, green andesites, light green felsites, and dark green chloritic sedimentary rocks. Primary features in the rocks of this unit are scarce, but megascopic features such as pillows and amygdules have been recognized by the writer. Rocks of this unit have undergone the same degree of metamorphism as the other units with the result that epidotization and propylitization are common. It is possible in detailed mapping programs to distinguish between basic flows and basic tuffs with some degree of success. From the close interlayered nature of many of the rocks of unit 4 with the deep water sediments of unit 5 above, it is concluded that many of these basic volcanics are subaqueous in origin.

The youngest rocks of the Tetagouche Group appear to be the graphite-rich slates and schists of unit 5. Mapped generally as argillites, these rocks show a well-developed cleavage, are often highly crinkled and crumbled and show varying degrees of quartz-veining and pyritic dissemination. The greatest thickness of argillaceous rocks occurs along the eastern and northeastern margins of the area. However, graphite-rich schists are interlayered with the other rock units of the area. Graphitic sedimentary rocks are common in areas of sulphide occurrence, in particular at the Caribou (N - 6) and Wedge (O - 8) properties.

Large to small, conformable to disconformable bodies of basic intrusive rocks (8) are quite common in association with the rocks of the Ordovician volcanic complex. Several of the larger bodies are shown on Plates I and VII, but smaller bodies are widespread and are shown only on larger scale maps (Plates II, III, and IV). The basic bodies, many showing diabasic textures, are thought to be of two, or possibly three, different ages. They cut both Ordovician and Silurian rocks of the central structure, and basic dykes are known to cut flat-lying Carboniferous strata to the east. Detailed mapping, particularly in the O - 7 and O - 8 areas, has shown the basic intrusive bodies to be both conformable to the structure and intruded along fault zones. It is probable, therefore, that both Ordovician and Devonian intrusives are present. In many instances what is interpreted as a basic intrusive outcrop might well be the coarse-grained phase of a slowly-cooled flow. Several such bodies were observed on the N - 6 and O - 7 sheets.

Granitic batholiths and stocks are common in the Central Highlands which traverse the province northeasterly from the Maine border. These intrusives are of undoubted Devonian age, whereas no granites of Ordovician age are present (Neale, et al., 1961). Smith (1957), however, recognized two types of granite; (1) gneissic varieties emplaced during deformation of the area (possibly Ordovician?) and (2) massive varieties which were emplaced subsequent to the main period of deformation. Examples of the latter are the bodies to the north in the Silurian strata and the large body south of the town of Bathurst. Smith (1957) states:

Many of the biotite granite bodies are surrounded by a distinctive thermal metamorphic aureole characterized by the development of biotite in both sedimentary and volcanic host rocks. Contact metamorphic effects may extend as far as a mile or more from the nearest granite outcrop. Near the granite the sedimentary rocks are altered to a fine-grained, rusty weathering, purplish biotite hornfels carrying cordierite and andalusite. In places quartz - biotite gneiss is found. The quartz-feldspar porphyry (3), west of Little Bald Mountain (N - 8), is altered to a gneissic biotite - quartz - feldspar rock resembling a granite gneiss.

## Structure of the Ordovician Folded Complex

At the present time no definite stratigraphic sequence has been established for the area so that all interpretations are of a conjectural nature. Uncertainty over the stratigraphic succession of the Tetagouche Group makes interpretation of the main structure as a dome or basin purely hypothetical. In most of the area, primary features in sedimentary and volcanic rocks have been destroyed by metamorphism, and this coupled with a strong regional development of a nearly vertical schistosity makes it most difficult to determine tops and bottoms of horizons.

Smith (1957) divides the Ordovician folded belt into two distinct units by a line running northwesterly from the area immediately south of the Heath Steele property (See Plate VII). On the northeastern side of this line the dominant structural features are two major anticlinoria, one immediately west of the Bathurst batholith (Brunswick anticline) and the other further west, south of the head-water lakes of the Tetagouche River (Tetagouche anticline). These two structures are separated by a major syncline (Nine Mile Brook Syncline) containing great thicknesses of intermediate volcanic rocks (Plate VII). These structures are very complex within themselves, but the regional structures plunge steeply northeast and southwest. For the most part the schistosity seems to parallel the limbs of the folds as bedding schistosity. Locally, this may not be the case, as detailed mapping of mine properties has shown. In the gross picture schistosity is an invaluable guide to regional structure.

Reconnaissance and detailed mapping has established that both northeasterly and northwesterly structural axes exist. This is shown, for example, by the faulted and drag-folded patterns shown on the N - 6, O - 7 and O - 8 sheets (Plates II, III and IV) which the writer has mapped.

Smith (1957) describes the northwesterly structure axis (Plate VII) as a fault zone along which schistosity has been developed parallel to the fault zone, and along which the northeasterly-trending beds have been deflected towards the southwest. Other major faults in this same general direction do occur, and it is the writer's contention that much of the structure so laboriously interpreted in the past by folding should be redefined in the light of transcurrent faulting.

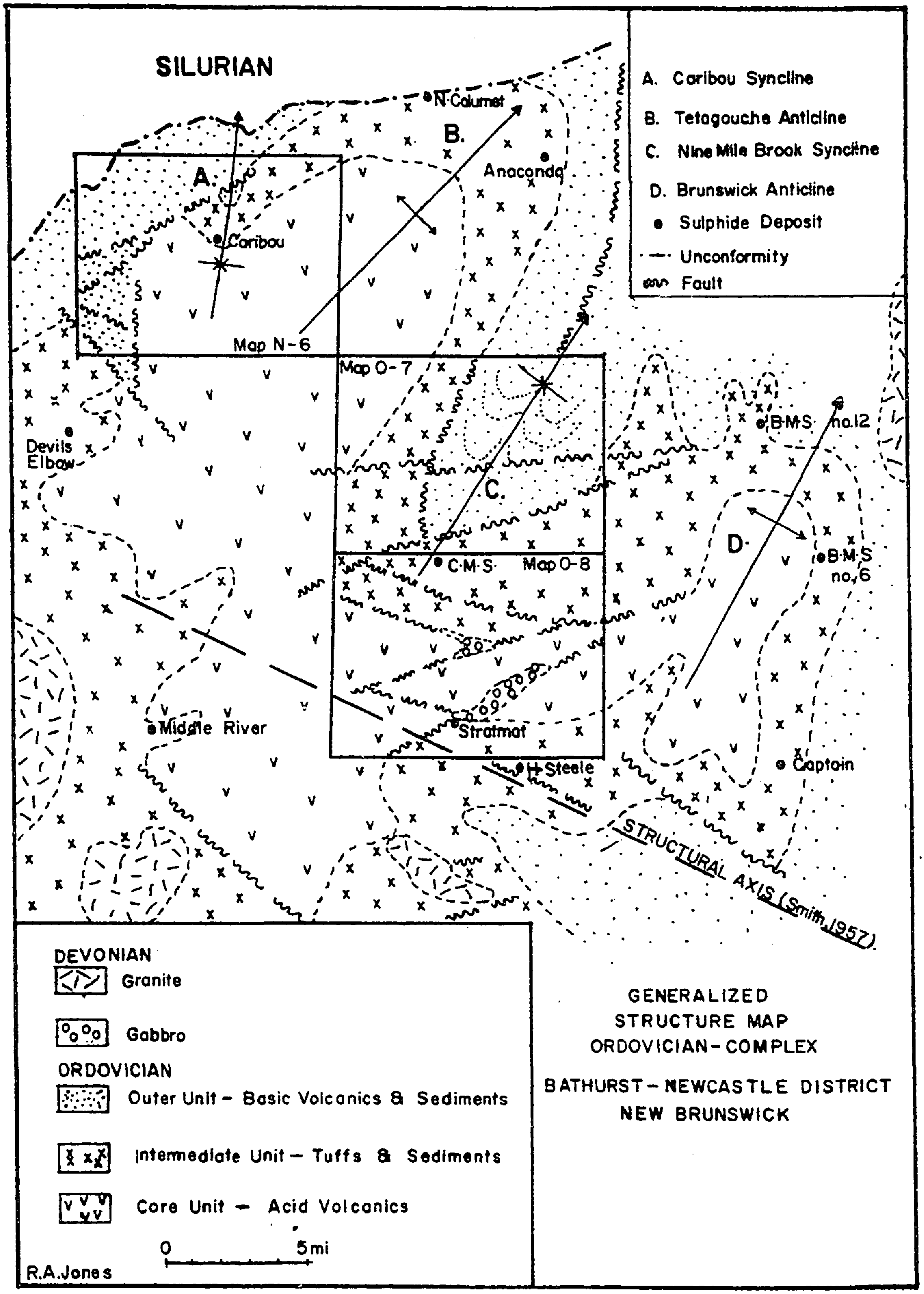
The writer is unfamiliar with the structure in the area south of Smith's axis (Plate VII), but it has been described (Smith, 1957) as being similar to that above, with northeast trending fold axes, characterized by both northeasterly and southwesterly plunging axial lines. Low angle cleavage is common in this area and may reflect recumbent folding or thrust faulting.

Holyk (1956), McAllister (1960) and several other writers all refer to isoclinal folding in the area, especially in areas of thick graphite-rich sedimentary rock sequences.

To the west the Ordovician structures are obliterated by Devonian granite intrusions. To the south, the structures are also obliterated by granitic bodies or are covered up by the later Paleozoic sequences. To the east the Ordovician rocks pass under the Carboniferous basin. In the northerly region the main Ordovician structure is separated from the younger Silurian folded belt by the Rocky Brook-Millstream break.

This contact is interpreted as a thrust fault (Skinner, 1953), or as an unconformity (Alcock, 1941

# PLATE VII


SILURIAN
A. Caribou Syncline
B. Tetagouche Anticline
C. Nine Mile Brook Syncline
D. Brunswick Anticline
Sulphide Deposit
Unconformity
Fault
N·Calumet
Anaconda
Caribou
Map N-6
Map O-7
Map O-8
Devils Elbow
B·M·S no.12
B·M·S no.6
C·M·S
Middle River
Stratmat
Steele
Captain
STRUCTURAL AXIS (Smith, 1957)
DEVONIAN
Granite
Gabbro
ORDOVICIAN
Outer Unit - Basic Volcanics & Sediments
Intermediate Unit — Tuffs & Sediments
Core Unit — Acid Volcanics
0
5mi
R.A.Jones
GENERALIZED STRUCTURE MAP ORDOVICIAN-COMPLEX
BATHURST-NEWCASTLE DISTRICT NEW BRUNSWICK

and Jones, 1960). In some areas the contact constitutes a zone and is invariably present as a major topographic expression. Skinner (1953) states:

> The contact between the Ordovician and Silurian rocks appears to be a thrust fault. Numerous high-angle faults intersect both Silurian and Ordovician strata, and are commonly expressed by long, straight valleys. The more conspicuous of these indicate strike faults, but transverse faults are not uncommon. The so-called Rocky Brook-Millstream 'break' is a series of normal en échelon, strike faults intersecting Silurian greywacke.

On Plate I the contact has been interpreted as a fault, yet nowhere is the contact exposed, and field evidence in the N - 6 map sheet area indicates that the contact is most probably an unconformity (Plate VII and Figure 14, Plate XI).

In summary, Skinner (1956), who mapped the whole Tetagouche sequence, postulates that the region was folded along northwesterly trending axes (Taconic) and was later refolded around northeasterly trending axes (Acadian).

<u>The Silurian Folded Belt</u>

The Silurian beds are not as highly deformed as the Ordovician beds but do occupy a well-defined, northeast trending syncline, in agreement with the last major compressions in the Ordovician system (Smith and Skinner, 1958). The Silurian beds have also been highly intruded by basic sills and by small granite stocks.

The Silurian rocks belong to the Chaleur Bay Group and consist predominantly of fossiliferous, greenish-grey, limy slate and greywacke with assorted volcanics.

## The Pennsylvanian Cover

On its eastern margin the Ordovician folded belt disappears under flat-lying beds of Pennsylvanian age. These beds unconformably overlie the Silurian rocks to the north and the Devonian granites to the south. The basal Pennsylvanian beds, belonging to the Bathurst formation, are mainly light red to pink conglomerates, with intercalated arkose and grit, in which pebbles are rounded to sub-rounded fragments of greenstone, greywacke, quartzite, and quartz up to two inches in maximum diameter. Red sandstone, siltstone and shale of the Clifton formation conformably overlies the Bathurst Formation.

# C H A P T E R

# T W O

## THE N - 6, O - 7, and O - 8 MAP SHEETS

### Mapping Program

During the summer field seasons of 1960, 1961, and 1962 the writer was employed by the New Brunswick Mines Branch as a party chief in a program of detailed geologic mapping in the Bathurst-Newcastle area. Each summer one map sheet on the scale of four inches to the mile was completed. The three sheets N - 6, O - 7 and O - 8 lie within the area of economic interest described in the preceding chapter. As soon as possible after the completion of the geologic mapping of a sheet, the Mines Branch proceeds with the publication of the map and a brief geologic description. The present sheets are listed in the bibliography (Jones, 1961, 1963, 1964).

This mapping allowed the writer to become familiar with a section across the center of the Ordovician folded belt (Plates I and VII). All of the rock types and their original and metamorphic variants were studied. Enough knowledge of the complex structure of the region was acquired to show that it will take many years to solve some of the basic tectonic problems. The area mapped includes a wide range of lithologies in the rhyolitic suite, from little metamorphosed rhyolite porphyries to "augen schists". The origin and history of these acid rocks is of special concern in the present paper.

## Location and Accessibility

The location of the three map sheets is indicated by heavy line on Plate I. Their geographic coordinates are listed in the following table:

| Map Sheet | Limiting Latitudes | Limiting Longitudes |
|---|---|---|
| N - 6 | 47°30', 47°36'N | 60°12', 60°24'W |
| 0 - 7 | 47°24', 47°30'N | 66°00', 66°12'W |
| 0 - 8 | 47°18', 47°24'N | 66°00', 66°12'W |

The whole area is readily accessible from Bathurst and Newcastle via a network of secondary roads shown on the three geologic maps (Plates II, III, IV). A first class road from Newcastle to the Heath Steele Mine goes on to connect with other roads and eventually with the Bathurst Power and Paper Company road crossing the 0 - 7 map sheet in a southwesterly direction from Bathurst. Logging, drilling, and fire roads greatly aided access to the "bush" from the secondary network.

## Topography

The mature topography of the region has been modified by glaciation, which scoured the higher areas and left behind a thick cover of drift. Flatter areas, like those around Canoe Landing Lake (0 - 7 sheet) are swampy, with abundant beaver ponds. The Nepisiquit River, crossing the 0 - 8 sheet, is a youthful stream flowing in a mature valley. The valley is relatively deep and wide, with youthful tributaries entering at a steep gradient. The highest elevation in the area mapped is Camel Back Mountain (2100 feet). The average relief of the region is 700 to 800 feet.

Outcrops are scarce except in areas of resistant rock types, along stream beds, and along spurs close to the main valleys. In areas burned by forest fires (0 - 8 sheet especially), outcrops are more abundant because of the removal of the forest cover and subsequent erosion.

## Field Procedure and Mapping Problems

Mapping parties consisted of four or five men including a party chief, senior assistant and two junior assistants. The fifth man was a Colombo Plan student on loan to the Provincial Survey from the Federal government. Mapping was generally conducted by one or two man field teams, traversing by pace and compass at intervals of 800 feet or less across the gross structure. Where available, mining company picket lines were utilized for traverse purposes. Roads and the main streams were covered in detail. Stream mapping in this region generally constitutes traversing both the stream bed and the banks, as many of the outcrops occur high on the slope back from the stream.

Aerial photographs prove to be a great asset when mapping in northern New Brunswick. Photos supplied on the same scale as the base map were used in the field to plot outcrop locations and for traverse ties. Photos are also valuable for the interpretation of structure in this type of topography.

Base maps on the scale of four inches to the mile were supplied by the New Brunswick Photogrammetry Branch of the Department of Lands and Mines. Field data was plotted each day as the work progressed.

Also utilized for interpretation purposes were regional aeromagnetic maps produced by the Federal government and the geophysical and diamond drill reports of private companies, filed at the Mines Branch office.

To date the Mines Branch has conducted its mapping program on a purely lithological basis. There are several factors which make this type of mapping most feasible in the Bathurst-Newcastle area. These factors are listed below:

1. Because of the glacial drift, swamps, and heavy forest cover, outcrops are limited to ridges, stream bottoms, road cuts, mine clearings, and areas of old forest fire burns.
2. Outcrops are generally deeply weathered.
3. Metamorphic processes have in many places obliterated the original structures of the sedimentary and volcanic rocks. Dynamic metamorphism has masked primary features by the superposition of one or more directions of cleavage or schistosity. Determinations of tops of beds and flows are few.
4. The original fabric of most rocks has been destroyed by recrystallization and migration of components.
5. Correlation along strike or down dip is virtually impossible over any distance. This condition is accentuated by the glacial cover and the metamorphism. However, correlation is a typical problem in any area of sedimentary - volcanic sequences.
6. Fossil remains are extremely rare within the sequence.
7. There have been several periods of metamorphism so that radiometric age determinations would be unreliable.
8. Specific rock types, distinguishable in the field, recur throughout the section as thick sequences or as intercalations in other rocks. For example, the presence of augen schists is most mapped units is confusing and is

in itself suggestive of more than one origin for that rock type.

9. The structure is complex. In addition to folding of several generations, faulting is known to be prevalent.

The complex geology of this region will continue to be solved by detailed mapping of key areas. The need for a stratigraphic sequence is evident. When it is established, the structural complexity of the area will be unraveled with greater success.

It was not until the summer of 1962, after having mapped the N - 6 and O - 7 areas, that the writer decided to use information from these map areas as an integral part of this dissertation and as a prelude to study of the acid volcanics of the region. Prior to this time emphasis was placed on making a study of the basic intrusive rocks. This project was dropped because of lack of exposures and the altered condition of outcrops.

The legend of each of the accompanying map sheets was established on a lithologic basis. As indicated above, this type of mapping is standard procedure for this area. When mapping the N - 6 sheet the writer was able to establish a broad stratigraphic sequence in the area from the oldest to the youngest rocks around the margin of the domal structure. However, editing during the subsequent reproduction resulted in loss of the stratigraphic significance of the legend. The legends of O - 7 and O - 8 are strictly lithological.

The three quadrangles were mapped and prepared for publication separately. Their legends, therefore, show marked differences, in part the results of increasing general knowledge of the region. The augen schists are distinguished as a separate unit on each sheet. In addition, individual outcrops of these rocks occur in areas too small to map within other units. Thus, these schists are mapped as unit 2a on N - 6, unit 7 on O - 7 and unit 6 on O - 8. On a minor scale they are also indicated by units 3c on N - 6; 3e, 5a and 6c on O - 7; and 2a, 3d, 4c, 5a and 7b on O - 8 (See Table II).

## Lithologic Units

### General Statement

The rocks of the areas under consideration are primarily of Ordovician age. They are highly deformed, unfossiliferous, and metamorphosed to the greenschist facies. Age relations were established by apparent structural position, lithologic comparison, and correlation with the rock units of adjacent areas previously mapped by Skinner (1956), Davies (1958) and Sims (1959). A small area in the northwest corner of the N - 6 sheet is underlain by folded Silurian conglomerates, greywackes, and limestones. Devonian basic intrusive rocks are common over the three sheets both as concordant and as discordant bodies. Petrographic descriptions of the acid volcanics of the Ordovician complex are included in Chapter III.

In the following descriptions of lithologies of the Ordovician rocks reference will be made to the "core area," "intermediate area," and the "outer area" of the structure. These terms require a brief explanation. In reference to Plate I it can be seen that the structure of the area is outlined by a domal feature. In order of succession the oldest rocks occur within the central area and the youngest towards the outer rim. The rocks may be divided into three rough stratigraphical units which are (Plate VII):

1. The core area, consisting of rocks of unit 2, Plate I.
2. The intermediate area, consisting of rocks of unit 3 and many of those included in unit 5.
3. The outer area, consiting of rocks of unit 4 and unit 5.

As a further caution the writer wants to make clear the fact that Plate I is a lithological map, so that there is considerable intercalation of the above units, but when restricted to sheets N - 6, O - 7 and O - 8 the above division is satisfactory.

The oldest rocks of the area mapped are the rhyolitic rocks of the central cores of the Ordovician folded structure (See Plate VII). These rocks are a complex of flow rocks, tuffs, and their metamorphic equivalents, most abundant in the N - 6 and O - 8 areas. Higher in the section are thick zones of augen schists derived from the metamorphism of rhyolitic tuffs and flow rocks, in part mapped in the field as dacites. Above and interbedded with these rocks are various metasedimentary rocks: argillite, metagreywacke, graphite schist, and cherty iron formation. The outer and higher structural zones are occupied by andesitic and basaltic flows and tuffs and their metamorphic equivalents, by other intermediate rocks provisionally classified as felsites, by chloritic metasediments and tuffs, and by manganiferous slates. Various intrusive rocks cut the intermediate and higher parts of the section. The general sequence of rocks in the region mapped is given in Table II, which also lists all the rock types and their designations on the three maps.

In a very general way, the order of the following lithologic descriptions is from oldest to youngest. The rhyolites to be described first are among the least metamorphosed rocks of the area in spite of their location at the deepest structural position. It will be seen that such apparent anomalies are largely due to the original physical properties of the rocks. Because the legends of the three geologic maps (Plates II, III, IV) are inconsistent with each other and because certain lithologic types appear at various levels in the stratigraphic sequence and are represented by several map units (Table II), numerous references to map sheets and mapped units are included in the text.

Rhyolites and rhyolite porphyries

In the southern, or core, area of the N - 6 sheet the rhyolites are massive grey-green and black rocks (unit 3). Other rhyolites in the same area (unit 3a) are highly contorted and folded. Primary structures such as flow bands have been destroyed in most outcrops but are discernible in some where weathering has not been very active and where the rock has withstood metamorphic processes. The rhyolites usually contain many short, narrow, contorted quartz veins. Discordant pegmatitic veins of quartz and orthoclase are common, generally being lens-shaped, not exceeding a foot in thickness and five feet in length. The rhyolites are characterized by their brilliant white weathered surfaces and their subconchoidal fractures. Pinkish-white porphyritic rhyolite is mapped separately as unit 3b on map N - 6.

## TABLE II

| | N - 6 | | O - 7 | | O - 8 | |
|---|---|---|---|---|---|---|
| | Major | Minor | Major | Minor | Major | Minor |
| **Post-Silurian** | | | | | | |
| Gabbro | 6 | - | 11 | 4b | 11 | 1a |
| **Silurian** | | | | | | |
| Conglomerates | 5a | - | - | - | - | - |
| Limestones | 5b | - | - | - | - | - |
| Greywackes | 5c | - | - | - | - | - |
| **Ordovician** | | | | | | |
| Quartz trachyte, syenite | 4a | - | - | - | - | - |
| Manganiferous & Hematitic Slates | 1g | 2g,4a | 10 | - | 9 | 10a |
| Chloritic metasedimentary rocks | 1a | 2f | - | - | - | - |
| Felsites | - | - | 3 | 2a,6e | - | 1b |
| Coarse Grained Volcanic Rocks | 1c | 3a | 4 | 2c,11a | - | 1d,11a |
| Basalt | 1b | 2c,3d | 1 | 2e | - | 1a |
| Andesite | 1b | 2c,3d, 4b | 2 | 3a,4a, 6f,11b | 1 | 3f,4f, 11b |
| Metasedimentary Rocks | | | | | | |
| Iron formation | 1h | - | - | - | 10 | - |
| Cherts and Metabentonites | - | 4e | - | 2f | - | 10 |
| Greywacke | - | - | 8b | - | - | - |
| Argillite | - | 1d | 8 | 9a | - | 8a,5e |
| Graphite Schist | 2b | 1d,3f 4c | 0 | 8a | 8 | - |
| Intrusive Rhyolite Porphyry | - | - | - | - | 7 | 2c,3c 4a,6b |
| Quartz-chlorite-sericite schist | 2e | 1e,3b | 5 | 2d,3d, 6d,7c, 8b | 5 | 2d,3e 4d,6d 7d |
| Dacite | - | - | - | - | 2 | 1b,3a 4e,5b 6a |
| Augen Schist | 2a | 3c | 7 | 3e,5a 6c | 6 | 2a,4b 4c,5b 6a |
| Rhyolite Tuffs | - | - | - | 3a,6a | 3 | 2e,4b 5d,6e 7c |
| Rhyolite and Porphyritic Ryolite | 3a | 1f,2d 4d | 6 | 3b,5b, 7b | 4 | 2b,3b 5c,6c 7a |

Table II - approximate Stratigraphic Section for sheets N - 6, O -7 and O - 8

Acid volcanic rocks of the core area are limited on the O - 7 map sheet (Plate VII). However, younger rhyolites (unit 6) are commonly interbedded with the rocks higher in the sequence (Plate III).

Minor rhyolites are common, interbedded with all of the other volcanic members in the region as indicated in Table II. In each case the rhyolites are typical of those described.

As a result of dynamic metamorphism mild schistosity has developed in some rhyolites, and in others schistosity is so strong that the rocks are transformed to quartz-sericite schists. Schistose varieties of rhyolites may represent either intercalated relatively soft rhyolitic ash flows or massive rhyolite flows which have developed schistosity in areas of structural weakness where folding and faulting have been intense.

## Rhyolite tuffs

Although rhyolite flows predominate in the N - 6 area, the rhyolites of the core area of the O - 8 sheet are tuffaceous. The tuffs are included in unit 3 of both the N - 6 and O - 8 sheets. On the O - 8 sheet rocks mapped within this unit can be differentiated into fine-grained tuffs and tuffs with abundant large rock fragments.

This unit occupies most of the area south of the Nepisiquit River and appears locally on the 0 - 7 map sheet. The tuffaceous rocks are variable in appearance. They range from pale pink through grey and green to black, are fine-grained, and contain broken rock fragments along with fractured quartz and feldspar crystals. The tuffs range from very schistose and sericitic to massive with fresh outcrops often showing original bedding. Tuffaceous rocks can be distinguished by the presence of rubbly weathered surfaces and the lack of subconchoidal fractures characteristic of the flow rocks.

The rocks of unit 3 west of Otter Brook on the 0 - 8 sheet contain an abundance of ellipsoidal rhyolitic rock fragments up to six inches in length. The rock fragments impart a knobby surface to the weathered rock and in any one outcrop tend to be oriented in a single direction. The rock fragments may have been wrenched from the rock conduit during violent eruptions.

Acid tuffs are less common as minor constituents of other mapped units than are the rhyolite flow rocks. The tuffs were recognized only in unit 3 on the N - 6 map, but, as indicated in Table II, are present in several units on the other sheets.

## Augen Schists

Although rhyolitic flow rocks and tuffs are dominant in the central part of the structure, quartz and feldspar augen schists are most abundant in the surrounding younger sequence (Table II). These schists are very variable in physical appearance and show gradational contacts with adjacent rhyolitic units, with considerable intercalation.

The augen schists of the N - 6 area are characteristic of those in the northwestern part of the Ordovician complex. In this area the well-developed schistosity of the augen schists, due to the abundance of sericite and chlorite, gives the rock a flaky appearance in weathered exposures. Relict phenocrysts of feldspar and quartz, in smaller amounts, form small augen structures in the rock. The unequal size and irregular distribution of the augen are notable features of this rock. Augen structure has been observed to vary, in a distance of twenty feet, from microscopic to one inch in length. Narrow lenses of feldspar augen schist are invariably interbedded with chloritic and sericitic schists and dark green argillites, a feature especially evident north and east of the Anaconda - Caribou Mine. Figures 7 and 8 (Plate VIII) show this interbedding with argillite in an outcrop north of Forty-Mile Brook where the Caribou Mine road crosses the brook.

The lens-like nature of the augen schist and the

PLATE VIII : EXPOSURES OF AUGEN SCHIST

Figure 7. Extremely schistose feldspar augen schist. Light colored rock in the foreground is augen schist. Dark colored rock in background is green argillite. The two rocks are interbedded.Outcrop near Forty Mile Brook at the Caribou Mine road.

Figure 8. Fine interbedding of dark green argillites and extremely schistose augen schists. Quartz veining is prominent in the argillite. Same locality as fig.7.

# PLATE VIII

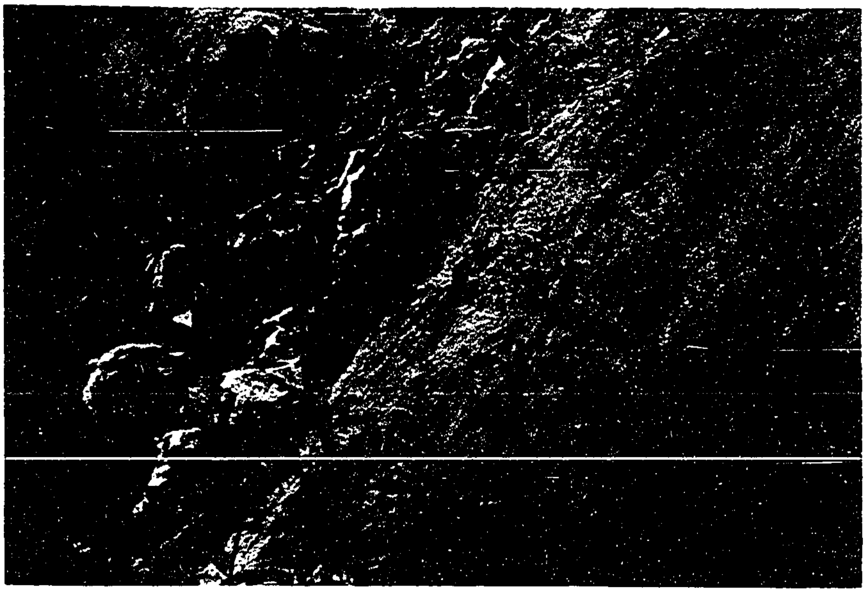


Figure 7

Figure 8

interlensing of augen schist with micaceous schists indicates that the schistosity in this area has been developed parallel to the bedding. The interbedding allows one to map original sedimentary structures.

The best sections of augen schist are along Forty-Mile Brook and the road leading to the Anaconda-Caribou Mine. At the mine adit the augen schist varies from a dark green, massive, chlorite-rich rock with white blocky feldspar augen to a light green, sericitic, highly schistose variety containing crushed, small to minute, augen of feldspar and quartz elongated along the schistosity planes. The latter type is illustrated by Figures 9 and 10 (Plate IX). Figure 9 shows the extreme schistosity of the rock. Offsets along a crosscutting quartz veinlet in the central region of the slide indicates that there has been slippage along the schistosity planes. Individual feldspar and quartz phenocrysts have been crushed. This, together with newly crystallized grains, causes the augen texture. In the top central area of the slide a small feldspar cleavage fragment lies with its long dimension nearly at right angles to the schistosity. Fine-grained quartz has recrystallized inthe lenticular areas sheltered by the large feldspar phenocrysts. In many instances recrystallization of quartz is thus responsible for the augen texture. Quartz also commonly occurs as recrystallized material in light-colored lenses, separated by darker mica-rich lenses.

Minor chevron crenulations, which are also characteristic of the augen schists of the Anaconda-Caribou area, are illustrated in Figure 10. The development of quartz-rich and sericite-rich bands is more pronounced. Secondary quartz, which has been recrystallized in areas of low chemical potential, particularly in the nose areas of the micro-folds, is shown by the light grey patches and stringers. On the N - 6 map augen schists are rather common as narrow beds (3c) within the older rhyolites of the central core.

To the southeast (O - 7) these schists are again closely associated with allied rock types. They vary from extremely schistose varieties typical of the N - 6 area to more massive and siliceous types. The more schistose varieties, common in the western and northwestern part of the O - 7 sheet, contain abundant feldspar augen with little or no quartz. They represent a continuation of the highly-sheared unit which is prominent in the Tetagouche anticline to the north and on the N - 6 map.

In the southern part of O - 7, along the Theriault Road, the schist unit appears to be more massive and siliceous. Quartz eyes increase in abundance and tend

PLATE IX : PHOTOMICROGRAPHS OF SCHISTOSE AUGEN SCHIST

Figure 9. Stained thin section. Schistose variety of augen schist from Anaconda Caribou region. Sample N - 6 - 1. Feldspar augen-dark grey. Quartz augen-light grey. Matrix consists of microcrystalline sericite, chlorite and quartz. Narrow quartz veinlet exhibits slip along the schistosity planes. Crossed nicols.

Figure 10. Stained thin section. Same general area as Figure 9. Micro-folds have developed by shear. Feldspars appear as dark grains. Quartz (light grey) is prominent in the noses of the Micro-folds. The matrix illustrates quartz-rich (light grey) and sericite-rich (grey) banding. Crossed nichols.

# PLATE IX

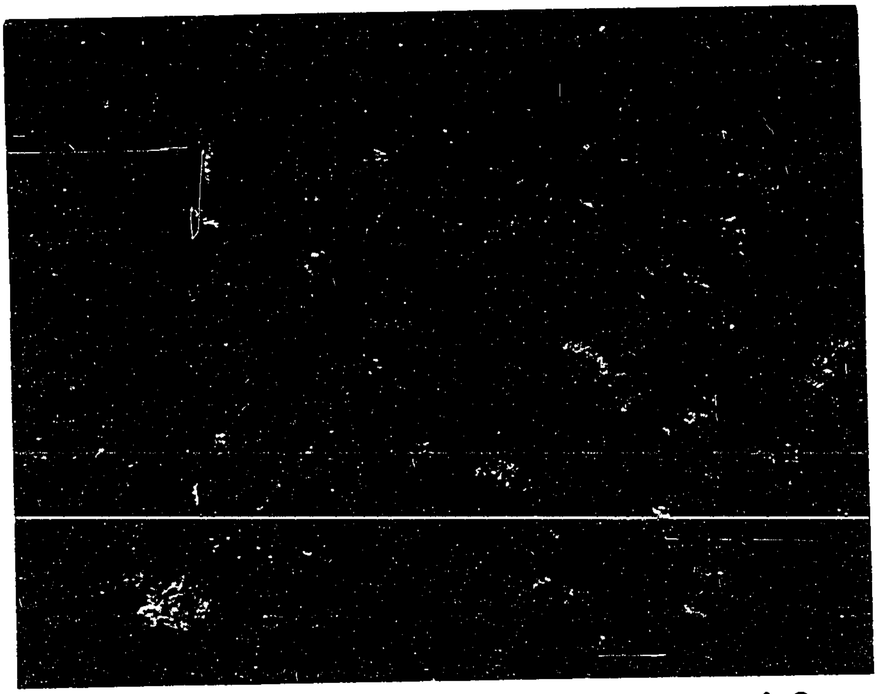


Figure 9 4·2x

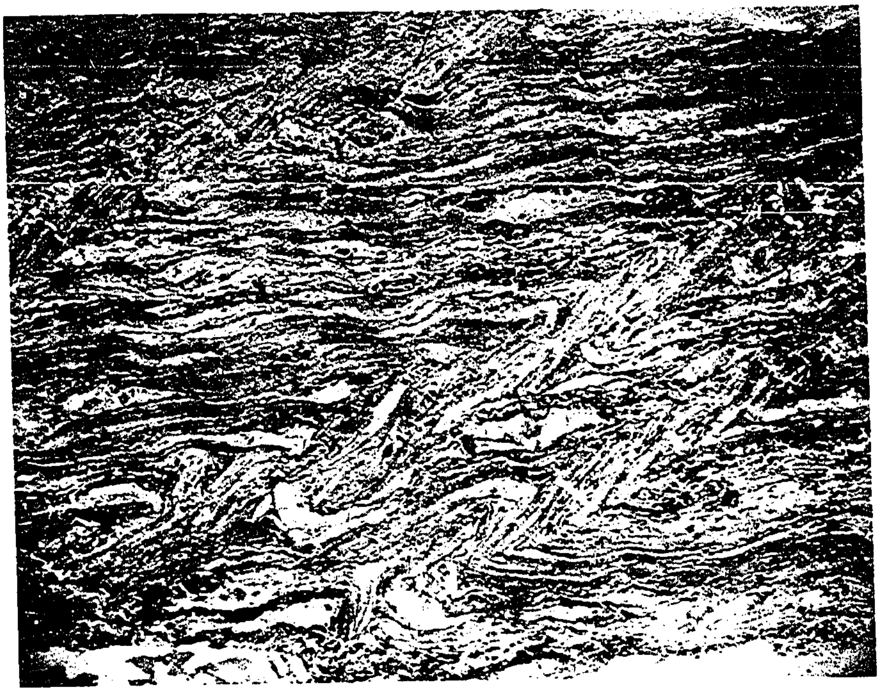


Figure 10 4·2x

to rival the feldspars in number and size. The distinction between augen schist and porphyritic rhyolite becomes difficult to discern. Many quartz crystals retain embayment structures typical of igneous phenocrysts. There is a gradation from rocks with euhedral or subhedral quartz and feldspar phenocrysts to those in which a distinct augen structure has developed.

The augen schists of the O - 7 sheet are intermediate between extremely schistose types to the northwest and the very massive varieties such as those at the Brunswick No.6 clearing to the east. It is within these rocks that primary tuffaceous structures are observed in thin section, and in Chapter II these rocks have been classed as rhyolite tuffs.

In the O - 7 area, as in N - 6, the augen schist units grade laterally into quartz-rich schists with a noted lack of phenocrysts.

Along the southern border of the O - 7 sheet, a variety of rock was mapped which had been, up to this time, included in the gross augen schist. The matrix is markedly chloritic and contains large phenocrysts of pink feldspar. The phenocrysts are highly fractured, and the rock tends to weather white like most of the rhyolites. Later mapping on the O - 8 sheet further south has shown this rock to belong to a suite of rocks quite different from the typical augen schists. These rocks, mapped as "dacites" on 0 - 8 are discussed at a later time.

Augen schists (unit 6) occur in wide distribution on map sheet 0 - 8 (Plate IV). The greatest concentration is in the southeast sector, where they are interbedded with quartz-sericite schists and reach a maximum thickness of one mile. This band of rock encompasses the sulphide deposits of the Heathe Steele Mine (0 - 9). Augen schists are common south of Tomogonops Lake, around the Stratmat ore zone and west of Forty-Mile Brook in association with the sulphide ores of the Wedge Mine.

Variation in the physical appearance of the various augen schist bands on 0 - 8 possibly reflects an original heterogeneity of origin. Feldspar forms the most prominent phenocrysts which range in size from small fragments to auhedral grains one half inch long. The feldspars vary from white to pink and do not appear to show any linear arrangement. Quartz crystals are subordinate in size and number and are generally rounded. The more massive rocks often show deeply embayed quartz phenocrysts. In some of the narrow bands of augen schist quartz phenocrysts outnumber the feldspars, and the rock takes on a darker color.

In the thick sequence north of the Heath Steele property, the augen schist is light-colored and has a fine-grained, siliceous and unaltered matrix. Quartz and feldspar are about equal in size and number. In the weathered rock the larger feldspar crystals tend to be rust stained along fractures and crystal boundaries.

In some areas the augen schists become extremely schistose, with microcrystalline folia of sericite and scattered feldspar augen. In such rocks the quartz phenocrysts take on a crushed appearance, the sericite content increases, and the rock develops a "sugary" texture.

Some of the augen schist units, as mapped, have been derived from pyroclastics. This is particularly true of the rocks in bands north and west of McCormack Lake. In these rocks the matrix is fine-grained with the quartz and feldspar crystals showing varying degrees of rounding.

"Dacite"

The rocks in unit 2 of map 0 - 8 were classified as dacites in the field. They are a mappable unit, recognized for the first time by the writer (Jones, 1964). These rocks are generally associated with augen schists, but in the three sheets mapped they occur almost exclusively on 0 - 8. In work prior to 1962 the "dacites" were not distinguished from the augen schists.

"Dacites" of the area are light green to greenish black, highly chloritic and sericitic and range from massive to very schistose. The schistose varieties display waxy surfaces resulting from the development of micaceous minerals in the schistosity planes. Feldspars are invariably present in several forms, ranging from large subhedral pink to white phenocrysts, through broken and crushed fragments, to small whitish crystallites and thin, splintery grains that appear to have been drawn out and aligned in the schistosity planes. The feldspars in many cases have undergone extreme alteration, often to the point where the crystal is either a sericite or an epidote pseudomorph. Such rocks appear to be more the rule than the exception.

An outcrop of typical "dacite" is located approximately three miles south of the Nepisiquit River where the stream which drains Rogers Lake crosses the powerline.

"Dacites" display the most evident tuffaceous texture seen in this area. Figure 11 (Plate X) illustrates a relic texture of possible tuffaceous origin. The abundant rodlike structures are patches of sericite which are thought to be the product of the devitrification of glass shards.

PLATE X : PHOTOMICROGRAPHS - TUFFACEOUS TEXTURES IN DACITE AUGEN SCHISTS.

Figure 11 . Relic shard structures in the matrix of dacite augen schist from O - 7 map (O - 7 - 1).Matrix is microcrystalline with abundant sericite. Crossed nichols.

Figure 12. Stained thin section.Plane light. Embayed quartz phenocrysts. Metamorphic rims on quartz grains gives them a lace-work contact with the matrix. Quartz stringers are evident connecting phenocrysts. Rock is highly epidotized (dark patches).

# PLATE X

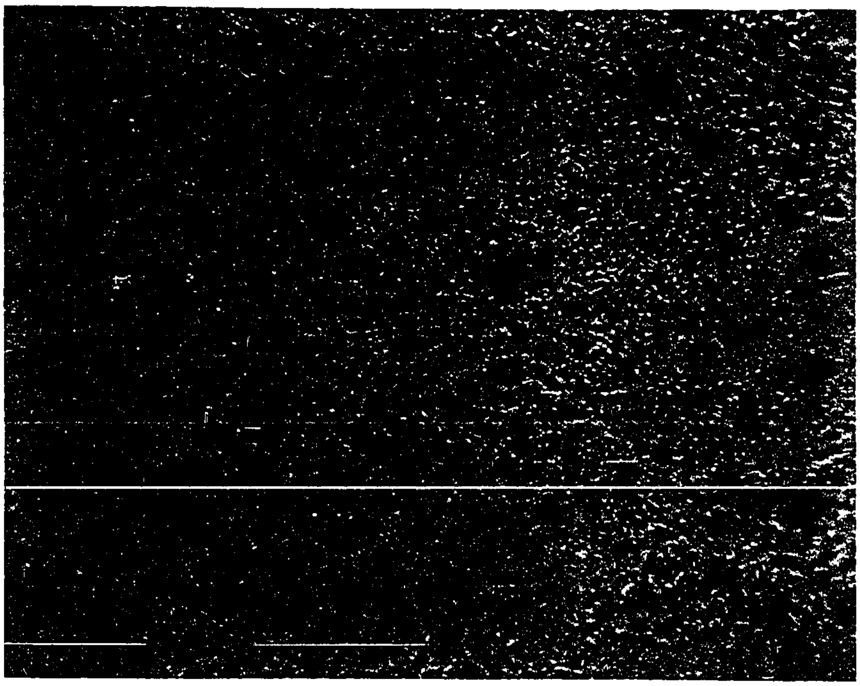


Figure 11 100 x

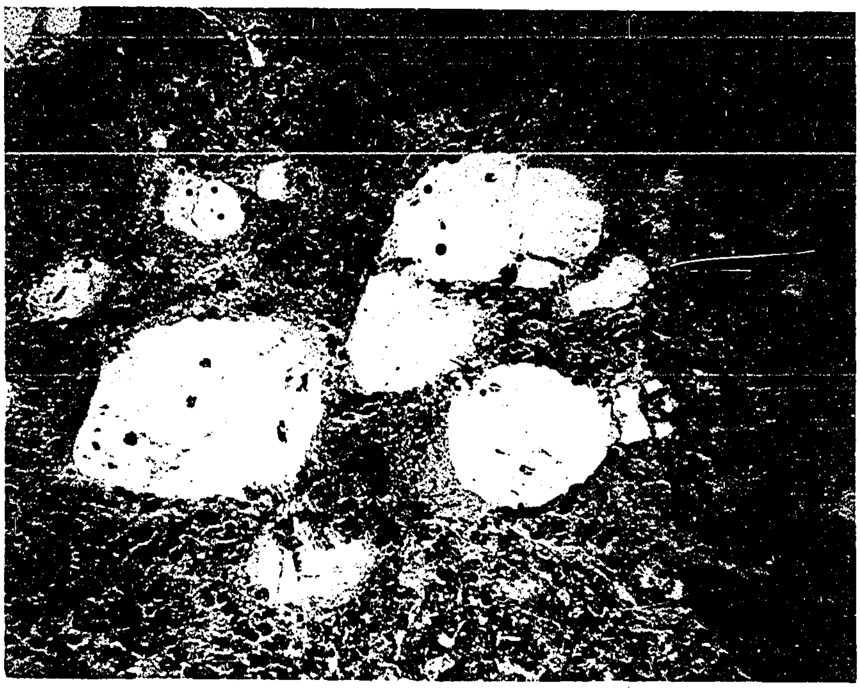


Figure 12 21 x

Rounded to subhedral grains of quartz with embayment structures are seen in many "dacites" (Figure 12, Plate X). Siliceous and massive "dacites" invariably contain both quartz and feldspar as phenocrysts.

In outcrops of schistose "dacite" where two dimensions can be viewed, it is evident that movement has occurred along the schistosity planes. This has led to the elongation of the feldspars and quartz phenocrysts in the plane of the rock cleavage, forming rods which constitute a b-lineation in the minor folds. Such features can be observed on the outcrop along the power-line at the stream which drains Rogers Lake.

More detailed work will be needed to determine the exact relation of this rock to augen schists. "Dacites" now appear to be common over wide areas of the district and are especially common along the Narrows of the Nepisiquit River, six or seven miles east of the O - 8 sheet. Similar rocks occur quite commonly in the other units of the O - 8 map (Table II) but were not mapped on the O - 7 and N - 6 sheets.

Chlorite and Sericite Schist

Chlorite and sericite schists increase in abundance from the O - 8 area, in the southeast, to the N - 6 area, in the northwest. They are associated with volcanic and sedimentary rocks throughout the Ordovician sequence and are not confined to any stratigraphic position. Schists associated with rhyolites are rich in sericite, whereas those associated with graphite schists and andesites are chlorite-rich.

In the N - 6 area the chlorite-sericite schists closely resemble the matrix material of the augen schists. Since the two rock types are so closely associated, the augen-free variety is thought to represent a facies of the augen-bearing type. Quartz-sericite schists are associated with the massive rhyolites and in this case are apparently schistose varieties of acid volcanics.

On map O - 7 chlorite and sericite schists (unit 5) are mainly in the western and southwestern regions as thin beds in association with acid volcanic rocks. They are also common as thin bands associated with other volcanic and sedimentary rocks (Table II).

Although sericite schists are common on sheets N - 6 and O - 7, they are relatively uncommon on the O - 8 sheet (Table II). The quartz-sericite schists associated with the acid volcanic members are light in color, siliceous, and contain abundant sericite along planes of schistosity. The quartz-rich schists display a sugary texture, and some contain scattered feldspar and quartz phenocrysts. It appears from field observations that the quartz-rich schists are the product of dynamically-altered quartz and feldspar augen schists. Pearce (1963) substantiates these observations by chemical analyses of rocks in the vicinity of the Brunswick sulphide deposits.

The chlorite-rich schists (1e of N - 6, 2d of O - 7, and 2d of O - 8) are associated with the intermediate volcanics and graphite schists and appear to be dynamically metamorphosed basic tuffs. These rocks are dark green, soft, flaky and highly schistose. Calcite is common as veinlets and as replacement masses.

## Intrusive Rhyolite Porphyry

Massive porphyritic rhyolites are prominent in the less deformed areas of the map sheets and in areas where there appears to have been a great amount of acid volcanic activity. This rock type is pronounced on the O - 8 map (unit 7), less common on O - 7 and scarce on N - 6. The rhyolites commonly form hills and ridges, mainly within the acid tuff and volcanic core area. An example of such a topographic feature is Razor Back Ridge, a linear ridge in an old fire burn approximately one mile west of Rogers Lake. Here a rhyolite porphyry mass, presumably offset by faulting, forms a group of ridges at least two miles long and a mile wide (Figure 13, Plate XI).

PLATE XI : VOLCANIC CORE AND SKETCH OF ORDOVICIAN - SILURIAN CONTACT.

Figure 13. View east from top of Razor Back Ridge in central part of O - 8 map. Rogers Lake in background. Rhyolite mass (white) which composes the ridge represents the remnant core of an Ordovician Volcano.

Figure 14. Hypothetical sketch across the Ordovician-silurian contact on map N - 6. Assumed contact is an unconformity. Illustrates gross stratigraphic units.

# PLATE XI

Figure 13

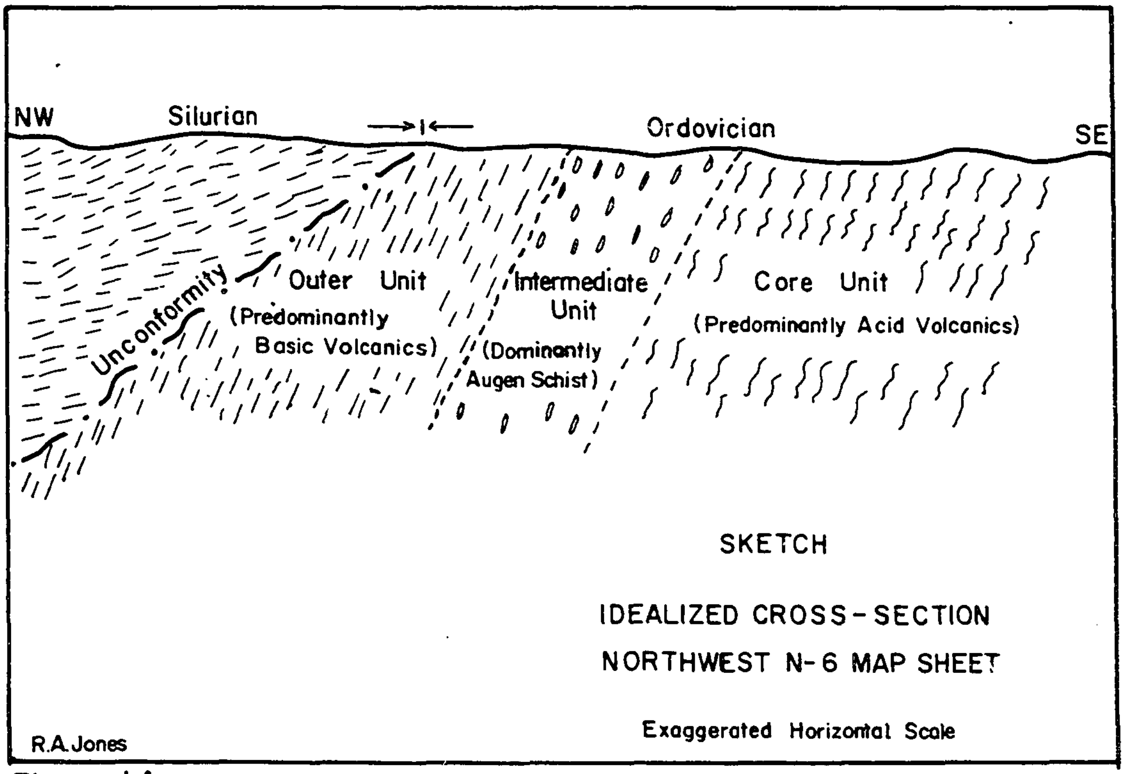



Figure 14

The intrusive rhyolite occurs in isolated masses throughout the district. They appear to represent the necks, or cores, of the volcanoes which must have been active during the period when great sequences of acidic volcanics were accumulating. These rock masses, being composed of a denser and more resistant material, were able to withstand the various periods of deformation and still show many of their original structures and textures. Examples of massive intrusive rhyolites are the large isolated masses at the Nine-Mile Fire Tower (P - 7) and on Little Bald Mountain (N - 8) (Plate 1).

The intrusive rhyolites are generally massive and blocky with a dense, hard, fine-grained matrix which typically fractures along subconchoidal breaks. They are generally cut by many quartz veins and transected by numerous joints. The rocks range from green through brown to a maroon-red, and generally contain abundant small pink and white feldspar phenocrysts and small rounded quartz grains. Quartz phenocrysts are embayed and clear albite rims perthitic feldspar phenocrysts (Figure 15, Plate XII). The dense matrix material is evident. Figure 16 (Plate XII) illustrates the igneous texture of the rock and suggests the presence of flow bands.

Phenocrysts are not always present in these rocks, but where they occur they show a random distribution and

PLATE XII : PHOTOMICROGRAPHS OF MASSIVE INTRUSIVE RHYOLITE.

Figure 15. Stained thin section. Massive rhyolite porphyry from Razor Back Ridge. Sample O - 8 - 3. Clear quartz phenocrysts show embayment structures. Deeply stained feldspar phenocryst in center of slide is rimmed by clear Na-feldspar.Veinlets are composed of quartz (light) and K-feldspar (grey). The matrix of the rock has taken on a high potassium stain and is indistinct. Rounded black spots are bubbles in the mounting media.

Figure 16. Massive rhyolite with typical quartz phenocrysts which are embayed and which show metamorphic rims. Feldspar phenocrysts are rare. The matrix consists of microcrystalline quartz, orthoclase and sericite. Flow banding is evident. Rock sample is located near Razor Back Ridge, map O - 8 (Sample J-776).

# PLATE XII

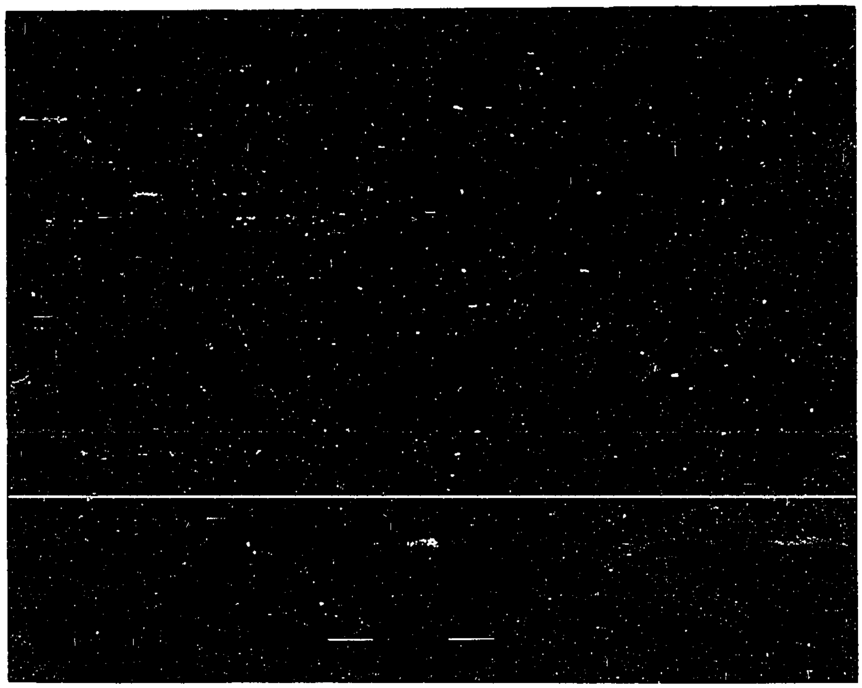


Figure 15 21x

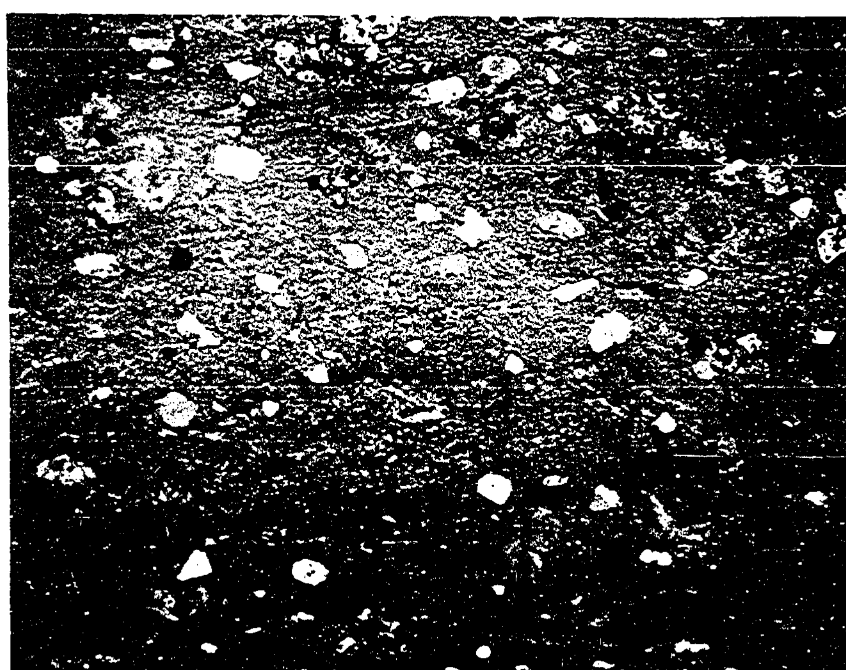


Figure 16 4·2x

orientation.

Flow banding is commonly evident on the weathered surfaces of rock exposures. Some of the outcrops show rare inclusions of rock, which are generally elongated and lie with their long direction parallel to the flow bands.

Whereas the above rocks are described as intrusives, it is concluded that porphyritic rhyolite flows also exist and occur in association with other acid volcanics of the area. For example, on the O - 8 sheet porphyritic rhyolites occur as minor members with the "dacites," acid volcanics, rhyolites, and augen schists (Table II).

The intrusive nature of some of the porphyritic rhyolites was not recognized during mapping of the O - 7 sheet. Porphyritic rhyolites of O - 7 are more highly deformed than those of O - 8 and contain an abundance of euhedral to fragmental quartz and feldspar phenocrysts. In the northern part of O - 7, porphyritic rhyolite flows grade into augen schists. Similarly, on the N - 6 map sheet, no massive porphyritic rhyolites were mapped, but possible schistose examples were included within the augen schist units.

## Metasedimentary Rocks

### Graphite Schist

Associated with the augen schists and related acid volcanic rocks are various metasedimentary rocks. Graphite schists, the most common rock type, is associated with minor amounts of argillite, greywacke and metabentonites. In combination with the volcanic units, this metasedimentary band forms the middle member of the stratigraphic sequence (Plate VII).

The writer found no fossil remains in any of the sedimentary rocks from these regions, but graptolites are abundant in the graphite schists near Bathurst. Graphite schists form topographic lows, and the best outcrops are found along road cuts or in the beds of streams. Although this schist seldom outcrops in the bush, it is a good conductor and can be traced with success in areas of no outcrop through the interpretation of electromagnetic surveys.

Graphite schist, argillite and augen schist seem to form a common association with several of the massive sulphide deposits in the area. Graphite is the footwall rock of the Anaconda-Caribou sulphide zone, whereas argillites are prevalent at the Wedge Mine, and both occur at several other smaller sulphide occurrences.

Graphite schists are one of the major rock types of the 0 - 8 sheet. For the most part, the schists are black, soft, very schistose and highly graphitic. These incompetent rocks are generally highly contorted and injected by concordant and discordant quartz veins. Pyrite is common as disseminated cubes and films along joint surfaces. Argillite, greywacke, and quartz-chlorite-sericite schist form minor members of the graphite schist unit.

Graphite schist crosses the northern part of the 0 - 8 sheet from east to west as a band several thousand feet thick. In the eastern half of the area the Nepisiquit River has cut its valley within this unit. To the west the graphite schists have been partially obliterated by faulting and tend to disappear as a result of interfingering with volcanic units, pinch-outs, and faulting all in combination.

Graphite schists of the 0 - 7 sheet (Table II), like those of 0 - 8, are commonly associated with siliceous, fine-grained and laminated argillites. In some areas, as along South Forty-Mile Brook, the graphite schist unit is represented by paper-thin shales.

The incompetent graphite schists are favorable loci for the intrusion of igneous rocks. This is illustrated on the 0 - 7 sheet (Plate III) where the intrusion of a large basic body caused considerable flowage in the schists.

Similar graphite schists are common in the N - 6 area associated with augen schist and as minor beds with acidic and basic volcanics (Table II).

## Argillite

Argillite is common in the region around Forty-Mile Brook and the Wedge Mine (0 - 7 and 0 - 8 maps), where it is closely associated with greywacke. The argillite is siliceous and less schistose than the graphite schists. Siliceous argillites form the footwall of the ore zone at the Consolidated Mining and Smelting Wedge property.

Argillites were not mapped as a separate unit on the 0 - 8 or the N - 6 sheets. In the N - 6 region chlorite-rich metasedimentary rocks were mapped and might be equivalent to the 0 - 7 argillites.

## Greywacke

Greywackes are confined to the 0 - 7 and 0 - 8 areas. They are commonly associated with argillites and are most prevalent in a band immediately east of the Wedge Mine (0 - 8). Greywackes are evident in the workings at the mine. The rock outcrops on the south side of the road 300 feet east of the gate. In hand specimen the rock appears massive and medium-grained with a "dirty" matrix composed largely of feldspar and quartz fragments. Angular rock fragments up to 2 inches in length are common. Greywacke is rather massive and, minus the large rock fragments, would be difficult to distinguish in hand specimen from many rocks in the area which are presently being included in the acid volcanics.

The texture and mineralogy of the greywacke is best studied in thin section, and two examples have been included (Plate XIII). The rock appears relatively unaltered in relation to the amount of deformation that the area has undergone. It is composed of approximately 50% clear, highly angular quartz grains up to 1 mm. long. Quartz grains show no apparent orientation or lineation, and much of it is strained. Angular quartz grains apparently have not been transported any great distance. Feldspar forms a minor clastic fraction and occurs as angular to rounded grains, usually showing well-developed albite twinning (Figure 18, Plate XIII). Angular to rounded rock fragments also form clastic constituents, with shale forming the most prominent (Figure 17, Plate XIII). The shale fragments are extremely fine-grained and sericitic with minute quartz inclusions. Other rock fragments consist of rounded rhyolite pebbles. The matrix of the greywacke is a finely crystalline mass of quartz and sericite with some calcite. Pyrite is fairly common as replacement blebs and as films along fractures.

## Cherts and Metabentonites

The graphite schist sequence on O - 8 contains interbeds of green, weakly magnetic, cherty, sedimentary rock.

PLATE XIII : PHOTOMICROGRAPHS OF WEDGE GREYWACKE

Figure 17. Greywacke from the Wedge Mine. Sample O - 7 - 12. Rock is dominantly angular quartz (light) with rock fragments in an argillaceous matrix. Large shale fragment is bottom of photo,with other dark and scattered fragments common(S). Rounded rhyolite pebble (R) appears in center of slide.

Figure 18. Stained thin section. Same locality as above. Illustrates the nature of greywacke matrix. Matrix dominantly angular quartz (light). Rounded grain of unaltered albite displays well developed twinning. Rounded rhyolite fragment is southwest corner. Fine grained material has absorbed the potassium stain.

# PLATE XIII

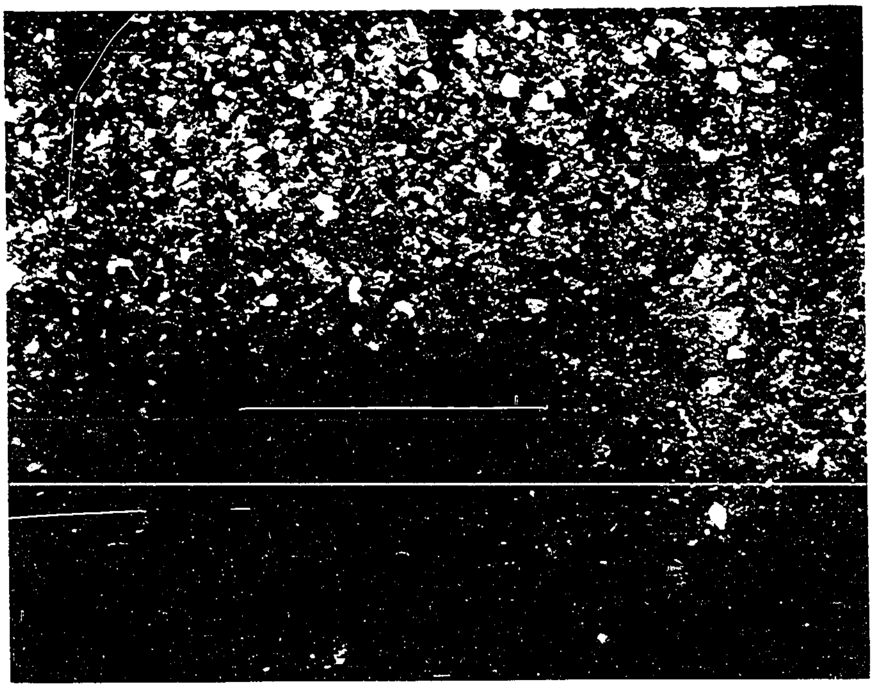


Figure 17 4·2x

Figure 18 70x

The chert commonly occurs as narrow 1 to 3 inch beds but has been observed in beds up to twenty feet thick. Their most common occurrence is along the Nepisiquit River near the east edge of the O - 8 map.

Some of the cherty sediments may be metabentonites. The metabentonites are extremely fine-grained, dense, siliceous, and under high magnification structures characteristic of glass shards are suggested by laths and patches of micaceous material. Further detailed study would be required to more fully establish this rock as a metabentonite.

### Iron Formation

On the O - 8 map iron formation is associated with graphite schists along the Nepisiquit River, as extremely cherty and fine-grained beds, ranging from weakly magnetic varieties to totally non-magnetic cherts and quartzites. These rocks are closely associated with the apparent metabentonites. In other areas they were also observed to grade into red hematitic slates.

The second type of iron formation is a magnetite-bearing rock associated with basic intrusive rocks, notably along the power line three miles south of the Nepisiquit River. These rocks are sedimentary, display red and green laminated beds, are magnetic, contorted, and display abundant quartz veins. Magnetite is visible in hand specimen and in thin section as small euhedral crystals.

The only outcrop of iron formation mapped on the N - 6 sheet is north of the Tetagouche River and west of the Caribou Road. The iron formation at this locality is a green, hard, and extremely fine-grained cherty sediment with streaks of magnetite along the fractures. Pyrite is common as disseminated blebs along fractures and within the rock. The iron formation in this area is also closely associated with basic volcanic rocks.

Andesites

In contrast to the oldest rocks of the Ordovician complex, the youngest rocks are predominantly basic to intermediate volcanics and occur near the outer rim of the folded structure (Plate VII). Andesites are common on the N - 6 and O - 7 sheets and only slightly less so on O - 8. Andesite flows and tuffs are fairly constant in physical appearance over the region.

In the east-central part of O - 7 andesites form a thick sequence in the nose of the Nine-Mile Brook syncline. The andesite is green, fine to medium grained, massive to extremely schistose and slightly calcareous. Calcite occurs as finely disseminated blebs, as fillings in vesicles and as films along veinlets and fractures. These andesites continue southwest onto the O - 8 sheet.

Andesites of N - 6 are somewhat more schistose than those of O - 7 with a higher development of micaceous minerals along the planes of schistosity. Hematitic staining, with the secondary mica, imparts a glossy red appearance to the rock.

Many of the andesites are tuffs. These tuffaceous rocks are usually green, medium to coarse-grained, with an ashy or spongy texture caused by the presence of pumiceous material and abundant rock fragments in the aphanitic matrix. The tuffs are generally more highly chloritized and epidotized than the flow rocks and weather to a pale green which contrasts with the darker green of the flows. The tuffs display a rubbly surface as a result of differential weathering of the softer chloritic matrix and the more resistant fragmental material. The andesite tuffs also show a bedding lamination not characteristic of the flows.

In the intermediate flows and tuffs, veining is common with abundant concordant and discordant veins of quartz and epidote. Disseminated pyrite is a common constituent of the andesites.

Andesites are commonly associated with other volcanic rocks on a minor scale and have been included within the other units, as indicated in Table II.

## Basalt

Basalt was mapped as a distinct unit on the O - 7 sheet but was included as a minor unit in the andesites of N - 6 and O - 8. Basalts are dark green to black, fine to medium grained, and usually very massive with a blocky fracture. They are commonly amygdaloidal, the vesicles being filled with white and pink calcite. Pyrite is a minor constituent as disseminated blebs.

On the O - 7 map the most prominent occurrence of basalt is east of Forty-Mile Brook in the north-central area of the sheet. Many lone basalt outcrops occur in the andesite unit. Although the above description fits the basalts associated with the andesites, those associated with more siliceous rocks are dark red, dark green and brown, with epidote in veinlets along fractures. The lighter basalts are locally tuffaceous in appearance and are commonly associated with thin beds of green laminated chert up to 6 inches thick. Many of these less common basalt types are slightly magnetic.

## Coarse-Grained Basic Volcanics

Associated with the andesites in many areas are other basic extrusive rocks which differ from the andesites in having a coarser grain size. Rocks mapped as coarse-grained basic flows are common in unit 1 of map N - 6 (Plate II). This rock has been highly altered, and secondary chlorite is pronounced, a feature which distinguishes it from the gabbro intrusives in the area.

On the O - 7 sheet coarse-grained basic flows are also rather common. They are generally dark green, medium to coarse-grained, massive to schistose, with an ophitic texture. Disseminated pyrite is common. Quartz, calcite, epidote and chlorite are common along fractures and joint planes.

Some of these rocks may be pyroclastic, as suggested by fragmental texture and the apparent susceptibility of the rock to alteration. In the O - 8 area, where outcrops are more abundant, fine-grained andesites were seen to grade laterally into coarse-grained varieties. Where such variation could be observed the coarser-grained rocks were mapped as equivalents of the andesites and were observed in some instances to comprise the central parts of flows.

Light Green Felsites

In the O - 7 map area rocks mapped as light green felsites make up the dominant lithology of unit 3. Light green felsites are associated with andesites, and considerable practice in the field is necessary in order to differentiate between the two on the basis of color.

Recognition of the felsites as a mappable unit resulted from attempts to sub-divide the thick sequence of greenstones within the core of the Nine-Mile Brook syncline (O - 7).

Light green felsites were not mapped on the N - 6 sheet, and are very minor in the O - 8 area.

— Felsites are light green, fine to medium-grained, generally massive, and in some cases siliceous to such an extent that they have a "sandy" appearance. Many felsites are bedded, fragmental, quite schistose and are seen to display ellipsoidal structures which may represent flow features. Narrow beds of felsite occur with other rock types (Table II).

Chloritic Metasedimentary Rocks.

In the N - 6 area the intermediate volcanic rocks are associated with fine-grained, chlorite-rich rocks which are interpreted as representing primary sediments. The sedimentary rocks are dark green, often sericitic, and display concordant and discordant veins of quartz. They generally display bedding, and epidotization is common along bedding planes.

They also occur as a harder, more massive, silica-rich variety. Some are tuffaceous and can be differentiated from the sedimentary rocks by a characteristic rubbly weathered surface. These rocks have been interpreted as the silicate facies of sedimentary iron formation (McAllister, 1960; Jones, 1960). Chloritic sedimentary rocks have not been mapped in the 0 - 7 or 0 - 8 areas, but it is suggested that green argillites in these areas are equivalent.

Manganiferous and Hematitic Slates

Red manganiferous and hematitic sedimentary rocks are associated with intermediate volcanic rocks of all three sheets. These rocks are typically red, laminated, fine-grained, soft, and interbedded with some green varieties. Small one-inch knots of pyrolusite and rhodochrosite are common. The slates are generally contorted and cut by many quartz veins.

In the 0 - 8 area red slates were seen to be associated with basic intrusive rocks and were also observed to be confined to the contact area of the inner core acid volcanics and the intermediate sedimentary members. The best exposures were observed along the stream which flows out of Rogers Lake, approximately one mile east of where the stream crosses the power line. It can be said that these slates are similar to the iron formations in this area (0 - 8) but are non-magnetic.

Quartz Trachyte and Related Intrusive Rocks

Rocks in unit 4 (N - 6) are practically impossible to correlate with the other units of the same sheet. These rocks are confined to the western and southwestern region (N - 6) where considerable faulting has occurred.

The dominant rock type is quartz trachyte, which supports prominent land forms such as Camel Back Mountain (2100'). The trachyte is massive, fine-grained, light red to dark greenish-black, and is characterized by laths of pink and white feldspar, with scattered flecks of magnetite and hematite. At one locality, on Camel Back Mountain, an occurrence of red cherty jasper was mapped in association with the quartz trachyte. The trachytes extend in outcrop and drill core to within two miles of the Anaconda-Caribou sulphide deposit where they abruptly disappear. The disappearance is believed to have been caused by displacement along a major northeasterly trending fault.

Other scattered outcrops of related rock types occur within the core area of the N - 6 map and represent syenite or monzonite dykes.

Silurian Rocks

Rocks of Silurian age were mapped in the extreme northwestern corner of the N - 6 sheet. Silurian rocks are separated from Ordovician rocks by a major unconformity. Rocks of Silurian age consist of conglomerates, limestones, and greywackes. The conglomerate overlying the unconformity is very massive with large angular pebbles of quartz, manganiferous slates and basic volcanics up to two inches in cross-section. The matrix material is fine to medium grained, green, and slightly calcareous. Limestones are grey-green, fine to coarsely crystalline, and are generally slightly fragmental. Greywacke is fine to medium grained, slightly calcareous, and consists principally of small fragments of manganiferous slates and basic volcanics similar to the underlying Ordovician sequence. The greywackes contain fragments of brachiopods and corals which serve to place the rock sequence above the non-fossiliferous Ordovician complex.

Post-Silurian Rocks

Post-Silurian rocks of N - 6, O - 7, and O - 8 are represented by massive gabbro intrusives.

In general the gabbros are dark green to black, very massive and coarse-grained. Individual outcrops of gabbro show notable degrees of variation. Where the width of outcrop permitted, a gradation in grain size could be seen from coarse-grained interiors to finer grained border areas.

The gabbros show their greatest degree of variation texturally. Hypidiomorphic textures are common with well-developed euhedral crystals of feldspar and pyroxene. Other gabbro bodies, such as the ones north and west of California Lake (O - 7), present a glomero-porphyritic texture in which the matrix is fine-grained, altered and contains large irregular to rounded patches of feldspar crystals up to one-quarter inch in dimension.

The gabbros appear to have been forcefully intruded along fault planes, into the noses of folds, or into areas of incompetent beds. Along the eastern margin of the O - 7 sheet a large mass of mobile basic magma was intruded into a thick sequence of incompetent graphite schists causing them to be squeezed outward and to outline the shape of the igneous mass.

Mapping to the south (Jones, 1964), where outcrop are more plentiful, substantiated the earlier view that much of the faulting in this area pre-dated the intrusion of the basic bodies. Since two main periods of faulting occurred, during Ordovician and Devonian time, it is then conceivable that the gabbros are Devonian in age. It is postulated that a more schistose variety of coarse-grained basic rock, which has been mapped as flows (page 79), might represent gabbro sills of Ordovician age that have been later metamorphosed by subsequent periods of deformation.

Diabasic dykes were observed (0 - 8) cutting the acid volcanic rocks. In some instances the entire width of the dyke (4 feet maximum) could be observed in outcrop. It is possible that these rocks might be Triassic in age, since very similar occurrences have been recorded in the Carboniferous Basin east of Bathurst.

## Structure

### General Statement

Interpretation of structure from the available evidence is very speculative. Lack of outcrop, destruction of primary features by metamorphism, lack of marker horizons, the complexity of the structure, and the scale of mapping followed necessitates indication of gross structural trends only. In the mapped area the strucutal picture is one of extreme faulting and folding. Whereas folding is more prominent in the N - 6 and O - 7 areas, faulting is more pronounced in the O - 8 area (Plate VII).

Structures from at least two major orogenies, the Taconic (Ordovician) and the Acadian (Devonian), have been superimposed on the area. It appears that the major folded structures, which display prominent northeast trends, have developed during the Acadian orogeny. The trend of the structure prior to the Acadian deformation was probably northwest, as evidenced by lesser northwest trends still evident in some areas.

From the scarce amount of data obtained the writer was unable to relate structure to periods of deformation. The description of folds and faults to follow is, then, geometrical.

Most of the tuffaceous and sedimentary rocks within the Ordovician complex display a prominent schistosity which has developed as a bedding foliation in the rocks through compaction and dynamic metamorphism. Schistosity was utilized in mapping lithologic trends.

Dips on the schistosity planes vary from very steep to nearly vertical. However, in the southwest region of O - 8, dips are low. Smith (1957) interprets these particular low dips as an indicator of his structural axis, which runs through the area (Chapter I). Smith's axis, with its northwest trend, has not been clarified in any previous publication.

## Major Folds

In the area mapped by the writer the major folds are associated with axes that strike in a northeast direction and plunge steeply northeast and southwest off the flanks of the dome.

In the northwest (N - 6) the structure is dominated by the west limb of the Tetagouche anticline (Plate VII) which strikes northeast and plunges in the same direction. The east limb of the same anticline extends southerly into the O - 7 area.

Within the boundaries of the N - 6 sheet the principal structure is the broad Caribou syncline which has been developed on the west limb of the Tetagouche anticline. The axial trace of the Caribou syncline is curved but strikes approximately N 20° E. The plunge of the axial line is steeply to the northeast, and the axial plane dips steeply west. This structure may be outlined by lineations on aerial photos and was mapped from the schistosity of the rock units (Jones, 1960).

The trace of the axial plane of the Caribou syncline curves northward out of the augen schist sequence and leaves the N - 6 map sheet striking slightly west of north. Since east-west faults are prominent in this area, it is thought that the curvature of the axial trace has resulted from horizontal displacement along the faults.

Folding is tightest in the vicinity of the Anaconda-Caribou sulphide deposit and opens to the north. The folded structure dies out south of Forty-Mile Brook where it passes into the acidic volcanic rocks of the central core (Plate II).

The east limb of the Caribou syncline passes onto the 0 - 5 map sheet as the west limb of the Tetagouche anticline. The west limb of the syncline is partly cut off two miles northwest of the Caribou sulphide deposit by a series of prominent southwest striking faults.

Folding is prominent in the 0 - 7 map area, where the tightly compressed Nine-Mile Brook syncline lies between the Tetagouche anticline to the north and the Brunswick anticline to the east (Plate VII). The structure again plunges steeply northeast. The Nine-Mile Brook syncline is suggested by the few top determinations that were available in the basic volcanic sequence. Plate I, compiled by the Geological Survey of Canada, shows the folded structure much as outlined on Plate III (Jones, 1963).

The synclinal pattern is the northeast quarter of 0 - 7 can be traced over the whole of the map sheet, where it broadens out rapidly in the acid volcanic rocks to the south.

Folding is not as pronounced on the 0 - 8 sheet as in the N - 6 and 0 - 7 areas. The broad synclinal structure from 0 - 7 dies out but can be traced as far south as the assumed contact between the core acid volcanic rocks and the sedimentary units where it is terminated by faulting.

In the northwest sector of the sheet an open fold was traced by the mapping of a swarm of basic sills which are post-folding. A synclinal axis lies close to the western border and strikes north-northwest. The west limb was mapped by McNutt (1964) on map N - 8.

Major folded structures are traced more easily in the outer two stratigraphic units and are generally lost in the central acid volcanic core. In contrast, faults can be traced through all of the stratigraphic units.

Minor Folds

Minor folding is interpreted as being associated with shearing along faults, intrusion, refolding, or crinkling within major folds.

The central part of the Nine-Mile Brook syncline (O - 7) has been tightly compressed and has buckled into sharp chevron folds in the centre of the trough. This folded pattern is open to interpretation, since it is apparent that a north-south fault through the trough of the fold would give much the same structural pattern and has been postulated on Plate I (G.S.C.). Isoclinal folding has been noted in other parts of the district and would also present much the same pattern (Pearce, 1963 and Skinner, 1956). However, the interpretation shown on Plate III is reasonable and adequately accounts for the great thickness of intermediate volcanic rocks in this area.

In many outcrops over the district small folds have been mapped with amplitudes from one foot to several tens of feet. These folds parallel the major structure, plunge steeply northeast or southwest, and occur in less competent beds as the result of flow during formation of the major folds.

Minor shear folding is common in areas of faulting. Attempts have been made to explain the complicated structure in the southwest quarter of the 0 - 8 map sheet by isoclinal shear folding.

Intrusions of igneous bodies into the stratified layers of tuffs, flows, and sediments has resulted in these beds being warped into small doubly plunging anticlines which surround the intrusion. This feature is evident on Plate IV (Jones, 1964).

Many minor crenulations have been observed, and are associated with slip cleavage. In these cases the amplitude of the folding is less than one inch. The most common crenulation is associated with a near horizontal slip cleavage.

## Faults

Two major fault systems, one striking northwest-southeast and the other approximately at right angles, are apparent in the area mapped. The northeast-southwest system appears to be the more pronounced and terminates the northwest-southeast set in most instances. The more prominent set parallels the direction of the major orogenic axis as postulated by Smith and Skinner (1958). In most cases the type of faulting involved and the displacement cannot be determined accurately with the data available.

On the N - 6 sheet three major faults extend from the western border of the area, across the west limb of the Caribou syncline and intersect the east limb where they trend parallel to the beds (Plate II). This series of faults possibly represents a continuation of a large east-west shear zone mapped by Sims (1960) on the M - 6 sheet. Mapping of these faults on the N - 6 map represents a major contribution to the geology of the area, since faulting adequately accounts for the sudden disappearance of the thick sequence of augen schist which is prevalent in the nose of the fold. Skinner (1956) attributes the disappearance of augen schist to interfingering of several narrow extensions of the augen schist into rocks of Smith's (1957) greenstone division (Plate I). Detailed mapping in the area two miles northwest of the nose of the Caribou syncline confirmed the presence of faulting and further indicated that the augen schists disappear as a result of displacement along the faults. The west limb of the Caribou syncline passes through the fault zone into the east limb of a broad anticlinal structure the axis of which strikes approximately north-northwest.

Another area of faulting in the southwest corner of the N - 6 sheet is related to the system of faults with northwest-southeast trends. The most prominent is a large fault which extends from the M - 6 sheet (Sims, 1960), crosses the southwest corner of the N - 6 sheet (Plate II), and extends for a considerable distance south along the valley of Forty-Mile Brook. This fault is characterized by a deep linear depression where it crosses the N - 6 map and rocks south of the fault appear unrelated to the rocks north of the fault. The amount and direction of displacement along the fault is unknown. It has been postulated that the above fault may form part of a major fault zone which follows the Forty-Four Mile Brook valley southeast to the Nepisiquit River and on along the Tomogonops River to the edge of the Pennsylvanian cover. Part of this fault zone is indicated on Plates I and VII.

Camel Back Mountain (N - 6) is flanked by fault zones, and only relative movements have been indicated. However, it is proposed that significant vertical movement has elevated the trachytic rocks of unit 4 into their present position.

The same fault systems as those outlined on N - 6 contribute to the complex structure of the 0 - 7 map. The great thickness of intermediate volcanics in the northeastern area, are terminated to the south by east-west faults and are partly cut off to the west by a major north-south fault.

Faulting is more important than folding in controlling the structure in the acid volcanic core of the 0 - 8 sheet. The most notable feature is that faulting does not appear to offset basic intrusive bodies which are located in and along areas of mapped fault zones. Several of the basic intrusive bodies are confined to areas of fault intersections. In the N - 6 sheets and 0 - 7 sheets faults are shown to cut basic intrusives, but these maps with their interpretation were published before these relations were established (Jones, 1964).

## Conclusions

The writer is of the opinion that much of the structure in the Bathurst-Newcastle camp has been interpreted in the past to be folding because of the implication that folded structures in conjunction with suitable rock types imply favorable conditions for the presence of sulphide deposits. Mapping of the N - 6, 0 - 7 and 0 - 8 sheets has been convincing that much of the folded structure can be better defined by faulting.

The contact between the Ordovician and Silurian sequences is variously interpreted as a fault (Skinner, 1956) or unconformity (Smith and Skinner, 1958). From reliable field evidence the writer interpreted the contact as an unconformity (Jones, 1961). The contact is irregular (Plate II), and the rock assemblage of the Silurian immediately above the Ordovician contains fragments and pebbles lithologically similar to the uppermost Ordovician (unit 1) of map sheet N - 6. Assuming that the Ordovician complex is a domal structure, the interpretation of the Silurian-Ordovician contact as an unconformity is the basis whereby a gross stratigraphic sequence can be established for the Ordovician rocks (See Figure 14, Plate XI).

## Economic Geology

### General Statement

During the mapping period (1960-1964) one mine was in production, and several areas of interest were being actively investigated. The producing property is the Consolidated Mining and Smelting-Wedge Mine, immediately west of Forty-Mile Brook on the north side of the Nepisiquit River (O - 8).

The only other major sulphide occurrence of economic interest within this area (N - 6, O - 7, O - 8) is the Anaconda-Caribou deposit on N - 6 (Plate I). At the present time the property is dormant, and development work includes the completion of an adit intersecting the western limb of the sulphide zone.

Descriptions of Sulphide Occurrences

The reader is referred to Jones (1960) for detailed information concerning the geology and origin of sulphide deposits in the Bathurst-Newcastle area. However, the deposits do have several features in common which are listed below:

1. Sulphide zones are conformable to sedimentary and volcanic horizons in association with augen schists.
2. All of the massive sulphides show bedded and banded features.
3. The deposits are elongate, lens-like bodies parallel to the local bedding.
4. Metal ratios appear consistent.
5. Regional zoning is lacking.

Mineralogically the deposits consistently fall into one of two major types. The most common type is fine-grained and massive, consisting of 70 - 80 per cent pyrite and up to 7 per cent sphalerite and smaller amounts of galena. The second mineral assemblage is composed mainly of pyrrhotite and chalcopyrite with little or no galena and sphalerite. These two types of ore may occur separately or in conjunction with each other.

The reader is referred to Jones (1961, 1963, 1964) for descriptions of minor sulphide occurrences scattered over the N - 6, O - 7 and O - 8 maps.

## Contributions Made to the Local Geology

During the field work several observations were made which constitute contributions towards a better understanding of the geology of the district. These observations and contributions are listed below:

1. Recognition of reliable data for the existence of a major unconformity between the folded Ordovician complex and the overlying Silurian sequence.
2. The establishment of an unconformity allows for recognition of relative age relationships in the rocks of the Ordovician complex. Assuming a domal structure, the core rocks are the older, with decreasing age outwards towards the rim.
3. Large displacement faulting in the west limb of the Anaconda-Caribou syncline has accounted for the disappearance of the great thickness of augen schists that

occur in the nose of the fold. Prior to this interpretation the problem was solved by interfingering of augen schists with basic volcanics (Smith, 1957).

4. An additional acid intrusive rock type, "quartz trachyte," was recognized in the Camel Back Mountain area (N - 6).
5. Establishment of a "chloritic sedimentary rock" unit associated with basic volcanics in the northern sections of the N - 6 sheet. It is possible that these rocks represent the silicate facies of iron formation.
6. The development of "quartz-sericite" schist by dynamic metamorphism of augen schist. On map N - 6 quartz-sericite schists and augen schists are closely associated and often interbedded so that the quartz-sericite schists appear to be nonporphyritic varieties of augen schist. In other cases it is evident that as the degree of shearing increased phenocrysts disappeared with the production of a sericite-rich schist. This relationship has been suggested by other workers and has been fully established in the progress of mapping the three sheets in the particular order followed (N - 6, O - 7 and O - 8).
7. There is a physical gradation in the "augen schist" band from the N - 6 sheet to the O - 8 sheet. Whereas the rocks of O - 8 are very massive and contain equal numbers of quartz and feldspar phenocrysts, the rocks of N - 6 contain relatively few quartz phenocrysts and an abundance

of feldspar augen. This gradation can be followed on the O - 7 sheet. In the north-central area (O - 7) the augen schists are similar to those of N - 6, although they are not as schistose and the feldspars are not as altered. Following the same bands towards the southeast (O - 7) the rocks become more massive and appear similar to these of O - 8.

8. Mapping the intermediate volcanic sequence on the O - 7 map resulted in the sub-division of this unit into andesites and light green felsites, which could be traced as a mappable unit.

9. Recognition of the light green felsites aided in interpretation of chevron folds within the tightly-compressed nose of the Nine-Mile Brook syncline (O - 7). Chevron folding has resulted from flexure and shearing within this tight structure.

10. Three possible ages of gabbro were recognized from field relations and relative degrees of alteration. Ordovician gabbros occur as altered, conformable bodies that resemble sills or flows. These rocks have been deformed by subsequent periods of deformation. Devonian gabbros are massive, fresh, and undeformed. They occur as massive intrusive stocks and smaller cross-cutting bodies. Some of the massive, narrow diabasic dyke rocks are possibly Triassic in age.

11. Devonian gabbros have been intruded along planes of weakness; in areas of graphite schist or "dacite" occurrence and in areas of faulting and folding.

12. The quartz and feldspar augen schists were successfully subdivided, and a new mappable unit was recognized as "dacite" on the O - 8 sheet. "Dacite" has characteristics which are recognizable on a regional scale, and it is felt that future mapping of this unit may lead to a better understanding of the gross structure.

13. Mapping the O - 8 sheet has substantiated the writer's contention that many of the porphyritic rhyolites represent necks or plugs from volcanoes of the Ordovician terrain. Rhyolite intrusives are relatively unmetamorphosed in comparison to rhyolite tuffs, and it is proposed that they formed competent masses that were able to withstand the effects of several periods of deformation. An alternative would be that massive rhyolite intrusions might represent Devonian or younger intrusive rocks. On a regional scale rhyolite intrusive masses tend to follow linear trends.

14. As a corollary to 13, above, lithic tuffs were recognized in the southwestern region of the O - 8 sheet in association with the intrusives. These rocks are quite distinct from other tuffaceous units mapped in

the region by their rock fragment content.

15. Some success was obtained in subdividing the central volcanic core rock into flows and tuffaceous units.

16. Two major fault systems were established, one striking north of west and the other northeast-southwest.

17. Possible metabentonites were recognized on the 0 - 8 map in association with graphite schists.

18. During the early history of the district there was a tendency to associate massive sulphides with folded structures. This led to "overfolding" the structure in the region. This recent mapping program suggests that faulting may have played a larger role in shaping the structure than did folding. Many of the earlier structures that were solved by complicated folded patterns have been solved more easily in the light of faulting.

# C H A P T E R

# T H R E E

# PETROGRAPHY OF THE ACID VOLCANIC ROCKS

## General Statement

The purpose of this chapter is to discuss the petrography of the acid volcanic rocks, utilizing information obtained from thin section study of abundant rock samples and heavy mineral studies from a few selected rocks. The sheets N - 6, O - 7 and O - 8 were a basis for the study, but additional material was used from widely-spaced localities over the entire area.

Locations for the samples illustrated are indicated in the captions for each figure. Samples are listed by map and number for the particular sheet. For example, in each figure a notation such as (O - 8 - 3) has been made. This indicates that the reader is referred to sample 3 from the O - 8 quarter-mile sheet. Sample locations have been plotted in the same manner on Plate I.

The acid volcanic rocks have been divided into four main divisions, ranging from the least metamorphosed types to the most metamorphosed types. These are:

1. Massive rhyolite intrusives and flows.
2. Massive and bedded rhyolite tuffs
3. Augen schists.
4. Quartz mica schists.

It is the writer's intention to show the progression of metamorphism as expressed in the texture and mineralogy of the rocks.

All of the rocks of the area have been metamorphosed to the greenschist facies of Turner and Verhoogen (1960). Not enough evidence is available to subdivide the area into subfacies within the main facies. However, it is felt that various intensities of metamorphism can be recognized within the greenschist facies. It is proposed that the existence of a varying metamorphic intensity results because equilibrium has not been reached, since intense deformation (shearing) has had varying effects on a rock assemblage that contained various physical rock types (tuffs, flows, intrusives).

Various thin sections and rock slabs were stained to show tectural and mineralogical relations better. Staining affected the appearance of the minerals both under the microscope and in photomicrographs. A short note is inserted here to explain the methods used and the results obtained.

Staining: Several techniques for the staining of thin sections have appeared in the literature. The one utilized by the writer consisted of a combination of various methods, and the steps are outlined as follows:

(1) A small polyetheline container was filled to within one-quarter inch of the top with 52 per cent hydrofluoric acid.

(2) Thin sections were etched over the HF fumes for three minutes.

(3) Sodium cobaltinitrate powder and water were mixed in 5:3 proportions and poured over the etched samples after the HF condensation was allowed to dry. The K-feldspar was coated with a bright yellow stain after about one minute. The thin section was then washed thoroughly.

(4) Thin sections were quickly dipped into a 5 percent barium chlorite solution and rinsed to remove the excess barium chloride.

(5) 0.05 grams of rhodizonic acid potassium salt was dissolved in 20 ml. of water. The solution was poured over the thin section and after 15 seconds a brick-red stain formed on the plagioclase feldspar. The sample was immediately washed and allowed to dry.

In thin section the K-feldspar phenocrysts and many of the plagioclase feldspar phenocrysts appear heavily stained. In the accompanying photomicrographs of stained thin sections the feldspars appear as dark grains. In some the matrix has been heavuly stained and in photomicrographs appears as a dark, indistinct mass.

## Rhyolite

### General Statement

The rocks of this unit represent the least metamorphosed types in the district. Their groundmasses have been recrystallized, and they show little indication of being deformed.

As pointed out in Chapter II, these rhyolites are interpreted either as flows or as the cores of Ordovician volcanoes. In areas where they are highly concentrated, such as around the Nine-Mile fire tower (P - 7) or on Razor Back Ridge ( O - 8), they are interpreted as core structures, and in areas of sparse occurrence they are flows.

Rhyolites of this group are both porphyritic and non-porphyritic. Where the two occur together there seems to be a gradation from one to the other.

Individual bands of rhyolite are difficult to trace.

### Megascopic Description

These rocks are very massive, dense and aphanitic; they weather white. The presence of abundant joint planes causes the rocks to be blocky. The rhyolite fractures with a typical subconchoidal break. Quartz veins are common and in areas where weathering has not been too extreme, original flow banding is evident.

Phenocrysts are quartz and feldspar, generally less than 2 mm. in dimension. Quartz phenocrysts are clear, glassy and euhedral. Feldspars range from pink to white and vary from good euhedral forms to broken and fragmental grains. The phenocrysts do not show any preferred orientation.

Microscopic Description

As stated earlier, the rocks have been metamorphosed, and the mineralogy and texture have been affected to varying degrees. Any discussion of mineralogy must consider the effect of metamorphism. Whereas the mineralogy of the whole acid volcanic sequence is similar, the discussion of detailed mineralogy is postponed to a later time.

Texture - The texture of the rhyolite is modified by recrystallization. The groundmass is composed of a microcrystalline mosaic of quartz and K-feldspar, with grain size not exceeding 0.5 mm. The matrix is dense, and mica minerals are not abundant enough to impart schistosity to the rock (See figures 15 and 16, Plate XII; and Figures 20 and 21, Plate XIV).

Where present, quartz and low temperature feldspar phenocrysts make up the most prominent feature of the rock.

Mineralogy - Mineralogically the rocks are simple. Both igneous and metamorphic assemblages are present. The former is expressed in the phenocrysts, where low temperature inversion K-feldspars predominate. The metamorphic assemblage is expressed by the matrix, where recrystallization has been prevalent.

## Rhyolite Tuffs

### General Statement

Rhyolite tuffs are more altered and metamorphosed than are the flows and intrusives. However, in many cases the alteration effects have not been extreme enough to destroy the original tuffaceous structures, and it is this group of rocks which present the best evidence for origin of the sequence.

The rhyolite tuffs are varied in physical appearance and for convenience may be divided into massive and bedded types. In the former, microscopic evidence of origin is present, whereas in the latter field evidence provides the best information.

Rocks from this group have invariably been placed within the augen schist unit in any mapping program. For example, the massive tuffs include rocks which have been mapped by the writer as "dacite" from their megascopic

PLATE XIV : PHOTOMICROGRAPHS OF MASSIVE RHYOLITES.

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Figure 19. Porphyritic rhyolite. Stained thin section. Sample J - 776A from Razor Back Ridge, map O - 8. Massive recrystallized matrix. Small patches of recrystallized quartz show serated grain boundaries. Large strained quartz phenocrysts show suggestion of crystal outline and embayments.

Figure 20. Massive, non-porphyritic rhyolite flow. Sample N - 8 - 2, north of the Nepisiquit River. Rock is relatively unaltered. Feldspar occurs as small laths. Quartz appears recrystallized as anhedral and sutured masses interstitial to the feldspar.

# PLATE XIV

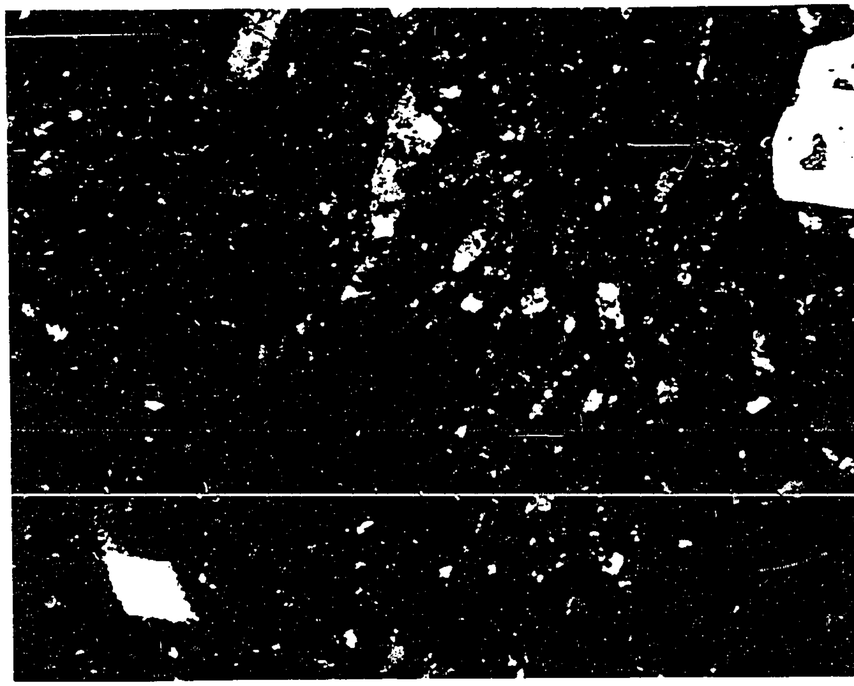

Figure 19 21 x

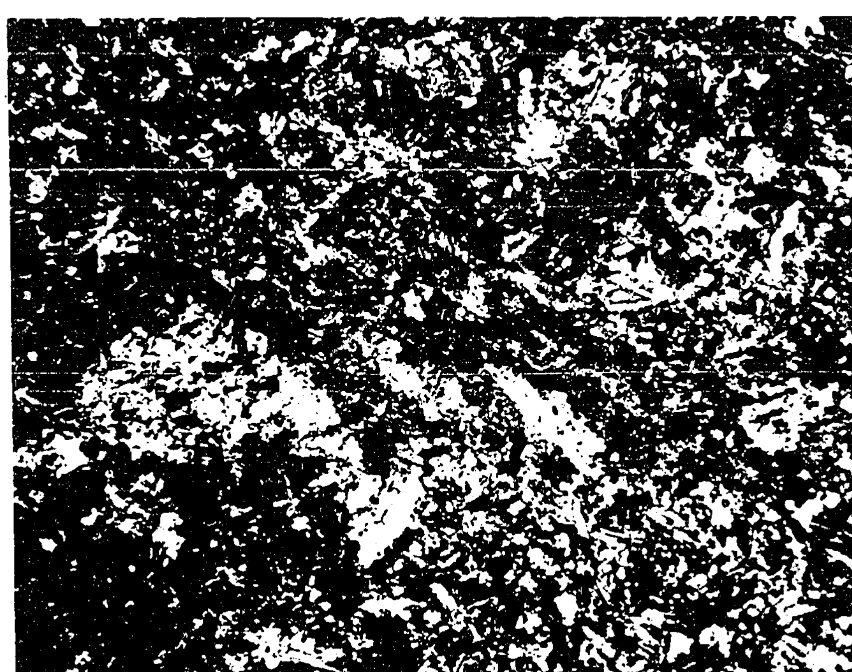

Figure 20 21x

appearance in the field (Jones, 1964). These rocks were earlier mapped as augen schists. The term "dacite" was found convenient for sub-dividing the acid volcanic series, but in the remainder of the work these rocks will be referred to as rhyolite tuffs unless necessity requires that they be differentiated as "dacites."

The "dacites" and other augen schists which show microscopic tuffaceous structures make up the massive rhyolite tuffs. The bedded tuffs are represented by types referred to in the field as "greywacke augen schist" and lithic tuff. The term, "greywacke augen schist," will be discarded, and the two rocks will be referred to henceforth as pyroclastics.

Megascopic Description

Rhyolite tuffs, since they are composed of several rock types, show wide variance in megascopic appearance. Each is considered briefly.

"Dacite" - is dark green, aphanitic, often cherty and generally massive but in local areas can be extremely schistose. Epidote is a characteristic mineral as replacements of feldspar phenocrysts. Dacites are porphyritic with K-feldspar forming the most common phenocrysts, ranging from large pink fragmental crystals to small white splintery grains. In the more schistose variety of rock, small subhedral quartz phenocrysts are common.

Rhyolite augen schists are characteristic of the O - 7 sheet and have been included within the augen schists (Jones, 1963). They are light green, generally massive (some are extremely schistose) and appear more siliceous than the "type" augen schist. Phenocrysts consist of both quartz and feldspar with the latter being the more abundant and ranging from small broken fragments to large euhedral crystals up to one-half inch in long dimension. Potassium feldspars are more common than albite. They lie with their long dimension parallel to the planes of schistosity. The pink color of the feldspar is characteristic of this rock and of the massive rhyolites. The feature which distinguishes this rock from the augen schists is that the feldspar phenocrysts are not lens-shaped but tend to show euhedral crystal outlines.

Pyroclastics represent the bedded rocks in this group. The lithic tuffs are characterized by rock fragments, which are predominantly rounded rhyolite pebbles, with lesser amounts of angular and splintery shale fragments. The fragments seldom exceed two inches in length and lie with this direction parallel to the schistosity of the rock and to the primary bedding. Rhyolite fragments, being more resistant to weathering than the matrix, impart a rubbly surface to the rock. In an outcrop west of Brunswick Number 12 (Sample P - 7 - 7) angular rhyolite fragments in excess of six inches in length are common.

The matrix is characterized by an abundance of small fragmental quartz and feldspar grains in a finer mosaic with an abundance of mica. The bedded nature is brought out by the rock fragments and mica-rich bands in the matrix.

"Greywacke" augen schists of Lee and Rancourt (1958) represent original sedimentary rocks. The matrix is extremely fine-grained, and mica is pronounced. Angular quartz and feldspar crystals up to 5 mm. across are common and show no preferred orientation. Bedding is imparted by thin (six inch) interbeds of massive, rhyolitic, volcanic rocks. The absence of rock fragments distinguishes these rocks from the lithic tuffs.

The massive rhyolite tuffs apparently originated as ash flows. The lithic tuffs have incorporated materials over which they have flowed.

Pyroclastic rocks are very localized within the acid volcanic sequence and cannot readily be traced from one outcrop to the next.

## Microscopic Description

Each rock type has microscopic features which are characteristic and which will be discussed individually.

<u>Texture</u> - The rocks of this group have been metamorphosed to a higher degree than have the massive intrusives and flows. The higher degree of metamorphism is thought to have depended on the original composition of the rock. That is, vitric tuffs react more rapidly than do crystalline flows under conditions of dynamic shear. The textures are, therefore, more indicative of metamorphic rocks than they are of volcanic rocks. It is evident that the phenocrysts are preserved but that the matrix has been largely reconstituted.

The matrix of the dacites is composed almost entirely of micaceous minerals and quartz. The rocks appear massive in hand sample, but the occurrence of sinuous, microcrystalline, sericite-rich bands imparts appreciable schistosity to the rocks in thin section (Figure 24, Plate XVI). In other cases the texture is dense, and the schistosity is not as pronounced (Figure 23, Plate XVI). Quartz in the matrix is highly recrystallized. Under plane polarized light the matrix of the dacites appears "dirty" with abundant minute opaque particles. By direct comparison of Figure 21 to Figure 22 (Plate XV) similarity is noted between the matrix of the metamorphosed tuffs from this district and the matrix of more recent, unmetamorphosed tuffs. Shard and pumice type outlines are still evident in the altered material (Figure 22).

PLATE XV : PHOTOMICROGRAPHS OF FRESH AND ALTERED TUFFACEOUS TEXTURES.

Figure 21. Tertiary rhyolitic ash flow, southern Peru. Rock consists of fine glass shards and pumice fragments. cf.Jenks and Goldich (1957). Rock sample AR-342.

Figure 22. Altered tuff from the Bathurst-Newcastle area. Possible relic shard and pumice fragments are evident. Shard-S.Pumice-P. Sample O - 7 - 5.Compare with Figure 21, above.

# PLATE XV

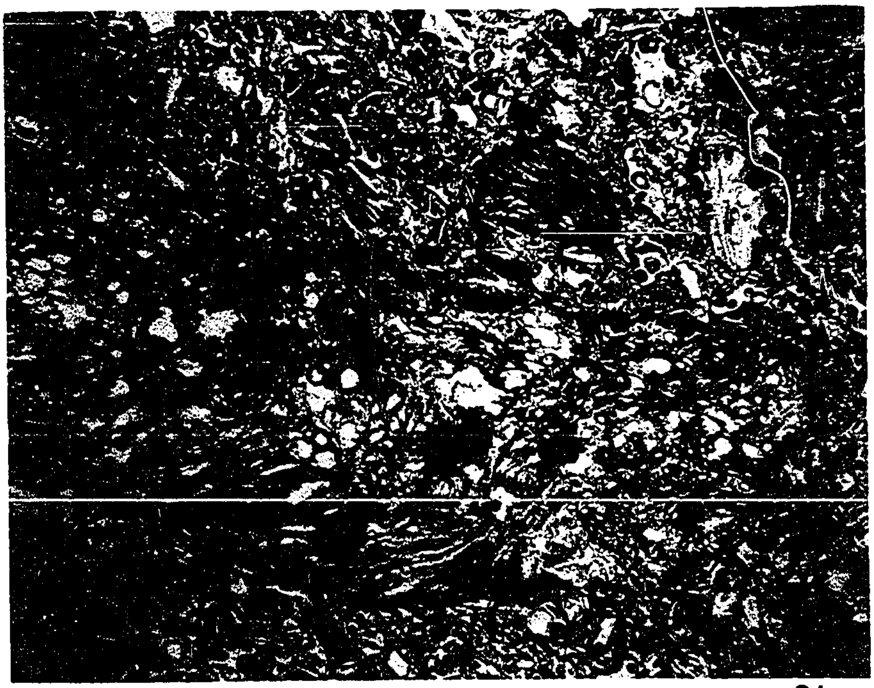

Figure 21 21x

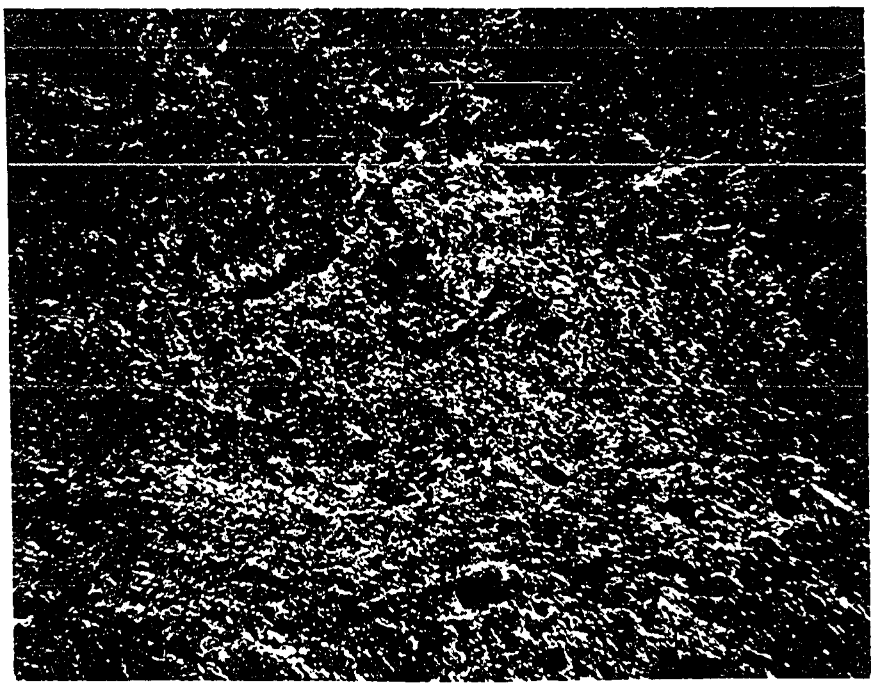

Figure 22 21x

PLATE XVI : PHOTOMICROGRAPHS OF MASSIVE DACITES.

Figure 23. Massive dacite. Sample 0 - 7 - 10. Quartz phenocrysts (white) are typically embayed. K-feldspar phenocrysts (grey) are being replaced by epidote(dark grey). Replacement is partial. Matrix consists of microcrystalline quartz, sericite and epidote.

Figure 24. Massive dacite. Sample 0 - 7 - 11, in close proximity to sample in Figure 23. Replacement of feldspar phenocrysts by epidote is complete. Epidote appears as dark,fractured patches. Light sinuous bands are microcrystalline sericite. Matrix consists of quartz, sericite and epidote.

# PLATE XVI

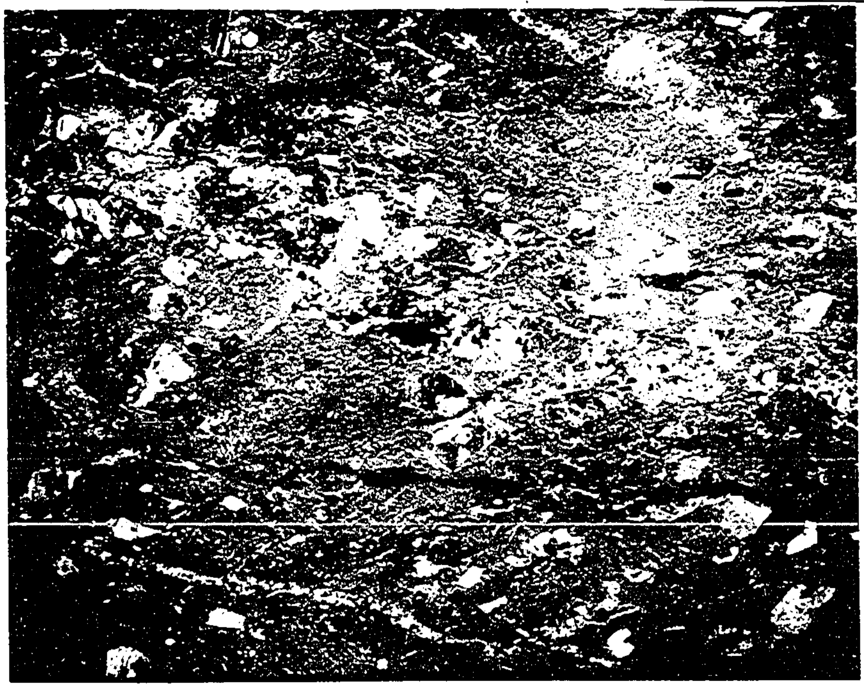

Figure 23 4·2 x

Figure 24 4·2 x

Quartz and feldspar phenocrysts within the dacites vary in shape and degree of alteration. Many of the quartz phenocrysts show growth rims, and the contacts with the matrix are often vague with considerable interfingering of the two (Figure 12, Plate X). Feldspars have commonly been epidotized. (See section: Alteration of "Dacite".)

The massive rhyolite tuffs are distinctive in not containing epidote and in approaching the augen schist in physical appearance. They are generally massive with large phenocrysts of quartz and K-feldspar scattered throughout a fine recrystallized matrix of quartz and feldspar. In the massive tuffs (Figues 25 and 26, Plate XVII) the large phenocrysts are unoriented, crystal outlines are sharp, and there has been little reaction between the phenocrysts and the matrix.

Other tuffs are roughly banded (Figures 27 and 29, Plate XVIII), and sericite is now a common constituent of the matrix. Feldspar phenocrysts show tendencies to be oriented and unmixed. Quartz is a common filling of the feldspar phenocrysts along fracture planes. Many of the quartz phenocrysts show embayment structures.

In the massive rhyolite tuffs several relic features were observed which represent evidence of tuffaceous origin. These features have been documented in a series

PLATE XVII : PHOTOMICROGRAPHS OF MASSIVE RHYOLITE TUFFS.

Figure 25. Stained thin section. Crossed nicols. Sample O - 7 - 1. Large phenocrysts are K-feldspar (black). Rims of clear Na-feldspar are evident. Matrix is massive and recrystallized. Matrix is composed of quartz, orthoclase and sericite. Small patches of devitrified glass impart a mottled appearance to the rock.

Figure 26. Sample O - 7 - 2. Crossed nicols. Massive rhyolite tuff. Large, euhedral patch perthitic feldspar phenocrysts have been altered, fractured and rotated in the soft matrix. Scattered, small patches of devitrified glass are common. Matrix consists of quartz, feldspar and sericite. Phenocrysts are being rotated into the plane of the developing schistosity.

# PLATE XVII

Figure 25 4·2 x

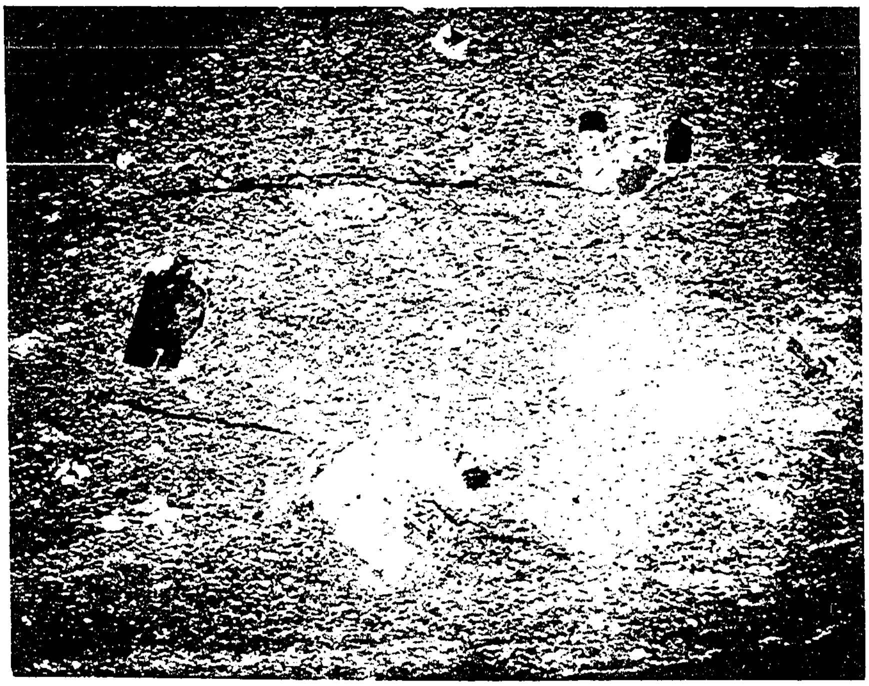

Figure 26 4·2 x

PLATE XVIII : PHOTOMICROGRAPHS OF RHYOLITE TUFF.

Figure 27. Stained thin section. Crossed nicols. Sample O - 5 - 15. Rhyolite tuff. Fine grained massive tuffaceous matrix. Large quartz phenocrysts (Q) are embayed. Patch perthitic feldspar phenocrysts (K) are present. Phenocrysts are generally aligned along the schistosity direction.

Figure 28. Stained thin section. Crossed nicols.Sample O - 8 - 2. Rhyolite tuff. Matrix relatively unmetamorphosed. Sericite bands(light) are developing around the phenocrysts. Large euhedral to subhedral patch perthitic feldspar phenocrysts have been heavily stained. Broken fragmental quartz phenocrysts(white) are abundant. Small unstained and twinned albite phenocrysts(A) are common. Albite displays bent twin lamellae.

# PLATE XVIII

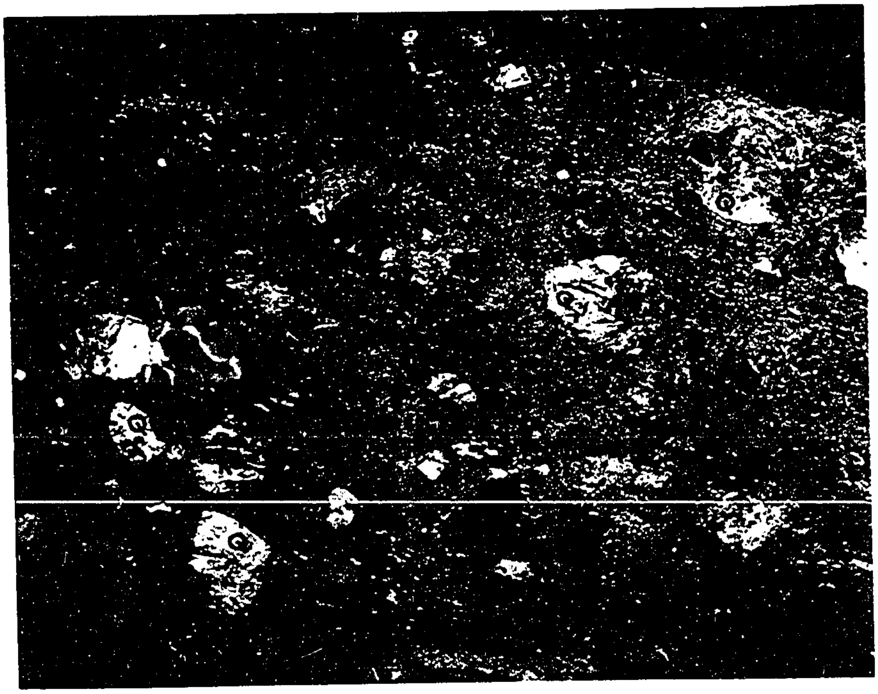

Figure 27 4·2 x

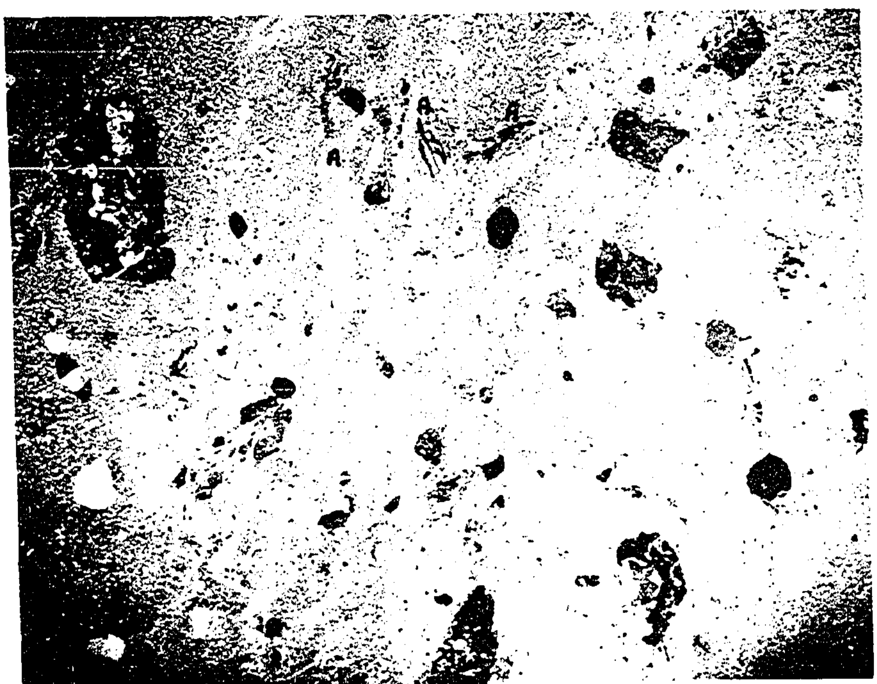

Figure 28 4·2 x

of photomicrographs and are:

1. Embayed quartz phenocrysts. See Figure 27 (Plate XVIII) and Figures 29 and 30 (Plate XIX). These can be compared to the embayed quartz from fresh unaltered tuff seen in Figure 31 (Plate XX).
2. Devitrified lapilli (Figure 33, Plate XXI). Johnston (1960) and others have interpreted these structures in the same way.
3. Axiolitic structures (Figure 34, Plate XXI). These are small patches of devitrified glass.
4. Small pumice particles. Figure 60 (Plate XXIV) illustrates an example.
5. Possible rock fragments. Figure 41 (Plate XXV) is an example.

The pyroclastics are characterized by rock fragments in a recrystallized matrix (Figure 35, Plate XXII). The fragments consist of both rhyolite and shale particles that lie with their long direction parallel to the schistosity of the rock. The matrix is sericitic and contains an abundance of fine clastic material.

Whereas, in the sample cited above, rock fragments are very pronounced, others show an abundance of large quartz and feldspar fragments. Such is illustrated by Figure 36 (Plate XXII). The rock is massive, and the shale

PLATE XIX : PHOTOMICROGRAPHS OF EMBAYED QUARTZ PHENOCRYSTS.

Figure 29. Sample Q - 7 - 1. Massive rhyolite tuff. Deep embayed volcanic quartz phenocryst in a recrystallized matrix. Dark oval inclusions represent embayments entering the grain from out of the plane of the thin section. Matrix material has been heavily stained. Microcrystalline quartz is recrystallizing in the shadow area of the phenocryst.

Figure 30. Sample Q - 7 - 2. Massive rhyolite tuff. Deep embayed quartz phenocryst,as Figure 29. Embayments filled with material representative of the original magma. Phenocryst has been rotated, with quartz and sericite recrystallizing in the shadow areas.Dark crenulated mineral flowing around the phenocryst is biotite.

# PLATE XIX

Figure 29 21x

Figure 30 21x

PLATE XX : PHOTOMICROGRAPHS OF EMBAYED QUARTZ AND CHEQUER-BOARD ALBITE.

Figure 31. Typical volcanic embayed quartz phenocryst in a Tertiary rhyolitic ash-flow, southern Peru. (sample MO - 10, Jenks and Goldich,1957). Photo by Jones, 1964.

Figure 32. Chequer-board albite phenocryst from a pyro-flow. Sample Q - 7 - 6. Albite twinning well developed with chequer-board structure on end of grain. Phenocryst has been heavily stained. Clastic quartz(white) evident in the matrix.

# PLATE XX

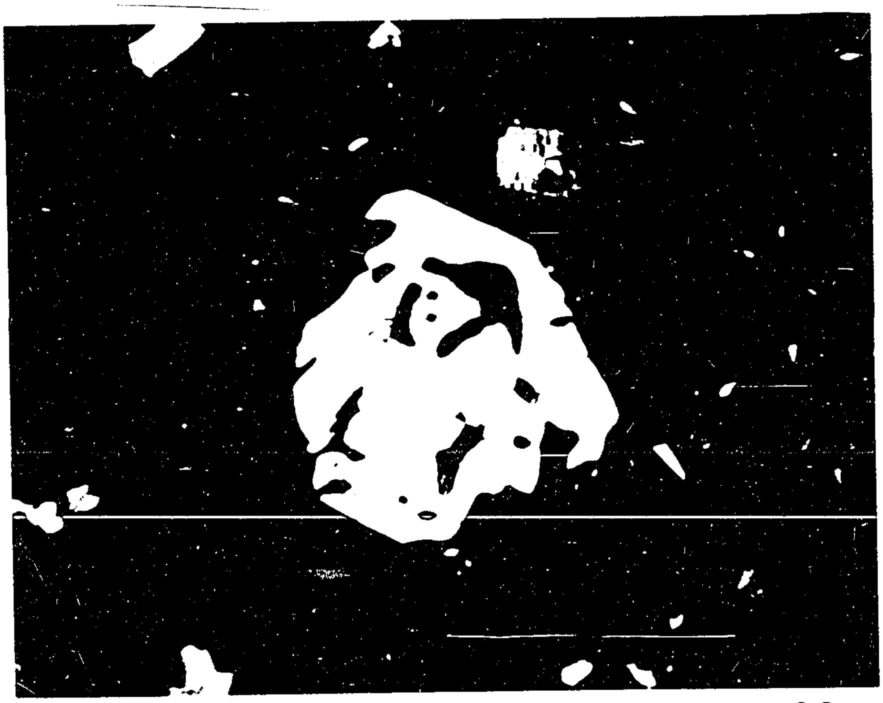

Figure 31 60x

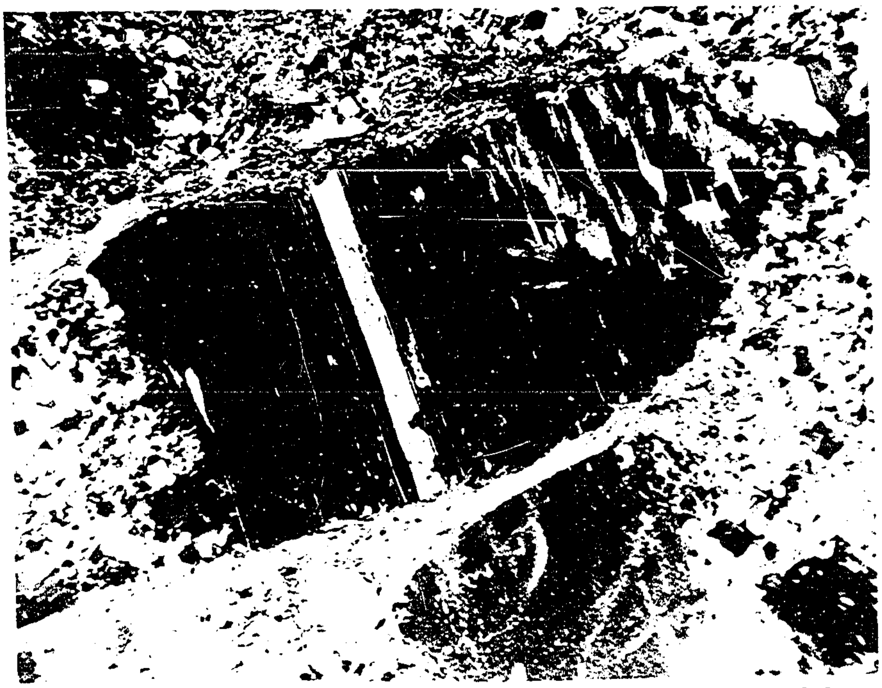

Figure 32 60x

PLATE XXI : PHOTOMICROGRAPHS OF TUFFACEOUS STRUCTURES.

Figure 33. Stained thin section. Crossed nicols. sample O - 7 - 2. Recrystallized tuffaceous matrix. Rounded, recrystallized quartz and orthoclase patches are interpreted as devitrified glass lapilli. Grains show typical sutured boundaries. Matrix is heavily stained, with a high sericite content. Schistosity is pronounced.

Figure 34. Stained thin section. Crossed nicols. Sample O - 7 - 7. Recrystallized rhyolite tuff. Small axiolitic structures are evident in the top central part of the figure (circled). Large K-feldspar phenocryst has been fractured along cleavage planes. Secondary quartz (white) fills the separated fractures. Chequerboard albite (A) appears in the central part of the figure. Feldspars show clear and mosaic type growth rims around the boundaries and in shadow areas.

# PLATE XXI

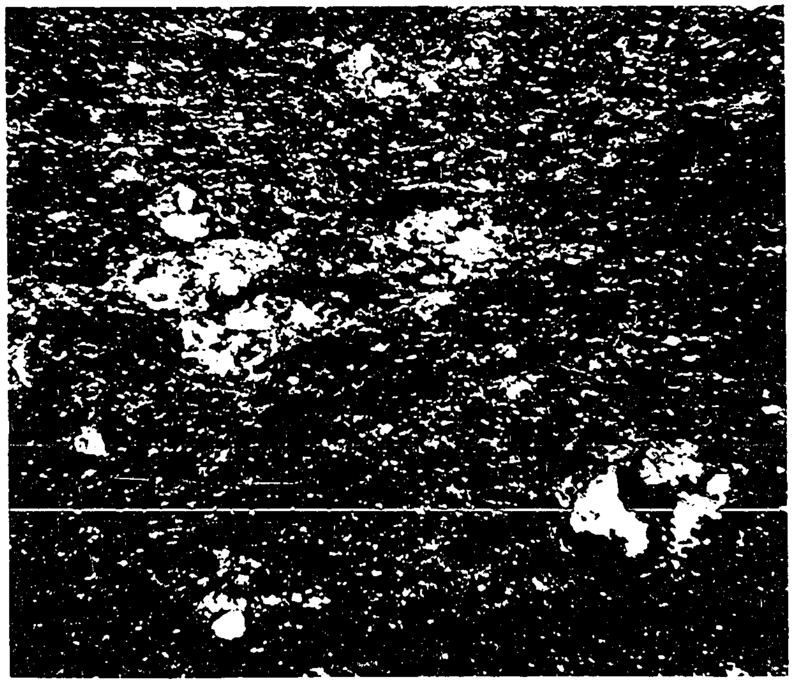

Figure 33 21x

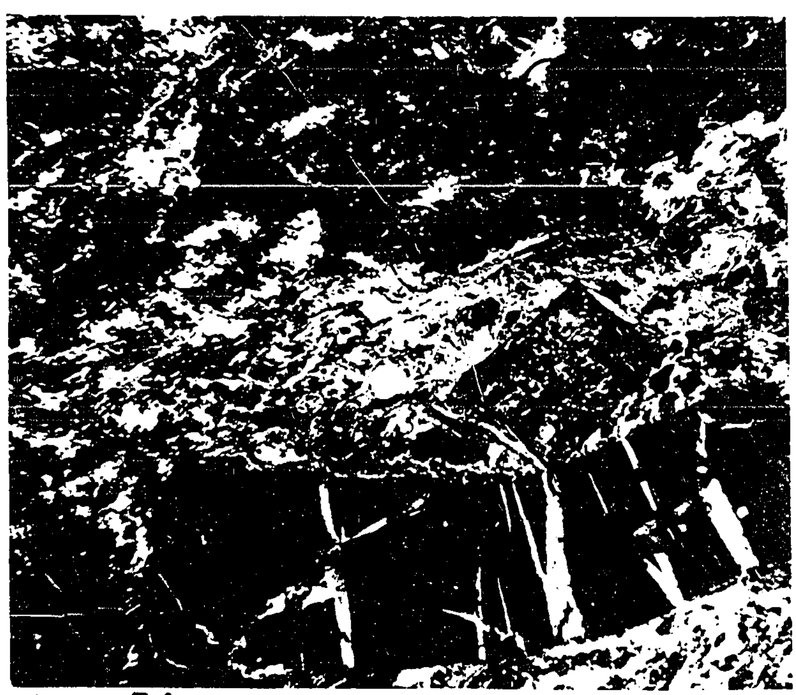

Figure 34 21x

PLATE XXII : PHOTOMICROGRAPHS OF PYROCLASTICS.

Figure 35. Stained thin section of lithic tuff. Crossed nicols. Sample P - 8 - 5, from the Narrows of the Nepisiquit River. Rock fragments consist of angular shale(black), rounded quartzose shale (S), and rounded rhyolite(R) pebbles. Matrix is clastic and highly sericitic. Schistosity is developed parallel to the bedding.

Figure 36. Stained thin section of lithic tuff. Crossed nicols. Sample P - 7 - 7, west of Brunswick Mining and Smelting Number 12 Mine. Clastic material predominantly angular embayed quartz grains(white). Plagioclase feldspar phenocrysts(A) are deeply stained, and some contain clear inclusions of K-feldspar (K) and quartz. Shale(S) makes up the rock fragment material and is seen to flow around the phenocrysts. This feature may be pre-lithification.

# PLATE XXII

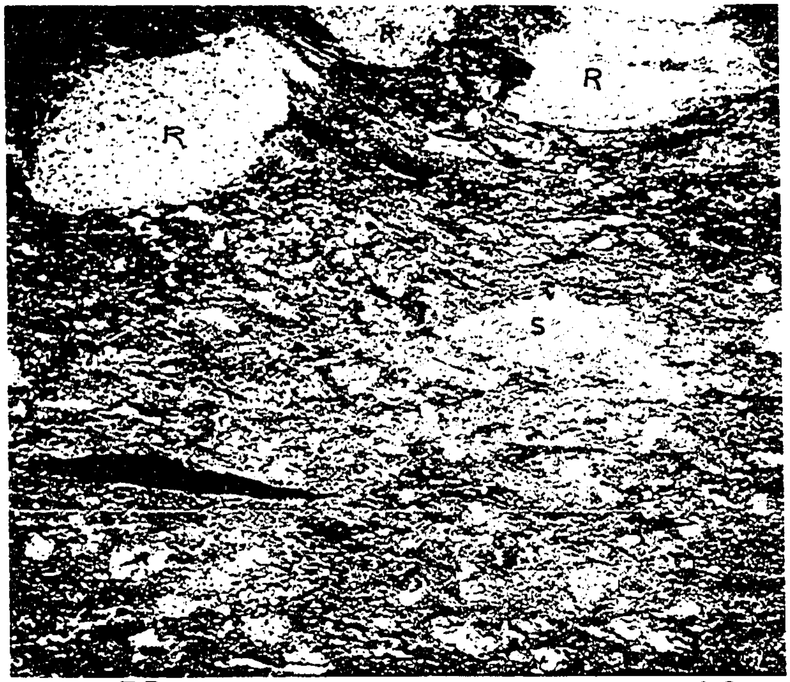


Figure 35 4·2 x

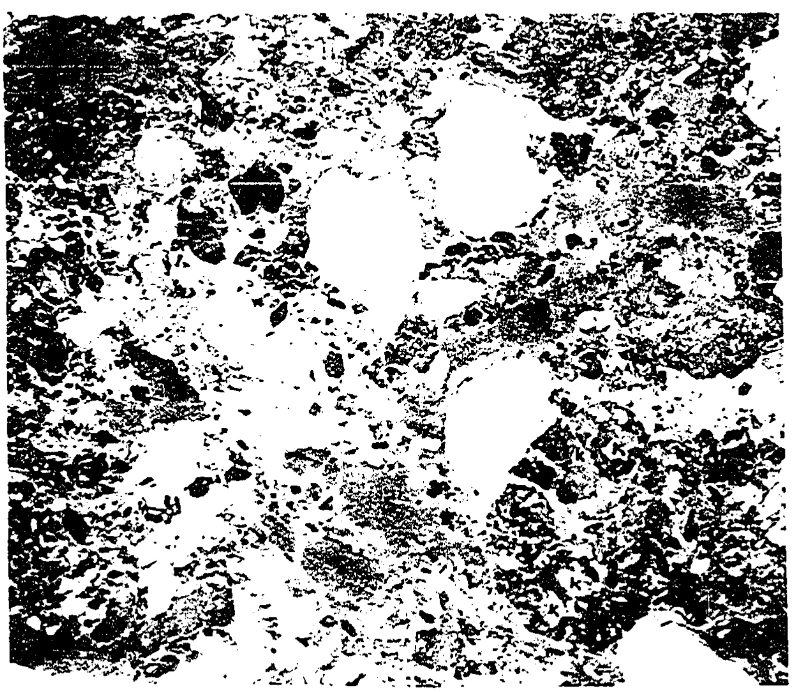

Figure 36 4·2 x

particles are observed to have flowed around the fragmental particles.

Figure 47, Plate XXVIII, illustrates a pyroclastic that has been metamorphosed almost to the state where it is representative of an augen schist.

Mineralogy - The rhyolite tuffs display a mineralogy that is indicative of both igneous and metamorphic assemblages as in the massive rhyolites (page 106). However, since a metamorphic progression is present in the acid volcanic rocks, the mineralogy of the tuffs will be discussed later at which time the whole assemblage will be considered.

Alteration of "Dacites" - The "dacites" have been altered by a process that is not related to the main period of deformation. The nature of the alteration has been the replacement of feldspar phenocrysts by epidote accompanied by epidotization, silicification and pyritization of the matrix.

Figures 23 and 24 (Plate XVI) illustrate the replacement of feldspar phenocrysts. Dark grains of epidote replace lighter feldspars. In some phenocrysts the replacement is complete (Figure 24), in others only partial (Figure 23). Much of the epidote appears in book form, with thick leaflets being separated by thin lenses of quartz which has recrystallized along separated cleavage planes, probably after epidotization.

In some instances it appears that epidote has replaced small oval pumice fragments, and that these might be confused with totally replaced feldspar phenocrysts.

Epidote commonly occurs in the matrix as small rounded granules (Figure 12, Plate X) and together with minute pyrite flecks impart a "dusty" appearance to the matrix.

Pyrite also occurs as anhedral masses within the matrix and as stringers along fractures.

Quartz veining is common, and quartz also appears in the matrix in micro-crystalline mosaics. Quartz phenocrysts commonly show the effects of silicification in that they exhibit secondary rims that show lacework in contact with the matrix (Figure 12, Plate X).

Chlorite is a common matrix constituent of these rocks in association with quartz and calcite.

In view of the evidence supporting epidotization, pyritization and silicification it is concluded that the alteration is characteristic of propylitization and that it was accomplished prior to the main period of deformation.

## Augen Schists

### General Statement

The augen schists in the Bathurst-Newcastle area have been subdivided into several different types in the field. These include rocks mapped as quartz-feldspar augen schists, quartz augen schists and feldspar augen schists, along with other derivatives, most of which have been included by the present writer within the rhyolite and rhyolite tuff series. The above three rock types are closely associated in the field as original types, whereas in other instances the occurrence of quartz and feldspar in any one rock depends on the degree of shearing that the rock has undergone. The writer draws little distinction between the three and refers to the whole assemblage as quartz and feldspar augen schists.

During the early studies of the region (1953-1957) the augen schists that occur in the southeast, around the Brunswick properties, were considered as the "type" rock for the sequence. This conception has been discredited by detailed mapping in other areas, and it now appears that the variations seen in this rock assemblage over the area depend on the conditions of original deposition and the varying amount of dynamic metamorphism that the area has undergone.

Augen schists have developed through the dynamic metamorphism of massive rhyolites and rhyolite tuffs, and many of the features displayed have been carried over from the original rocks.

Megascopic Description

There is a wide range of perfection in the development of the augen schists. This is the main reason why there has been such a discrepancy in the naming of the various volcanic members. Since the augen schists are thought to be genetically associated with sulphide mineralization, there has been a tendency to overuse the term.

Augen schists in the southeast are massive and fine-grained and bear little resemblance megascopically to the average augen schist. This is true in the area around the Brunswick properties where the term "porphyry" was established (Smith, 1957; Smith and Skinner, 1958). In this area both quartz and feldspar phenocrysts do occur and form prominent crystals up to 3/4 inch in size. Figure 37 (Plate XXIII) illustrates the massive nature of the augen schist from this area. In this example large K-feldspar phenocrysts up to one inch in length are pronounced. The surface weathers rubbly. Cross fracturing is evident, but no displacement has been involved.

In contrast to the massive augen schist, schistose varieties occur in the same local area. Figure 38 (Plate XXIII) is a surface exposure of the schistose variety. In this instance the bedding strikes at 35° with light, narrow 3 inch beds being separated by bands of darker

PLATE XXIII : EXPOSURES OF MASSIVE AUGEN SCHIST.

Figure 37. Massive augen schist, Brunswick Number 6 clearing. Pencil in scale is approximately 6 inches long. Large K-feldspar phenocrysts stand out on the weathered surface and impart a rubbly surface to the rock.

Figure 38. Massive augen schist, Brunswick Number 6 clearing. More schistose than Figure 37 with lack of large K-feldspar phenocrysts. Bedding strikes at $35^{\circ}$. Slip cleavage strikes at $355^{\circ}$. Intersection of the two planes imparts a ropey structure to the weathered surface.

# PLATE XXIII

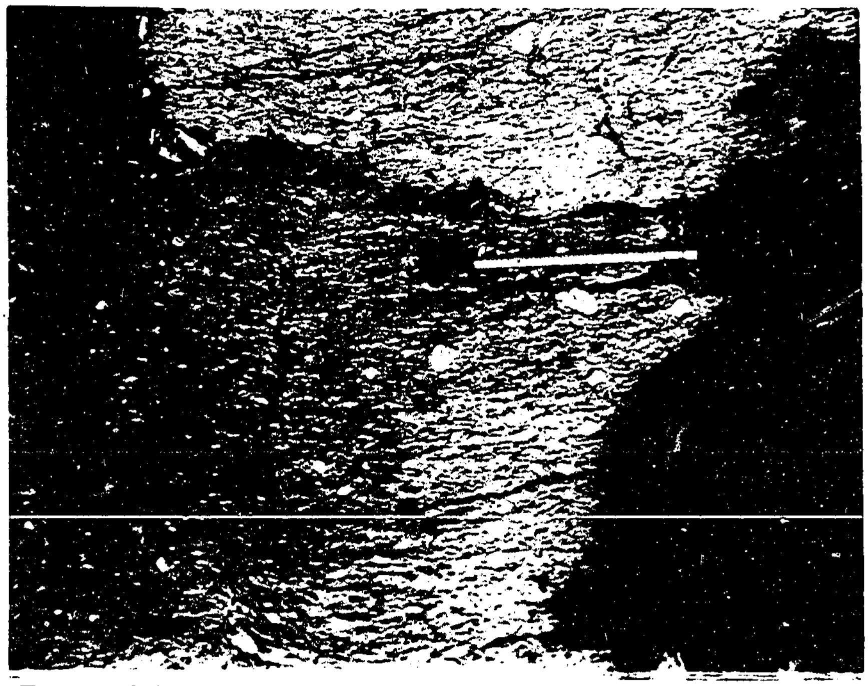

Figure 37

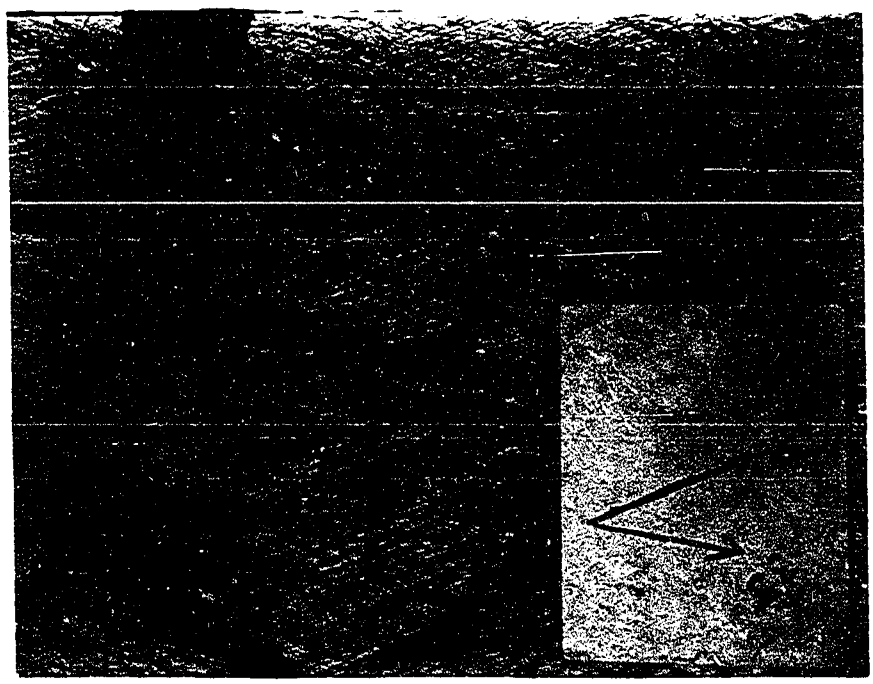

Figure 38

chlorite-rich material up to ½ inch thick. Development of a slip cleavage at 355° offsets the bedding, and the intersection of these two planes gives the rock surface a ropy appearance.

As a summation to the massive augen schists it may be said that their most pronounced feature is the occurrence in them of both quartz and feldspar in good crystalline form. Augen are not well-developed, and most of these rocks more closely approximate tuffs in appearance.

In contrast to the massive rocks are other types where schistosity development has been extreme and where augen structures are well-developed. Rocks of this type are best seen in the northwestern part of the area, particularly in the immediate vicinity of the Anaconda-Caribou sulphide zone and around the nose of the Tetagouche anticline.

Whereas the massive types seem to represent thick flows, the more schistose varieties are seen to be commonly interbedded with other rock types, particularly argillites (Figures 7 and 8, Plate VIII). In this area also, the augen schists are seen to grade along strike into sericite schists over a distance measured in tens of feet. The sericite schists contain few, if any, phenocrysts.

Figures 53 and 54 (Plate XXXI) illustrate the physical appearance of the schistose augen-bearing rocks.

Figure 53, from the vicinity of the Caribou Mine (N - 6), shows the bedded nature of the rock. This particular outcrop represents the most schistose in the area. Quartz augen are practically non-existent, but both K-feldspar and albite are abundant as small (up to 5mm.) grains that have been oriented parallel to the schistosity. The feldspars are authigenic. Milky quartz veins are common. Figure 54 illustrates the best example of bedding seen in the augen schist from the whole district. Beds are represented by alternating dark and light bands of chlorite-rich and sericite-rich material respectively. Close examination of the figure shows the long direction of the feldspar phenocrysts to parallel the bedding planes. Slip cleavage has developed nearly at right angles to bedding and has caused offsetting of the stratification. The feldspar phenocrysts have also been fractured and offset by the slip cleavage. Bedding in the original tuff has apparently been rhythmic. Is is also possible that long periods of leaching between deposition of succeeding beds has accounted for the sericite-rich bands in the tuff sequence.

In summary, it is pointed out that whereas both quartz and feldspar phenocrysts are common to the massive rocks, feldspars are more characteristic of the schistose rocks. This feature has resulted from the effect of shearing on quartz as opposed to feldspar. It is also evident that there must have existed marked differences in the conditions of deposition for the tuffs. As pointed out in Chapter II, the volcanic centres are in closer proximity to the more massive augen schists, so that these rocks may be indicative of ash flow deposits, whereas the finer-grained, more schistose rocks further from the source are indicative of air-deposited tuffs.

## Microscopic Description

The greatest variances in the rocks of the acid volcanic unit are evident in the microscopic features. The development of augen schists from rhyolite tuffs can be traced with considerable success in the texture and mineralogy of the rocks.

Texture - Several textural changes have resulted from the effects of dynamic metamorphism during the development of augen schists. These changes have been listed below and will be discussed in that order.

1. Development of Schistosity.
2. Destruction of Phenocrysts.
3. Rotation of Phenocrysts.
4. Neomineralization.
5. Reconstitution of the Matrix.

1. Development of Schistosity: Schistosity is a feature of all the rocks but is more pronounced in some members. In the massive rhyolites (intrusives and flows) schistosity is vague. In the rhyolite tuffs ("dacites" and pyroclastics) schistosity is more pronounced and is thought to be a pre-metamorphic character of the rock. That is, the tuffs, varying in physical and chemical properties, were more conducive to recrystallization, devitrification and compaction with the result that a bedding foliation was developed before metamorphism.

In the augen schists the development of schistosity is seen to parallel bedding in tuffs or flow banding in flows. Schistosity has been greatly emphasized by shearing.

Schistosity is imparted to the rocks by parallel flakes and layers of mica which have grown parallel to the bedding planes, oriented grains (possible b-lineations), and other lens-shaped masses of rock material.

The range in schistosity development from the massive rhyolites to extremely sheared augen schist can be seen in the following series of figures. The massive rhyolites of Figures 19 and 20 (Plate XIV) show no appreciable schistosity. The rhyolite tuffs of Figures 25 through 28 (Plates XVII and XVIII) show some suggestion of orientation of the matrix materials, but the large phenocrysts have been undisturbed. With the beginning of shear in the tuffs the phenocrysts and matrix start to show the effects (Figure 39 and 40 (Plate XXIV) and Figure 42 (Plate XXV). Figures 55 and 56 (Plate XXXII), Figures 9 and 10 (Plate IX) and Figure 57 (Plate XXXIII) illustrate extreme schistosity and well-developed augen.

Figures 23 and 24 (Plate XVI) illustrate massive "dacite" textures. In contrast Figures 49 and 50 (Plate XXIX) show maximum development of schistosity in this rock type through shear.

Figure 47 (Plate XXVIII) represents a sheared pyroclastic flow in which micas have been formed parallel to the original bedding.

2. Destruction of Phenocrysts: During the production of augen schists the phenocrysts of quartz and feldspar have been destroyed by the effects of dynamic metamorphism, mainly shearing.

The effect of shear pressure has been largely disregarded in consideration of the effects it produces in recrystallization and breakdown of mineral components. Fyfe, Turner and Verhoogen (1958) point out that the general impression is that it would be small in comparison to load pressure at depths greater than 5 km. Experimentation has shown that deformation under high confining pressures is largely by plastic flow.

Under conditions of low confining pressure deformation is probably both plastic and brittle. The range of temperatures associated with the greenschist facies appears in the range of 250-500°C and pressure ranges from 5 kilobars to 10 kilobars (Fyfe, Turner and Verhoogen, 1958). However, Ramberg (1952) states that the greenschist facies may start to form during diagensis as low as 100° C at very shallow depths.

Quartz and feldspar react in different ways to the stresses as an expression of their crystal structure. Quartz phenocrysts crush and rupture along uneven fractures, and the result is an elongated mass of fine quartz particles. Turner (1958) states that quartz will fail by brittle means at extreme confining pressures. Figure 48 (Plate XXVIII) and Figures 51 and 52 (Plate XXX) illustrate quartz phenocrysts that have been crushed and separated by shear. The shearing component has not had the effect of compressing the crystal but has smeared it along the shear planes. In other cases the rock has largely retained its massiveness, and the quartz phenocrysts have been crushed and compressed between schistosity planes (Figure 57, Plate XXXIII, and Figures 9 and 10, Plate IX). Crushing effects on quartz phenocrysts can be seen in almost any of the samples studied.

PLATE XXIV : PHOTOMICROGRAPHS OF RHYOLITE TUFFS OR MASSIVE AUGEN SCHIST.

Figure 39. Stained thin section. Crossed nicols.Sample P - 7 - 4. Massive rhyolite tuff, represents the first stage of development for augen schists. Large quartz phenocrysts(Q) show crushing action and tendency to be elongated in plane of developing schistosity. Shear planes are prominent. K-feldspar phenocrysts(K) have been little affected. Matrix consists of a microcrystalline mosaic of quartz and orthoclase with sericite.

Figure 40. Stained thin section. Crossed nicols. Sample O - 6 - 19. Rhyolite tuff,as Figure 39. Embayed quartz phenocrysts are being crushed. Heavily stained K-feldspar phenocrysts have fractured along cleavage planes. Sericite(S) and biotite(B) are forming patches parallel to the developing schistosity direction (direction of shear). Matrix is highly recrystallized.

# PLATE XXIV

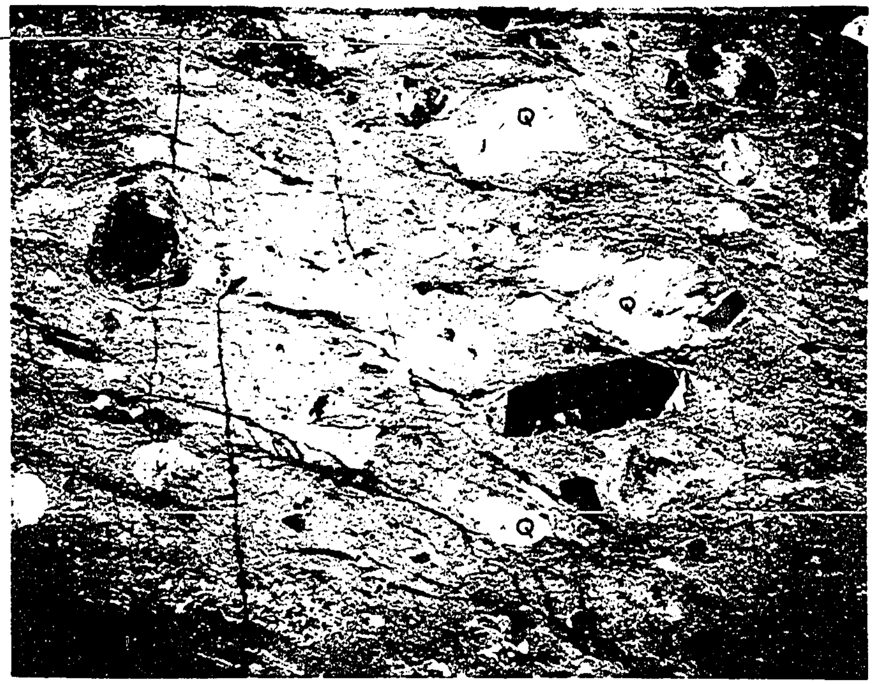


Figure 39 4·2 x

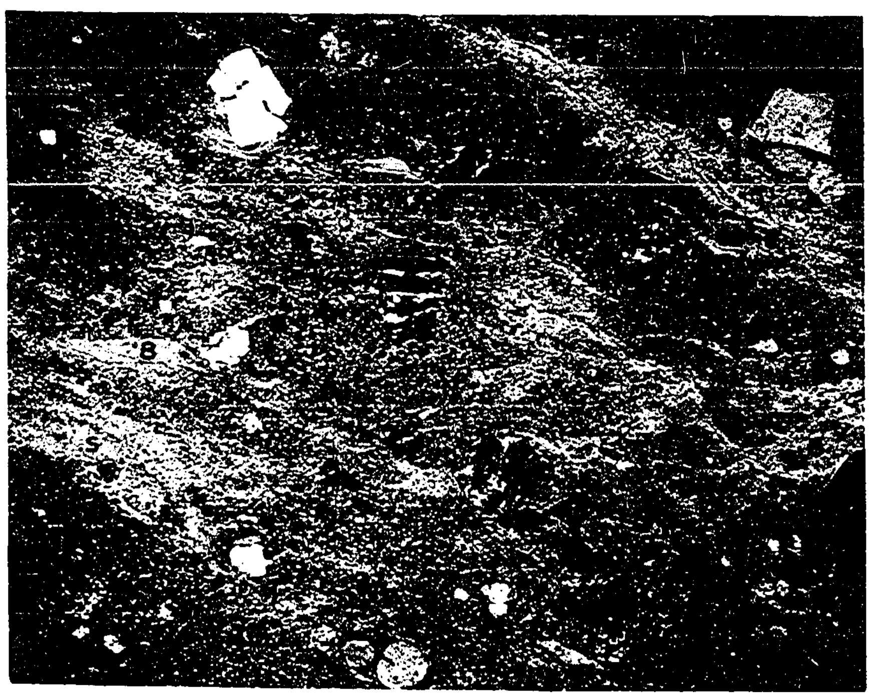


Figure 40 4·2 x

PLATE XXV : PHOTOMICROGRAPHS OF RHYOLITE TUFFS.

Figure 41. Crossed nicols. Sample P - 9 - 12. Rhyolite tuff, or massive augen schist. Quartz(Q) and K-feldspar(K) phenocrysts have been broken in situ. Rock displays a vague flow banding. Dark elongated patches (R) may represent rock fragments or areas of devitrified pumice.

Figure 42. Crossed nicols. Sample Q - 7 - 2. Massive augen schist or rhy lite tuff. Rock shows the development of schistosity with mica-rich bands(dark) alternating with quartz-rich bands(light).Large embayed quartz phenocrysts have been relatively unaffected by the shear. Biotite patches (B) are very pronounced developing around the phenocrysts.

# PLATE XXV

Figure 41 4·2x

Figure 42 4·2x

Feldspar phenocrysts react differently to shearing stresses than do quartz phenocrysts. The feldspars tend to fracture along cleavage planes which are in the closest proximity to the shear planes. As rupture occurs the grains slip along the planes and are elongated in the plane of shear, parallel to the schistosity. In Figure 40 (Plate XXIV) several feldspar phenocrysts show the effect of being separated along cleavage planes nearly parallel to the developing schistosity (shear planes). Figure 44 (Plate XXVI) illustrates the same feature on a more pronounced scale where fracturing has occurred along two sets of cleavage.

Figures 55 and 56 (Plate XXXII) illustrate well-developed augen schists. Large feldspar crystals in the bottom left of Figure 55 show slip along cleavage planes, and these grains have been elongated parallel to the schistosity, The same features are exhibited by the feldspar phenocrysts of Figure 56. It can be seen that if the shearing were continued the initial feldspar phenocrysts can become obliterated in the rocks. Figures 9 and 10 (Plate IX) are indicative of very elongated feldspar augen which have developed through shearing of phenocrysts.

It is realized also that shearing has had chemical as well as physical effects on the feldspar phenocrysts. This will be considered in a subsequent section on mineralogy of the acid volcanics.

3. <u>Rotation of Phenocrysts</u>: As a corollary to the above discussion of crushing and elongation of phenocrysts, the effect of shear has also tended to rotate the phenocrysts. Rotation is not apparent within the crystals themselves but is shown by the nature of the "soft" matrix surrounding the hard grains. As the phenocrysts are rotated low pressure zones result in the "shadow" areas of the phenocrysts. Secondary quartz is deposited in the shadows. In areas where rotation has been extreme quartz forms long tails, much like the tail of a comet. In areas where rotation has not been extreme and where little recrystallization has occurred the matrix simply appears disrupted around the grain.

Examples of rotation are included within the following list of figures. Figures 26 (Plate XVII) illustrates large feldspar phenocrysts that have been slightly rotated with disruption of the matrix. Figure 30 (Plate XIX) shows a large quartz phenocryst that has suffered considerable rotation, in which secondary quartz has been deposited in the shadow areas with secondary biotite forming projections away from the crystal. Figures 55 through 57 (Plates XXXII and XXXIII) represent cases of extreme rotation in which the operation was accompanied by fracturing and displacement within the grains.

4. Neomineralization: This process is closely associated with the deformation of the rock mass and with the development of schistosity, destruction of phenocrysts and rotation of grains. The higher the amount of deformation the greater is the amount of neomineralization which the rock displays.

During the development of schistosity sericite is the most common mineral which forms. The development of sericite results from the chemical breakdown of the matrix and feldspar phenocrysts in response to deformation. The sericite crystals form parallel to the plane of least resistance, which is the plane of schistosity.

Silica released by recrystallization of the matrix and from the destruction of phenocrysts during shearing has migrated into the low pressure areas and has recrystallized as fine sutured grains. Low pressure areas exist along fractures and at the ends of developing augen.

Other examples of neomineralization will be further discussed in a later section on the mineralogy of the various rocks. These include the production of albite and biotite as porphyroblasts in the rocks which also show high degrees of deformation.

5. Recrystallization of the matrix: The matrix of the

massive rhyolites and tuffs appears to have been little affected by metamorphism. Many primary features are still evident. However, in the augen schists the primary features have all been destroyed by recrystallization and the neomineralization of new minerals in response to dynamic stress. This is accompanied by an increase in grain size.

In the massive augen schists, as those seen in the southeastern area, the matrix is composed predominantly of anhedral quartz and orthoclase grains which average 0.01 to 0.05 mm. in dimension. Serate grain boundaries are distinctive. With increase in schistosity the sericite content of the matrix increases, and the mica is seen to occur as thin plates and bands which fold around the large phenocrysts (Figure 43, Plate XXVI).

In the augen schists where the megascopic schistosity is pronounced, the matrix is seen to consist of segregated bands of quartz-rich and sericite-rich material (Figures 55 and 56, Plate XXXII). In these instances the sericite occurs in the planes of shear, and the quartz occupies the interspace areas. Grain size increases to near 0.1 mm. diameter. The expressed difference from the more massive types is in the spacing of schistosity planes.

Mineralogy - The mineralogy of the augen schists is simple and similar to that of the rhyolites. The differences that exist are due to the effects of metamorphism on the primary rhyolite mineralogy and to the addition of new minerals through metamorphism.

## Quartz-Mica Schists

### General Statement

Quartz-mica schists of the acid volcanic series appear very similar to the more schistose variety of augen schist (as pointed out in Chapter I, the two rocks are interbedded in the area around the Tetagouche anticline). It is postulated that the quartz-mica schists have been derived by the dynamic metamorphism of augen schist rocks. In other words, these rocks form the last step in the destruction of rhyolites and rhyolitic tuffs through the agencies of dynamic metamorphism.

### Megascopic Descriptions

In outcrop the rocks are extremely schistose and alternating sericite-rich and quartz-rich bands are evident. These rocks resemble the augen schist matrix without the presence of phenocrysts. Quartz veining is very common as concordant and discordant masses in the rock. The quartz in the segregated veins is thought to have been released from the rocks during metamorphism and has been caused to migrate to its present site along a pressure gradient. This is an example of metamorphic differentiation.

Microscopic Descriptions

Texture: In thin section quartz-mica schists are microcrystalline with recrystallization being pronounced. Finely interbanded quartz-rich and sericite-rich bands are very prominent, with individual bands generally less than 0.5 mm. thick.

Texturally there is a transition between the quartz-feldspar augen schists and the quartz-mica schists. With increase in shearing there is further failure by plastic flow, recrystallization and brittle deformation. Increased slippage along the shear planes has accentuated the elongation of the phenocrysts (Figures 61 and 62, Plate XXXV).

Feldspar phenocrysts are further destroyed in response to the shearing stresses. They respond by greater alteration to sericite and quartz as the grains are smeared out along the shear planes (See Figures 9 and 10, Plate IX and Figures 61 and 62, Plate XXXV).

Mineralogy - The final product of the dynamic metamorphism is a rock that is composed almost entirely of quartz and sericite. Chlorite and biotite are common constituents. In many of the quartz-mica schists the feldspars have not been completely obliterated so that fragments still persist, although they are highly reconstituted. The feldspar is highly sericitized and in some cases shows abundant calcite along fractures.

## Mineralogy of the Acid Volcanics

Within this section it is the writer's intention to discuss the common mineralogy of the acid volcanic sequence and to follow the changes which occur as a result of dynamic metamorphism. That is, to show the changes which take place in the breakdown of the rhyolite assemblage to form augen schist and finally quartz-mica schist.

Quartz and K-feldspar are the main constituents of all the rocks. Sericite becomes more common with development of schistosity, and at the same time the feldspar is being destroyed so that the quartz-mica schists are composed almost entirely of quartz and sericite.

The mineralogy of the acid volcanic suite can be treated in three parts: phenocrysts, matrix, and accessories.

### Phenocrysts

K-feldspar forms the most prominent phenocrysts of the rhyolites and augen schists. In the massive intrusive rocks the crystals are perthitic and seldom exceed 2 mm. in long dimension. The perthitic feldspars in the massive rocks are crypoperthitic in nature and are evident from the staining techniques used. Perthitic structure is not common in thin section, but where seen it occurs in patch form. The feldspar phenocrysts of the massive rhyolites have not been deformed to any extent but have been affected by metamorphism as shown by clear rims of albite around many of the grains (Figure 15, Plate XII).

In the rhyolite tuffs and massive augen schists the K-feldspar phenocrysts are similar to those of the massive rhyolites but have been adversely affected by higher metamorphism and shearing. It is in the augen schists where the greatest variance is seen in the phenocrysts, and this is to be expected for two reasons. First, these rocks have been affected by metamorphism of a shearing nature, and, secondly, because the writer concentrated his studies mainly on this group of rocks.

Whereas the K-feldspar phenocrysts were relatively small in the massive rhyolites they attain a size in excess of 15 mm. in the tuffs and augen schists. Perthitic structures range from cryptoperthitic through microperthitic to patch perthites. The latter are the more abundant. The feldspar crystals of the massive augen schists and rhyolite tuffs (Figures 25 and 26, Plate XVII and Figures 43 and 44, Plate XXVI) range from euhedral shapes to highly fragmental types which

PLATE XXVI : PHOTOMICROGRAPHS OF AUGEN SCHISTS.

Figure 43. Stained thin section. Crossed nicols.Sample Q - 7 - 1. Quartz-feldspar augen schist east of Bathurst Mines. Large K-feldspar phenocrysts have been fractured and affected by alteration. Quartz(Q) and albite(A) inclusions are common within the large patch perthitic grains. Small embayed quartz(Q) and albite (A) phenocrysts are common. The matrix is highly sericitic and schistosity is well developed. Schistosity planes flow around the large phenocrysts. Matrix is recrystallized.

Figure 44. Stained thin section. Crossed nicols. Sample Q - 7 - 3.Same location as above. Massive augen schist. Large rounded patch perthitic feldspar(black) is partly replaced by quartz and sericite in fractures along cleavage planes. Quartz phenocrysts range from large embayed and subhedral grains to small and highly fractured grains. Large biotite patches(B) are developed parallel to the schistosity.

# PLATE XXVI

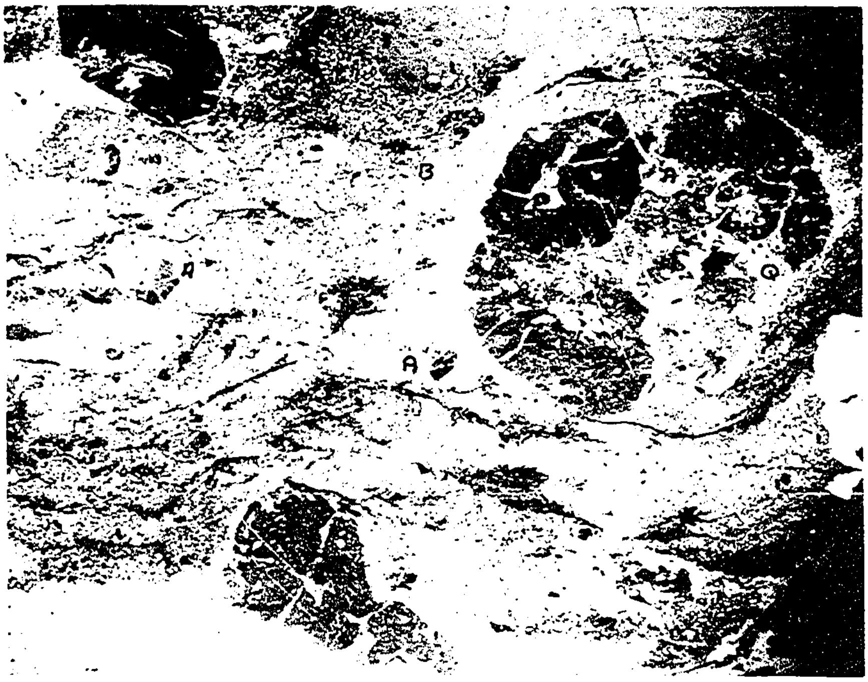


Figure 43 4·2 x

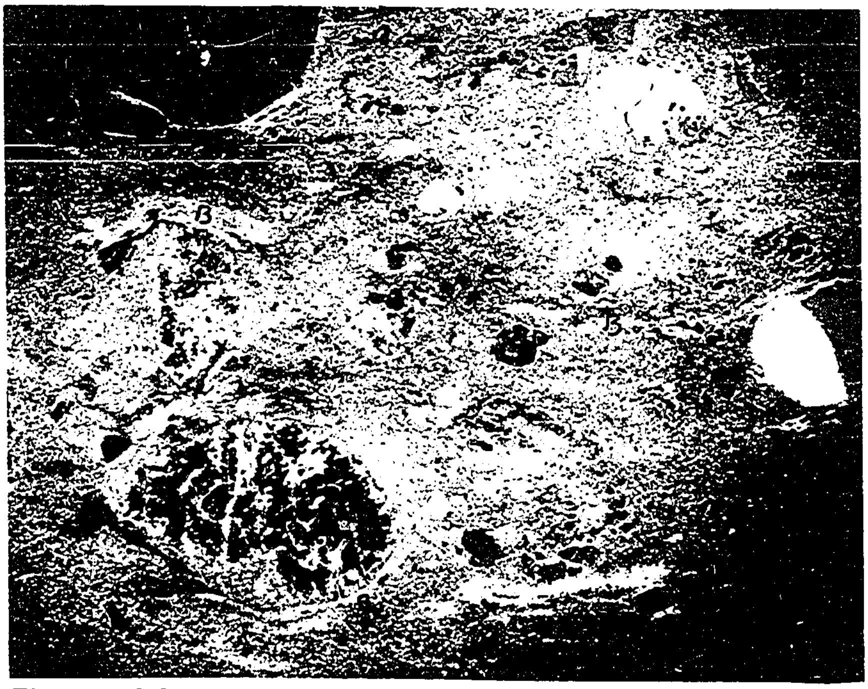


Figure 44 .4·2 x

represent original fragments. The euhedral feldspar phenocrysts in both the tuffs and augen schists have been fractured by deformation and show varied degrees of alteration. With increased schistosity the degree of fracturing increases. The nature of the fractured phenocrysts indicates cataclasis during deformation.

Patch perthites are characterized by the presence of small, clear, twinned and untwinned patches of albite. This feature was made evident by staining of the crystals for potassium. (In most of the accompanying photomicrographs the rocks have been quite heavily stained so that the potassium feldspars appear black; quartz appears white, and sodium feldspar which was etched but not stained appears as light grey patches within the host grain.

Patch perthitic textures are thought to have originated from the separation of high temperature components on cooling and metamorphism (Emmons, et al., 1950). Loudon (1960) has recognized patch perthitic textures in feldspars from the Elbow area (N - 7. He states:

> All perthites do not show the marked, patch-type structure described - - - -. Phenocrysts occasionally show a mottled appearance under crossed nicols. In these, the contact between albite patches and potash feldspar host is not sharp since difference in refractive index are not always observed. Differences in the extinction, and the near absence of dusty inclusions in the albite component, may be all that indicates a difference in composition.

> This mottled variety of perthite does, in part, result from the angle at which the section is cut relative to the contact of the albite and potash feldspar, but it may result also from the incomplete separation of the albite molecule from the host, so that there is a gradational change in composition.
>
> If this is the case, then there would appear to be a gradation between phenocrysts of micro-perthite, showing complete separation of the potash feldspar and albite components, and instances where their relationships are vague and poorly defined. More commonly, complete segregation has taken place, indicating that the perthitic intergrowth, as it is displayed in the phenocrysts of the Elbow 'porphyries,' has attained a stable condition.

This statement adequately describes the patch perthitic structures observed by the writer from the augen schists over the whole of the Bathurst-Newcastle area.

Other included material, common to the perthitic feldspars, is quartz, calcite, and finely crystalline mixtures of quartz, feldspar and sericite. Quartz most commonly occurs as replacement masses along fractures between separated cleavage planes (Figures 43 through 46, Plates XXVI and XXVII). The secondary quartz is inclusion free and unstrained. The second type of inclusion consists of a fine-grained mosaic of quartz, orthoclase and sericite which is seen to fill original embayments within the crystal, and is thought to represent devitrified glass. This type of inclusion is characteristic of the euhedral and subhedral phenocrysts seen in the massive augen schists (Figure 45,

Plate XXVII). In many of the K-feldspar phenocrysts, similar fine-grained aggregates are seen to fill ovoid areas up to 0.5 mm. in cross-section. These are simply embayments that enter into the crystal from a plane that is above or below the plane of the thin section. Calcite is common, associated with quartz, as replacement masses along fractures. (Figure 46, Plate XXVII).

The presence of devitrified glass in embayments of the feldspar crystals indicated that the grains, and hence the rocks, are of igneous origin. Combined with other textural features they represent clear evidence of a volcanic origin for the rocks.

Perthitic feldspars of the massive rhyolites and the feldspars of the more deformed rocks commonly show thin clear rims of sodium-feldspar. This feature is interpreted as r epresenting the deposition of the albite molecule, which, being geochemically more active than potassium, has moved out of the perthitic feldspars, or out of the matrix, in response to rising temperatures during metamorphism (Orville, 1962).

Not only does shearing cause physical destruction (crushing, rotation and slipping along cleavage planes), but it also promotes destruction of the phenocrysts by alteration to quartz and sericite. This is the main feature of the perthitic feldspars in areas of schistose

PLATE XXVII : PHOTOMICROGRAPHS OF PATCH PERTHITIC FELDSPARS.

Figure 45. Stained K-feldspar phenocryst. Sample Q - 7 - 3, as Figure 44. Clear, unstrained quartz(Q) replacing dark K-feldspar along fractures which parallel the cleavage planes. Microcrystalline mosaics of quartz and sericite (QS) fill original embayment structures. Bands of biotite(B) surround the feldspar.

Figure 46. Stained patch perthitic feldspar phenocryst. Crossed nicols. Sample O - 8 - 2. Quartz(Q) and calcite (C) replacement masses appear confined to cleavage planes. Albite(A) has separated out of the K-feldspar to form patches within the structure. Matrix is composed of finely recrystallized quartz,feldspar and sericite.Rounded structure in the centre of the crystal is a bubble in the mounting medium.

# PLATE XXVII

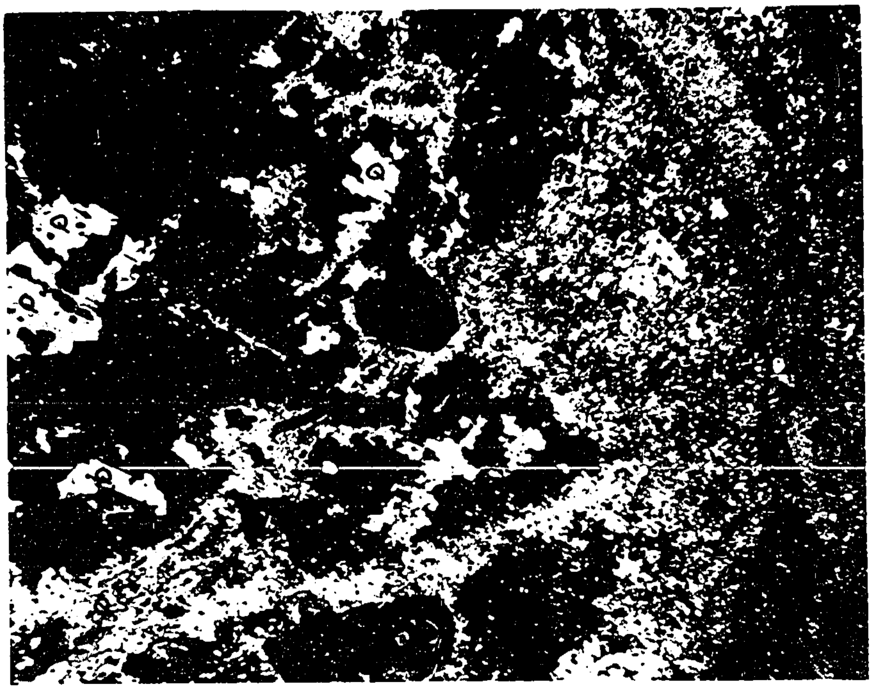

Figure 45 4·2 x

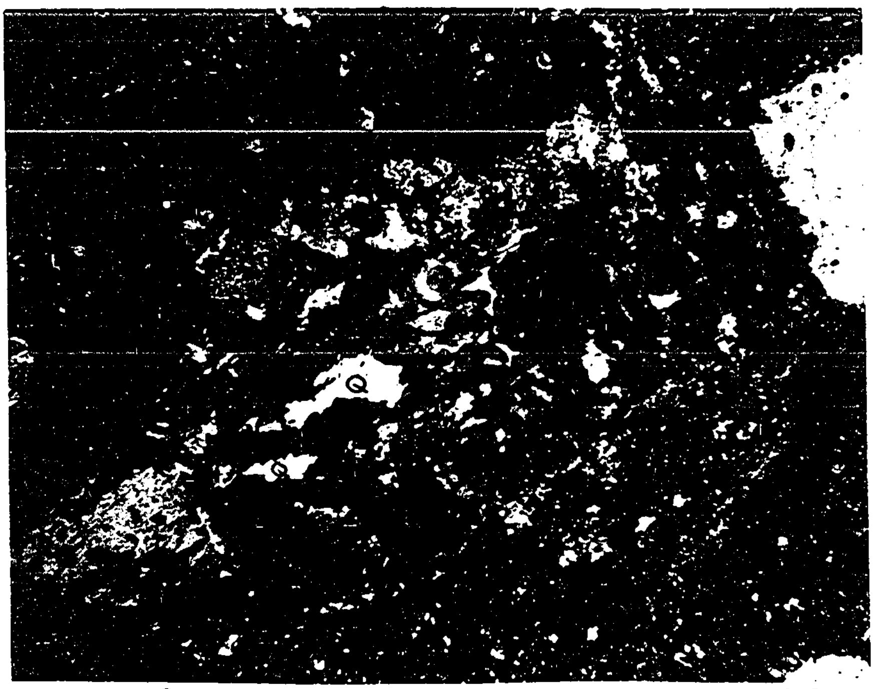

Figure 46 4·2 x

rocks. However, the original patch nature of the grains is usually retained.

Whereas the above discussion has been concerned with the changes in K-feldspars going from rhyolites and tuffs to augen schists, other changes are characteristic of the minerals within the "dacites." K-feldspar in various stages of fracture and alteration is present. It commonly occurs as small untwinned grains up to 3 mm. in diameter and ranges in shape from fragmental grains to subhedral crystals with evidence of rotation being common. Some grains show Carlsbad twins, and other grains show a vague microcline twinning which may be more indicative of a patch pethitic structure. In the augen schists derived from "dacites" the K-feldspar phenocrysts show a high degree of alteration and in many cases are completely altered and replaced by sericite and quartz. For example, Figure 49 (Plate XXIX) illustrates a large K-feldspar pseudomorph that has been completely replaced by quartz, sericite and epidote. Prior to the last alteration the grain was separated along cleavage planes with quartz recrystallizing in the fractures. Whereas in the above case the feldspar has been destroyed largely by alteration, other cases exist in the augen schists derived from "dacites" (Figure 50, Plate XXIX) where the phenocrysts have been destroyed by deformation and slippage along shear planes. Sericite is again a common product both in the matrix and within the feldspar grains.

It was difficult to trace the trend of feldspar destruction in the pyroclastics, since no good examples, other than Figure 47 (Plate XXVIII), were studied of augen schists derived from this rock type. In the massive pyroclastics K-feldspar grains are commonly angular and fractured, with quartz and calcite forming replacement masses along the fractures. The grains do not appear as altered as those of the volcanics and characteristically show Carlsbad twinning. Microcline is also evident, free of inclusions and showing characteristic twins. Patch perthitic types are common.

Quartz forms the second most pronounced phenocrystic constituent. They are more abundant than K-feldspar but much less conspicuous.

Within the massive intrusive rhyolites quartz occurs as euhedral crystals to angular fragments, generally less than 4 mm. in diameter. Most of the subhedral grains show deep embayment and corrosion features typical of many rhyolites (Figures 15 and 19, Plates XII and XIV). In smaller grains the embayments are not as common, and the crystals tend to show a higher degree of fragmentation. Quartz phenocrysts are strained. They commonly show a

PLATE XXVIII : PHOTOMICROGRAPHS OF AUGEN SCHISTS.

Figure 47. Stained thin section. Crossed nicols. Sample Q - 7 - 8. Augen schist derived from a pyroclastic rhyolite tuff. The original bedding is exemplified by the schistosity. Angular and embayed quartz grains make up the dominant clastic fraction. The matrix has been recrystallized and calcite(C) occurs as a common replacement mineral. No rock fragments are evident. Quartz-rich and biotite-rich stringers impart the schistosity to the rock.

Figure 48. Stained thin section. Crossed nicols. Sample O - 8 - 1, from along power-line south of the Nepisiquit River. This rock is characteristic of augen schists derived from "dacite". Small rounded quartz phenocrysts (white and black) are abundant. Feldspars have apparently been destroyed by alteration. Quartz phenocrysts have been extremely crushed. Schistosity is well developed. Matrix is dusty and consists of microcrystalline masses of quartz and sericite with common epidote and pyrite.

# PLATE XXVIII

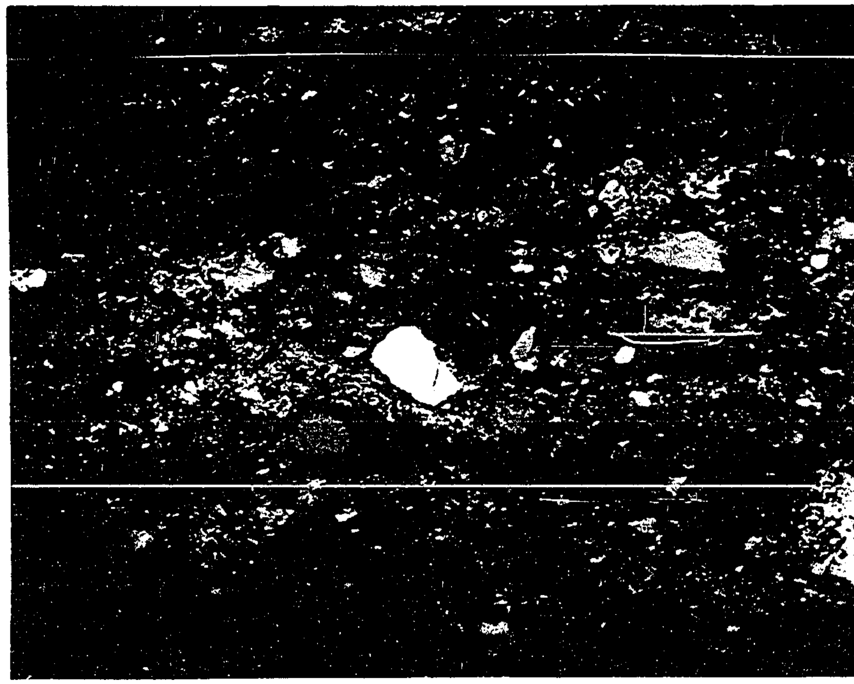

Figure 47 4·2x

Figure 48 4·2x

PLATE XXIX : PHOTOMICROGRAPHS OF AUGEN SCHISTS DERIVED FROM DACITES.

Figure 49. Stained thin section. Crossed nicols. Sample O - 8 - 7.Tuffaceous dacite augen schist. Large feldspar phenocryst im the center of the slide has been completely destroyed and replaced by sericite(dark) and quartz and sericite(light). Oval patches of epidote(black) replacing feldspars are common. The matrix consists of a microcrystalline growth of quartz and sericite, with possible devitrified glass. Quartz is also common forming narrow concordant veinlets.

Figure 50. Stained thin section. Crossed nicols. Sample P - 8 - 6. Augen schist derived from extreme cataclasis of a dacite tuff. Remnant feldspar phenocrysts exist as small fragments(black) along the schistosity planes. They have been partially replaced by epidote. Secondary quartz is abundant as small white augen structures that have resulted from the breakdown of feldspar and quartz phenocrysts by shear. Mica rich layers have absorbed a deep stain.

# PLATE XXIX

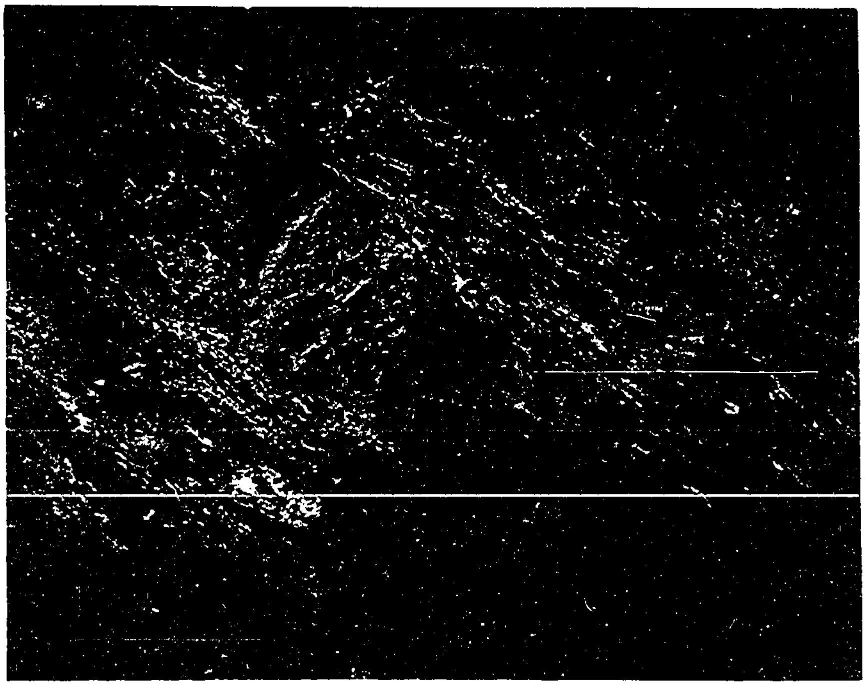

Figure 49 4·2x

Figure 50 4·2x

secondary rim of clear microcrystalline quartz, which causes the contact between phenocryst and matrix to be gradational. In other cases the crystals are partially rimmed by secondary quartz in optical continuity with the main grain.

Quartz phenocrysts within the massive rhyolite tuffs (other than "dacites) are typical of those in the massive augen schist. In these rocks quartz phenocrysts retain the deep embayments common to the rhyolites (Figures 27 and 28, Plate XVIII; Figures 39 and 40, Plate XXIV). On a larger scale deep embayed quartz phenocrysts are illustrated by Figures 29 and 30 of Plate XIX. Of special significance is the comparison of the quartz embayments as seen in the augen schists with the same feature as displayed in more recent unmetamorphosed welded tuffs (Figure 31, Plate XX). Corroded and embayed quartz grains are common in lava flows and ash flows. It seems unlikely that these quartz grains could have formed in any way other than by growth in a magma. The embayments are seen to be filled with microcrystalline masses of quartz, feldspar and sericite.

A high percentage of the quartz from the augen schists consists of fragmental grains. In instances where phenocrysts have fractured in situ the components form a cluster of particles. This feature is indicative of advanced deformation and the brittle response of quartz to shear (Figures 51 and 52, Plate XXX).

With increase in schistosity much of the quartz occurs in splinter form, very similar to that seen in the pyroclastic flows or metasedimentary rocks. In such cases it becomes difficult to decide whether the rock is a sediment or whether the clastic appearance is the result of cataclasis. The presence of matching fragments affords support for the latter origin.

All of the quartz phenocrysts show increasing degrees of straining with increase in deformation and schistosity. In the sheared rocks Boehme lamellae are common and are easily confused with strain features. In other cases the same feature has been confused with twinned albite grains. Boehme lamellae result from directed stress along the 001 direction of the crystal lattice (AGI Glossary).

In augen schists that show extreme schistosity the quartz loses most of its primary features. As discussed in an earlier section, quartz grains react in a brittle manner when subjected to directed stresses under confining pressures. In rocks such as those in the Tetagouche anticline where deformation is extreme, quartz phenocrysts are fractured, crushed, and recrystallized to a coarse grained mosaic of serrated particles that have assumed a noted augen shape (Figure 9, Plate IX and Figures 57

PLATE XXX : PHOTOMICROGRAPHS OF AUGEN SCHISTS.

Figure 51. Stained thin section. Crossed nicols. Sample P - 8 - 4. Highly schistose augen schist. Matrix highly sericitized, Quartz(white and grey) and K-feldspar(K) phenocrysts are highly fractured and crushed. Limonite staining is evident along the fractures. The matrix exhibits the same cataclastic nature as the phenocrysts.

Figure 52. Stained thin section. Crossed nicols. Sample O - 8 - 6. Highly schistose augen schist, as Figure 51. Large K-feldspar phenocrysts(K) appear black. Patch perthitic structure is evident. Quartz phenocrysts have been crushed and separated. The matrix is highly recrystallized.

# PLATE XXX

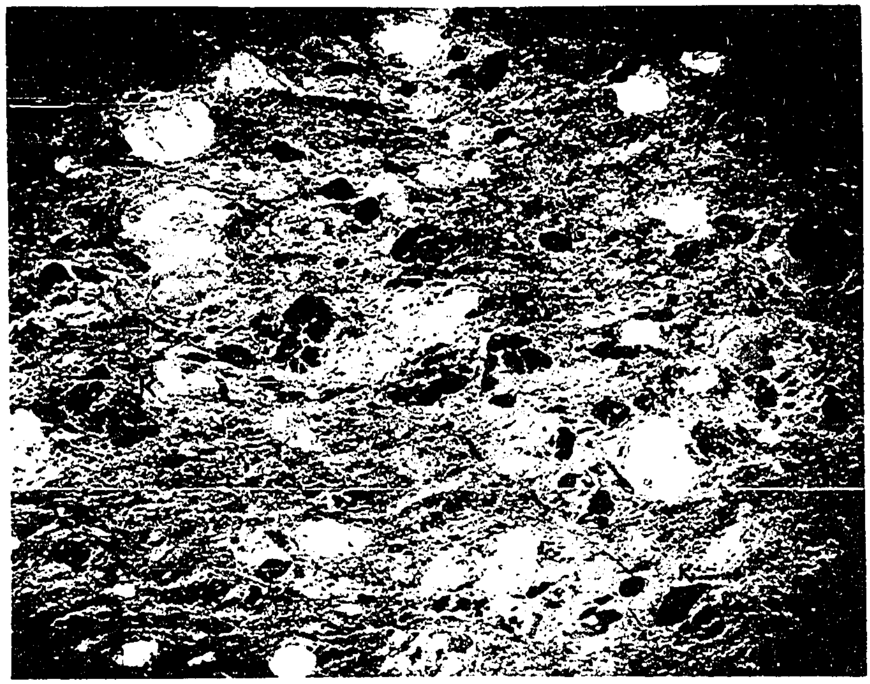

Figure 51 4·2 x

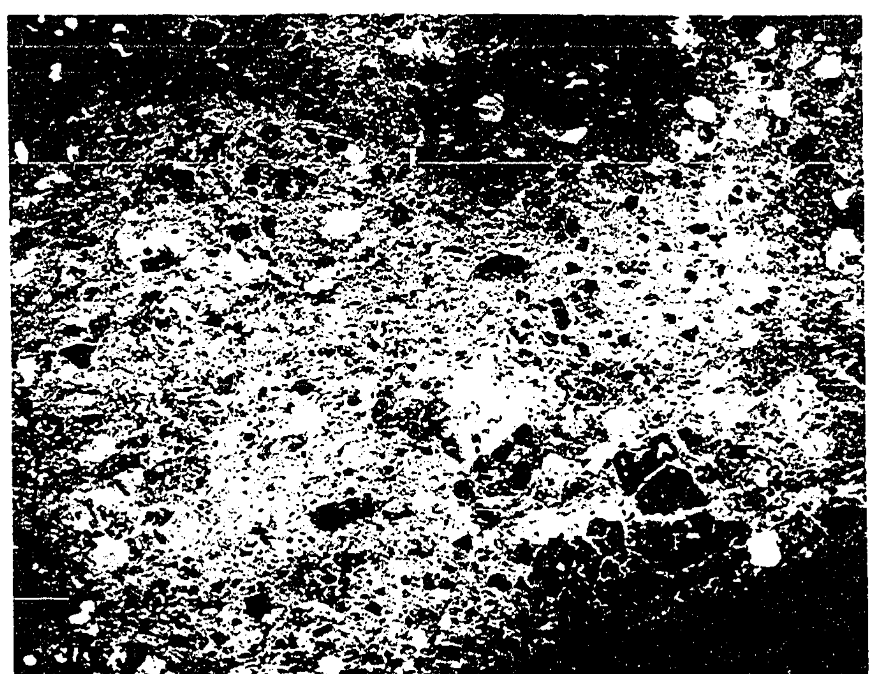

Figure 52 4·2 x

and 58, Plate XXXIII). Secondary growth phenomena are evident in the shadow areas at the ends of the phenocrysts. Many of the quartz augen exhibit lengthening attributed to shearing.

Although quartz is usually the only mineral in the augen, it is in some instances associated with secondary albite (Figure 59, Plate XXXV). In these structures the quartz grains are smaller than those of albite.

Many of the quartz augen in the extreme schistose rocks still maintain relatively unaltered quartz phenocrysts as a core structure. These grains are fragmental and many still show embayments (Figures 57 and 58, Plate XXXIII).

Figure 10, Plate IX represents a special case in which quartz has formed secondary lenticular structures in low pressure areas in the crests of the micro-folds.

The "dacites" are noted for their susceptibility to alteration. In the massive rocks no free quartz is evident, however, in the extremely sheared rocks free quartz is abundant as small, rounded phenocrysts up to 2 mm. in diameter. The majority of the grains are strained. Embayed grains have been observed, which rules out the possibility of porphyroblastic growth for at least some of the material. Quartz grains commonly show secondary growth rims and often display serrated edges forming interfingering contacts with the matrix (Figure 12, Plate X). Figure 48, Plate XXVIII also illustrates the quartz phenocrysts in a schistose dacite.

Quartz commonly forms the most prominent clastic material of the pyroclastic flows. It ranges from angular and splintery fragments to rounded grains that attain lengths up to 6 mm. and are aligned parallel to the schistosity (Figure 36, Plate XXII and Figure 47, Plate XXVIII). In the latter example rounded and embayed quartz grains are evident.

Whereas much of the clastic quartz in the augen schists was formed in situ, it is apparent that the clastic quartz of the pyroclastics was introduced in its present form.

Orthoclase feldspar phenocrysts were observed in the rhyolite tuffs and augen schists but form minor constituents. Staining techniques, which were utilized in bringing out the textures of the rock, proved helpful in distinguishing orthoclase from perthites. The perthite grains absorbed the potassium stain, and on further application of the plagioclase stain were seen to absorb it as a masking effect on the former, indicating the presence of both the potassium and calcium molecule. In unstained slides cryptoperthitic phenocrysts are easily mistaken for orthoclase.

In the schistose, augen bearing rocks, the orthoclase maintains its clear appearance and is characterized by the lack of quartz and albite inclusions. Small ovoid areas of devitrified glass are common, and the grains show Carlsbad twinning. Orthoclase grains appear quite common in the pyroclastic rocks.

Sodium plagioclase occurs in minor amounts in the intrusive rhyolites and flows where it was seen within the patch perthites and as clear thin rims around many of the large K-feldspar phenocrysts. It also appears commonly as small crystals, with quartz, in narrow veins which cut the rocks (Figure 12, Plate X).

Within the pyroclastic rocks (Figure 32, Plate XX and Figure 36, Plate XXII) albite occurs as small angular fragments and as larger grains up to 5 mm. in length that have been heavily fractured and altered.

Sodium plagioclase forms common phenocrysts within the rhyolite tuffs and massive augen schists. In all cases they are smaller than their potassium counterparts, reach a maximum length of 5 mm. (Figure 28, Plate XVIII) and do not show the degree of euhedral outline exhibited by the K-feldspars. Albite and Carlsbad twin lamellae are present without exception. Several phenocrysts in the above example exhibit bent twin lamellae. This feature represents pre-tectonic formation of the feldspars (Turner, p. 240, 1948). In the massive rocks the feldspars contain an abundance of sericite along fractures.

Two criteria were utilized in determining the composition of the plagioclase feldspar. First, although many slides were stained to bring out the rock and mineral texture, it was found to be impossible in most instances to stain the albite components. This indicated that the plagioclase feldspar contains less than 5% of the calcium molecule (Bailey and Stevens, 1960). Second, Rittman zone measurements (Emmons, 1943) on 2 samples of plagioclase from massive augen schists or tuffs (Q - 7 - 1 and Q - 7 - 3) showed the plagioclase crystals to have the composition of $An_6Ab_{94}$. Measurements from the tuff of Figure 28, Plate XVIII (Sample 0 - 8 - 2) showed the average plagioclase composition to be $An_3Ab_{97}$.

Albite occurs in several ways in the schistose rocks:

1. As subhedral to rounded phenocrysts up to 5 mm. long. The grains have been corroded and show secondary quartz around their margins (Figure 60, Plate XXXIV). Albite twinning is common, and the grains appear unaltered to any degree. Some internal rearrangement is displayed by the bladed chequer-board type twinning.
2. A more distinctive variety of albite occurs as small porphyroblasts associated with sutured quartz in small

augen. This albite exists as small euhedral crystals (0.5 mm. in length) which show Carlsbad twinning and which are randomly oriented within the augen (Figure 59, Plate XXXIV). Quartz and albite aggregates represent the destruction and replacement of original alkali feldspar grains through shearing stresses. The average composition of the above albite was determined as $An_4Ab_{96}$.

3. Albite also occurs within the sheared rocks as inclusions within the large K-feldspar grains and as secondary rims. These features were discussed earlier when considering the massive non-sheared rocks.

Matrix

Basically the mineralogy is very similar to that of the phenocrysts, but has been variously affected by recrystallization and the productions of new minerals as a response to shearing and other metamorphic processes.

The matrix of the massive intrusive rhyolites and flows is composed of a microcrystalline mass of quartz and K-feldspar. Grains are typically anhedral, sutured and have been recrystallized. Sericite is a common component and occurs as randomly oriented plates within the quartz-feldspar mosaic. Small (0.5 mm.) oval patches of microcrystalline quartz are rather common and are thought to represent devitrified glass lapilli.

The matrix constituents of the rhyolite tuffs and the massive augen schists are quartz, K-feldspar, Na-feldspar, sericite, biotite and chlorite. Each of these minerals is also present in variable amounts in the more sheared rocks.

Quartz is the major constituent of the matrix in all of the augen schists. It is associated with K-feldspar and sericite as small anhedral clear grains with serrated edges. Both the degree of recrystallization and the grain size increases with the increase in schistosity. Whereas the matrix quartz of the massive rhyolites averages between 0.01 and 0.05 mm. the quartz of the more schistose augen schists averages around 0.1 mm. in size.

With increased schistosity there is a greater tendency for augen formation, rotation of grains and fracture of grains. All of these features aid in the metamorphic differentiation of matrix silica into the resulting low pressure areas where it is deposited as coarser (0.5 to 1.0 mm.) quartz mosaics.

Orthoclase is more common in the matrix of the augen schists than as phenocrysts. It is similar to the quartz in occurrence and habit, being also clear and free of inclusions. These features are indicative of its secondary origin by recrystallization. In the more schistose rocks orthoclase seems to occur as a spongy, microcrystalline intergrowth with quartz and sericite. In rocks that show narrow quartz veining the orthoclase is seen to be a common vein component with quartz.

Albite of the matrix is very hard to distinguish from quartz and orthoclase. Staining of the thin section aids in identification. Small anhedral grains are untwinned and do not exceed 0.05 mm. in dimension.

Sericite probably represents the most characteristic mineral of the matrix of the augen schists. It is characterized by its platy structure and low order birefringence. With increase in schistosity there is a marked increase in the sericite content and there is a tendency for segregation of quartz-rich and sericite-rich bands. Segregation is related to shear. Sericite production is in response to shear by breakdown of matrix and phenocrystic feldspar with sericite concentrated along the shear planes. The higher the shearing the closer spaced are the sericite bands. It can then be seen that in extreme cases of shear the final product is a quartz-mica schist.

In the schistose rocks the mica bands are often sinuous and are seen to flow around the quartz and feldspar augen. In the more massive rocks sinuous bands are not as well developed, and sericite commonly occurs as shorter bands and lenses (Figure 28, Plate XVIII). In the massive rocks and tuffs, sericite also occurs as plates and flakes interstitial to quartz and feldspar.

In the massive rocks sericite commonly forms small individual masses less than 1 mm. in length. These patches have been interpreted (Johnston, 1960; Loudon, 1960) to represent the product of devitrification of glass or pumice in the original rocks.

Sericitization of feldspar phenocrysts is a common process, especially along fractures and cleavage planes. It also occurs at the ends of the feldspar cores within augen, where the grain is in contact with the quartz mosaic which forms the lens structure. Minute plates of sericite are common rimming altered feldspar phenocrysts and under high magnification these same flakes are seen within the edges of the grains where the breakdown has begun.

Sericitization is related to shearing. However, in some areas of massive rocks there would appear to be marked changes in sericite content from one rock to another where the mineralogy is much the same and where there appears to have been no pronounced shearing action. In such cases it is suggested, as an alternative hypothesis, that the rocks showing the highest content of sericite are probably the ones which originally contained the greatest amount of glass and dissolved water and that the sericite content is a product of devitrification.

Sericite also is abundant in the "dacites." In the massive rocks (Figure 24, Plate XVI) it occurs as sinuous bands of microcrystalline nature. These bands commonly grade into more tabular stringers that impart a suggestion of schistosity to the rock. In the augen schists derived from the dacitic rocks (Figure 50, Plate XXIX) the sericite has been segregated into bands that separate wider quartz-rich bands.

Biotite is not a constituent of the massive rhyolites. It occurs in minor amounts in the massive tuffs and massive augen schists, is common in the pyroclastic rocks, and becomes a major mineral in the augen schists. It occurs in several ways:

1. As fine, thin, flakes associated with sericite and chlorite. Individual crystals of biotite are aligned parallel to the main schistosity.
2. As irregular masses in association with pyrite. These are more common in the massive rocks. In the more schistose rocks the association is seen to occur along fractures in the rocks.
3. As stringers partially rimming large K-feldspar phenocrysts. Such stringers originate from the migration of potassium during metamorphism and shearing of the phenocrysts. This feature is illus-

trated in Figures 43 and 44 (Plate XXVI).

4. As microcrystalline flakes, commonly formed at right angles to the main rock schistosity, and associated with areas enriched in sericite and chlorite. Biotite of this type may indicate the biotite isograd. The reaction is expressed as:

Muscovite(Sericite) + Chlorite $\rightleftharpoons$ Biotite + Chlorite.

The above occurrences are common in both massive and more schistose augen schists. They are apparently indicative of reactions which took place late in the metamorphic history.

Biotite also occurs as probable porphyroblasts in the augen schists. This seems to be true of more massive types and especially the tuffs where shearing has not been too extreme. In these instances the biotite occurs as large patches or books which parallel the schistosity (Figure 40, Plate XXIV and Figure 42, Plate XXV). In the more schistose rocks the porphyroblasts are exceedingly elongated and appear to be masked by sericite and chlorite.

Biotite appears to be a secondary mineral in the pyroclastics and flows around the large clastic grains and rock fragments.

Chlorite content increases with increase in schistosity. In the volcanics around the Tetagouche anticline chlorite is common and imparts a light green color to the rocks. The chlorite is pleochroic from pale yellow to bright green, commonly with a deep blue interference color characteristic of the iron and magnesium chlorite, penninite. The chlorite in these rocks seems closely associated with biotite, apparently as an expression of the chlorite-biotite subfacies of the greenschist facies.

## Accessories

Accessory minerals form a very minor percentage of the rock. In thin section they are almost completely masked by the microcrystalline nature of the matrix and particularly by the high mica content. To aid the study, rock samples were dissolved in hydrofluoric acid, and several were crushed and separated by heavy liquids. The accessory minerals are zircon, garnet, pyrite, magnetite, apatite, epidote, calcite and limonite.

Zircon shows the same physical properties in all of the rocks studied. They are extremely small and range from doubly terminated crystals to broken and rounded fragments. The grains characteristically form thin rod-like crystals. Zircon crystals most commonly occur in association with the fine matrix mosaic but are also common as inclusions within feldspar phenocrysts. The zircons from the extremely schistose rocks in the Tetagouche anticline are more abundant and smaller than those of the massive rocks in the southeast.

Garnets are also typical of all the rock types except massive rhyolites. However, they appear more abundant in the more schistose rocks and in particular in the "dacites." The presence of greater abundances in any one rock type is accounted for by the higher iron content of the rock. It is suggested that shear has been a great aid in promoting faster reaction rates in the rocks during metamorphism. The garnets are characteristically small, rounded, orange-pink and extremely clear. The largest grains occur within the "dacites." X-ray analysis of the garnet fraction has shown it to be the high iron-bearing member, nearly pure almandine ($Fe_3Al_2(SiO_4)_3$).

Pyrite is a common accessory. In the massive rhyolites it occurs as small striated cubes and as anhedral masses. In the augen schists and tuffs it occurs in much the same manner but also appears associated with fracturing and as replacement masses within ruptured phenocrysts.

Magnetite in the massive rhyolites, tuffs, and their schistose derivatives occurs as small euhedral crystals in clusters in the matrix.

Apatite and epidote were recognized as accessories in the massive augen schists and in the rhyolite tuffs but were masked completely in the more schistose rocks. These two minerals are commonly associated with quartz in the matrix. Grains are very minute. Apatite grains are anhedral and distinguished by their relief.

Calcite is a common accessory of the tuffs and augen schists where it is most commonly associated with quartz as replacements within K-feldspars (Figure 46, Plate XXVII). Within the matrix calcite occurs as minute irregular blebs and as short narrow veinlets. Under high magnification calcite is distinguished by its characteristic twinning. Since the calcite is all secondary, it is thought to be the product of destruction of plagioclase feldspars with release of the calcium molecule. Calcite is much more common in the pyroclastics than it is in the augen schists (Figure 47, Plate XXVIII) and is thought to be indicative of higher calcium content in the original rock.

As an alternative hypothesis it is suggested that apatite, epidote, calcite and pyrite may be the products of propylitization.

Limonite is common in all of the rocks as weathering stains along fractures and around the phenocrysts. In areas where pyrite is common limonite is, of course, more abundant.

PLATE XXXI : EXPOSURES OF SCHISTOSE VARIETY OF AUGEN SCHISTS.

Figure 53. Augen schist with well developed foliation. Located on N - 6 map sheet. Small feldspar phenocrysts (augen) lie in the plane of the schistosity. Alternating dark argillaceous and lighter feldspar-rich bands impart bedding to the rock. Narrow white quartz veins are common. Pencil is approximately 6 inches long.

Figure 54. Schistose and bedded augen schist from the Devils Elbow area, map N - 7. Bedding is displayed by alternating dark chlorite-rich bands and lighter feldspar-rich bands. Slip cleavage offsets the bedding nearly at right angles. Large feldspar phenocrysts have been disturbed by development of the cleavage.

# PLATE XXXI

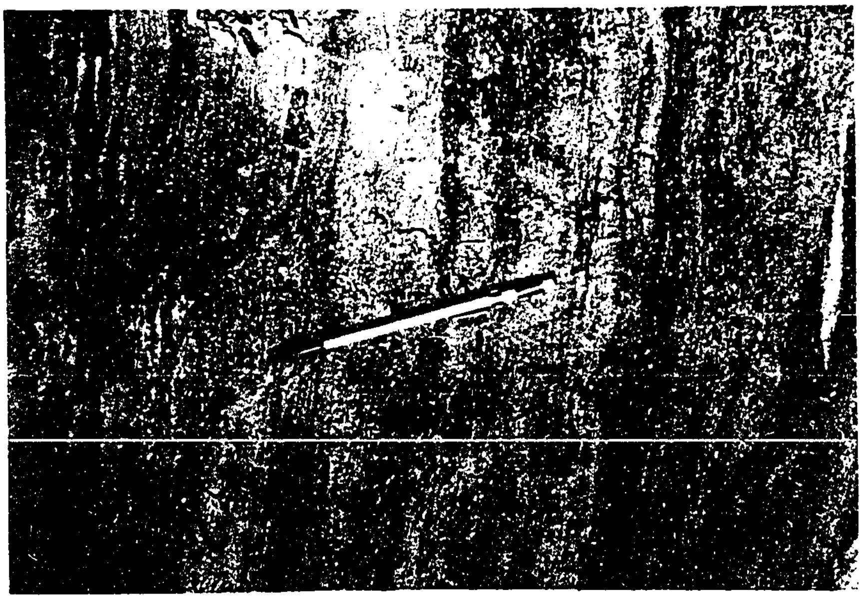

Figure 53

Figure 54

PLATE XXXII : PHOTOMICROGRAPHS OF AUGEN SCHIST.

Figure 55. Stained thin section. Crossed nicols. Sample N - 6 - 4, one mile south of Tetagouche fire tower.Large perthitic feldspar appear as black crystals(heavily stained). Feldspars are relatively unaltered but have been fractured and rotated in the matrix. Quartz phenocrysts have been destroyed and form augen composed of microcrystalline, sutured grains(white). Quartz has recrystallized in the fractures(feldspars) and in the pressure shadow areas of large phenocrysts. The matrix is composed of microcrystalline quartz and sericite. Staining has exemplified the quartz-rich and mica-rich banding.

Figure 56. Stained thin section. Crossed nicols.Sample O - 5 - 2. Typical schistose variety of augen schist. Sericite bands flow around large K-feldspar(black) and crushed quartz(white) augen. Feldspar phenocrysts have been fractured along cleavage planes. Some K-feldspars show Carlsbad twins. Patch perthitic structure is evident in some crystals. Quartz is common as small fragmentary grains and as recrystallized material in pressure shadow areas. Staining exemplifies the schistosity.

# PLATE XXXII

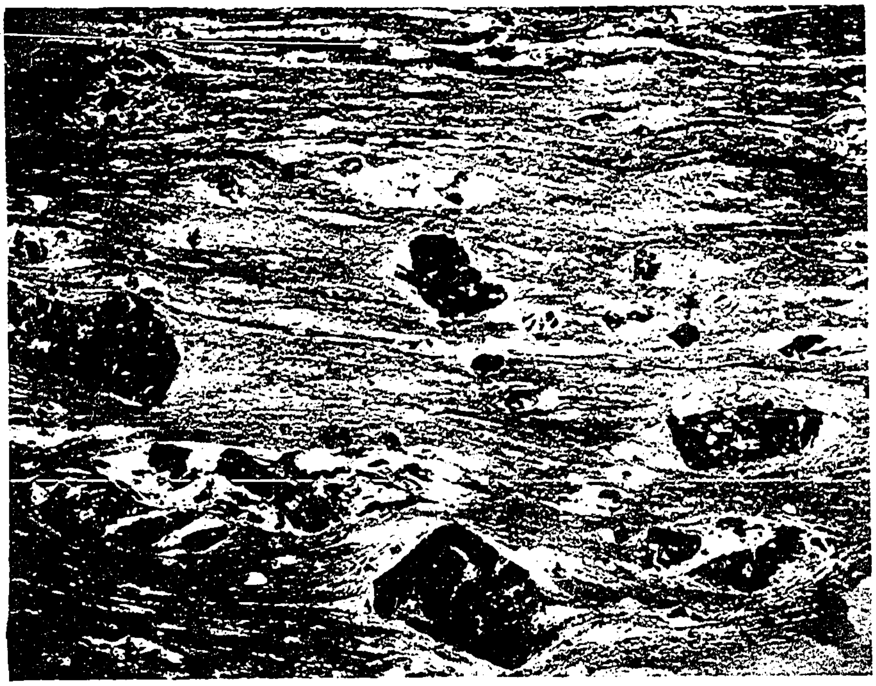

Figure 55 4·2 x

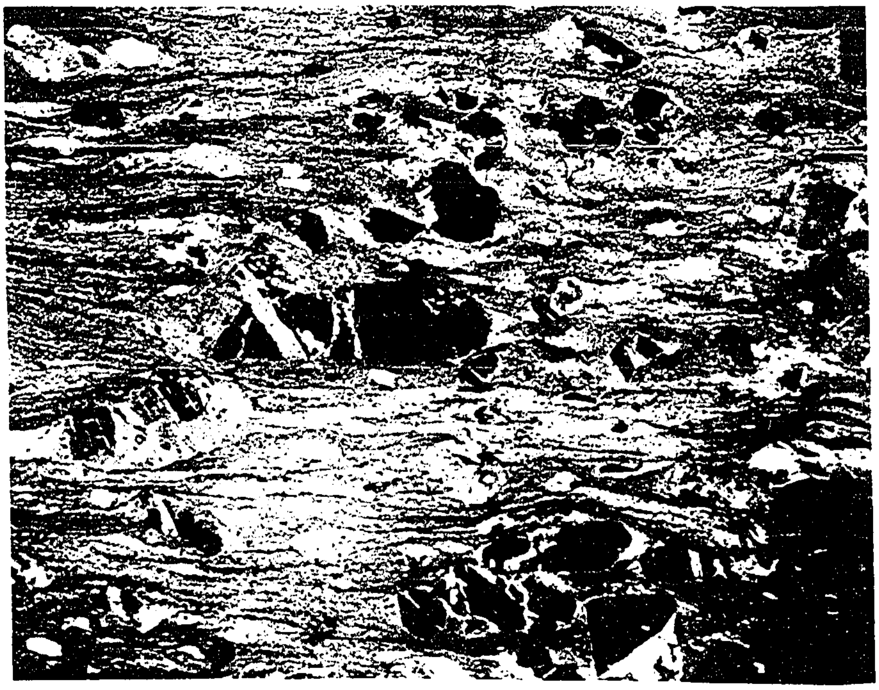

Figure 56 4·2 x

PLATE XXXIII : PHOTOMICROGRAPHS OF AUGEN SCHISTS.

Figure 57. Stained thin section.Crossed nicols. Sample 0 - 6 - 21. Quartz-feldspar augen schist. Augen of quartz(white) and K-feldspar(black) are exemplified by staining. Large quartz augen is crushed but still shows volcanic embayments. Large K-feldspar augen is patch perthitic and has been rotated in the soft matrix. Matrix largely recrystallized quartz and sericite.

Figure 58. Stained thin section. Crossed nicols. Sample 0 - 6 - 24. Matrix appears cataclastic. Abundant angular quartz(Q) as phenocrysts and as small matrix components. K-feldspar phenocrysts(K) are patch perthitic. Albite(A) occurs as smaller relatively unaltered and twinned crystals. Clear secondary quartz rims are evident around the dark feldspar crystals.

# PLATE XXXIII

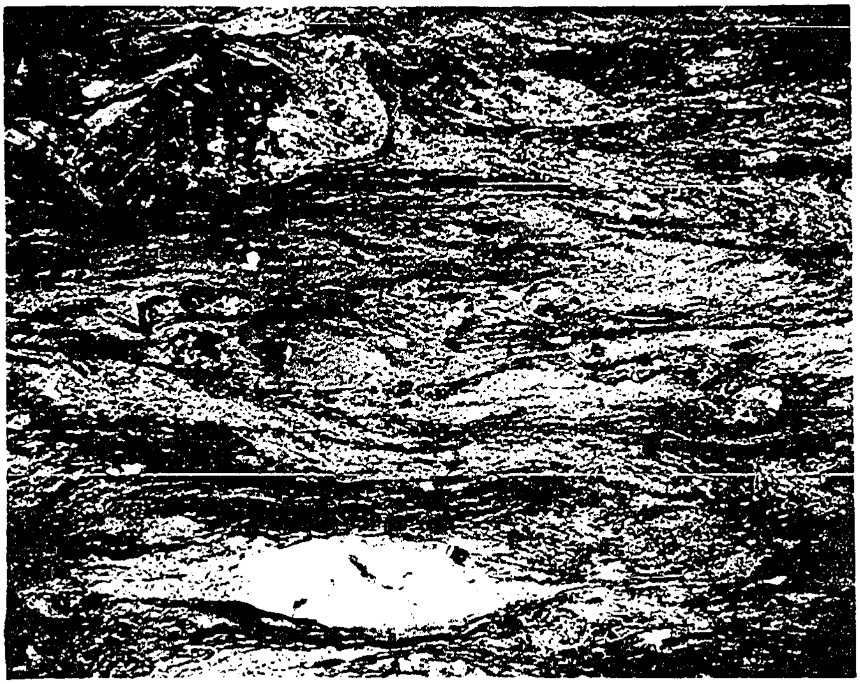


Figure 57 4·2 x

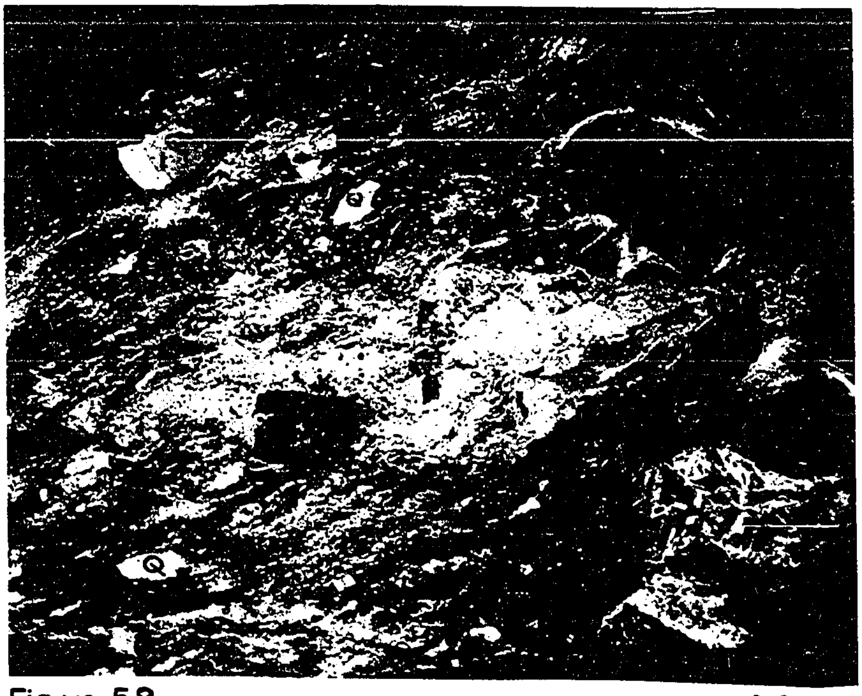

Figure 58 4·2 x

PLATE XXXIV : PHOTOMICROGRAPHS OF ALBITE PRIMARY AND SECONDARY ALBITE.

Figure 59. Stained thin section.Crossed nicols. Sample N - 6 - 2, from the area of the Caribou Mine. Quartz augen in a fine grained, schistose, sericitic and extremely stained matrix. Small 0.5 microlites of albite have developed at a large angle to the schistosity. Albite crystals are well developed.

Figure 60. Stained thin section. Crossed nicols. Sample O - 5 - 9. Tuffaceous matrix of augen schist. Rounded phenocryst of albite in right center of figure. Albite shows slight chequer-board structure. Matrix is composed of quartz,feldspar and sericite. Abundant secondary quartz grains(white) are evident around the albite phenocryst and in the matrix. A possible pumice fragment may be seen in the left central part of the photo.

# PLATE XXXIV

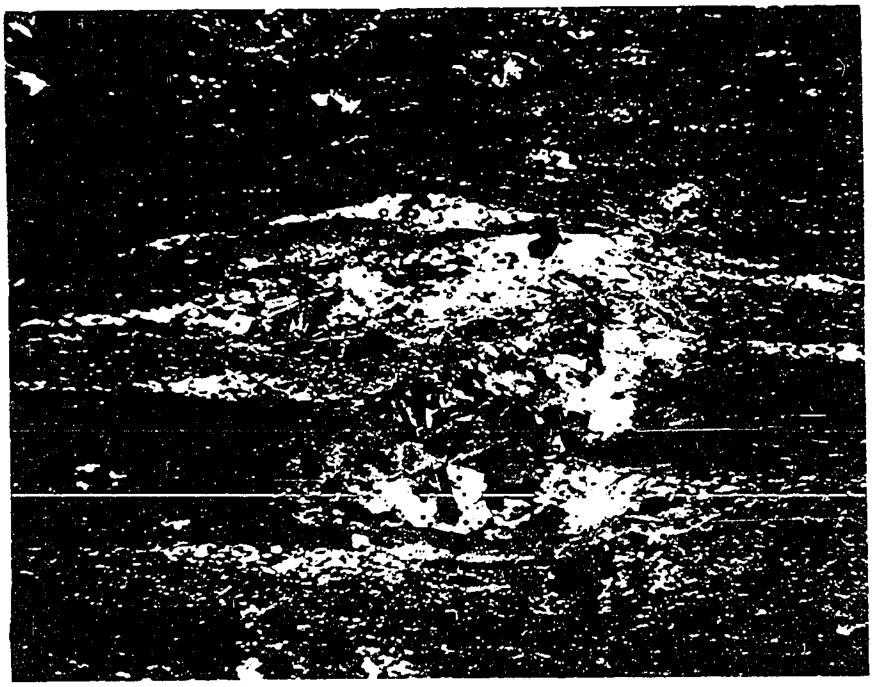

Figure 59 21 x

Figure 60 21x

PLATE XXXV : PHOTOMICROGRAPHS OF QUARTZ-MICA SCHISTS.

Figure 61. Stained thin section. Crossed nicols. Sample O - 6 - 4. Quartz-sericite schist. Schistosity well developed. Remnant feldspar phenocrysts(black) are evident along the schistosity planes. Quartz(white) forms elongated augen and stringers alternating with dark sericite rich bands.

Figure 62. Stained thin section. Crossed nicols. Sample O - 5 - 5. Quartz-sericite schist, as Figure 61. Feldspar augen are still evident. K-feldspar(K) and albite(A) are rimmed by bands of sericite(S). Quartz(white) occurs as segregated stringers. Patches of sericite(S) are common in the matrix.

# PLATE XXXV

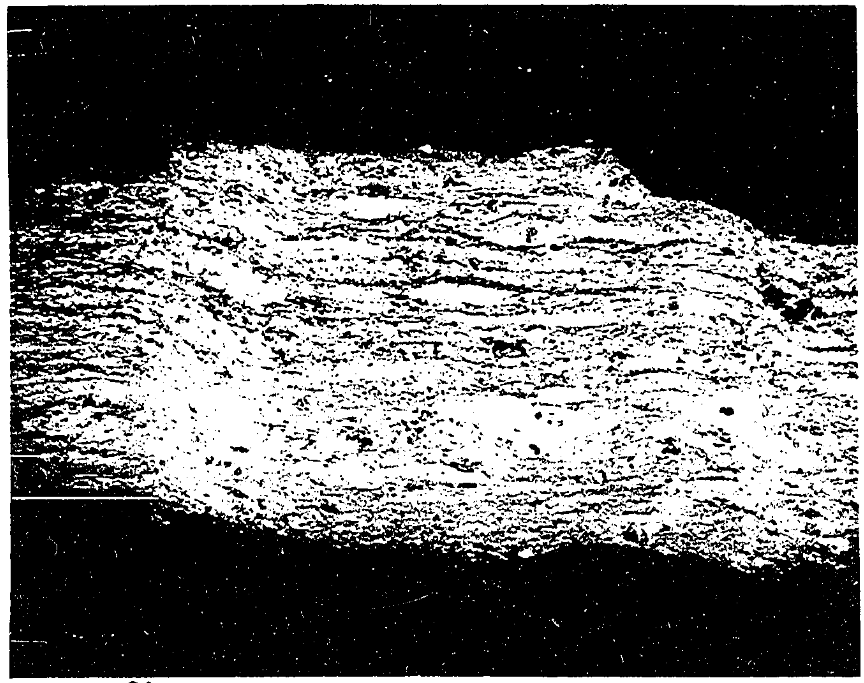

Figure 61 4·2 x

Figure 62 4·2x

# C H A P T E R
# F O U R

# ORIGIN AND METAMORPHISM OF THE AUGEN SCHISTS

## Introduction

### General Statement

The present uncertainty over the origin of the augen schists and their close spatial relationship to stratigraphically controlled sulphide deposits warrants the undertaking of this study. This is the first attempt at a regional study of the augen schists, although several works have appeared on local areas. For example, Loudon (1960) conducted a petrographic study of acid volcanic rocks from the Devils Elbow property (N - 7), whereas earlier work by Sawyer (1957), Lee and Rancourt (1958) and later petrochemical work by Pearce (1963) has all been confined to the immediate area of the Brunswick Mining and Smelting Number 6 ore deposit. It has been contended that the "type" augen schist occurs in the southeast area, but the present work considers the augen schists over the whole district as representing a continuing series of volcanic and tuffaceous rocks which have been variously affected because of their depositional and metamorphic histories.

The regional geology of the area has been presented by Skinner (1953, 1956), by Smith (1957), and by Smith and Skinner (1958). In each the augen schist is treated in a general manner, and several broad generalizations have been made. The present work involves a study of acid volcanics over the region and a more detailed study from selected areas.

The writer mapped an area of approximately 200 square miles, which traversed a complete stratigraphic section across the rock units of the Ordovician complex (Plates I and VII). Additional reconnaissance field work outside the three maps allowed the writer to study the augen schist sequence over the gross structure and to collect samples for laboratory study on a regional basis.

Laboratory studies were confined to textural relationships and mineralogy within the rock units in tracing the development of augen schists through the dynamic metamorphism of rhyolite flows and tuffs.

Prior to discussion of the origin of the augen schists it is felt that some background material should be presented for readers unfamiliar with the geology of the area and the problems presented by this rock unit.

## Previous Terminology and Descriptions

Young (1911) recognized the augen schists south of the present site of the Brunswick Number 6 sulphide deposit as possible tuffs. He states:

The rock (quartz-free porphyry) is usually of a dark, greyish black colour, but in not a few instances green; it is usually very fine-grained, dense, but showing scattered tiny cleavage faces. In most cases the rock has at least an irregular schistose parting, and in many instances has been sheared to a glistening or dull sericite and chlorite schist.

*Examined in thin section, the quartz-*free porphyry consists of a very finely crystalline base, holding a few, very small phenocrysts of plagioclase. In some instances the fine-grained base consists largely of minute laths of plagioclase, but more commonly the ground is finely granular, with much quartz present. At times the general structure suggests that the rock is a tuff, .... Various secondary minerals, chlorite, sericite, calcite, etc., occur in varying quantities, apparently directly proportional to the amount of shearing the rock has suffered.

....The quartz porphyry always has a hackly parting plane, and varies in colour from nearly black to dark, greenish grey, the lighter colours being characteristic of the more schistose varieties, which grade into sericite schists. The rock, when not too much sheared is crowded with crystal fragments of glassy quartz and white feldspar, that lie in a dense base. The crystal fragments, or phenocrysts, vary widely in size from exposure to exposure, though fairly uniform over considerable areas. In many instances the feldspar individuals measure over one-half inch in length, in others they are not above the size of small shot.

In thin sections, the quartz porphyries are seen to be composed of angular individuals of quartz, orthoclase, and acid plagioclase, crowded together in a finely granular ground of quartz and orthoclase. In most cases the phenocrysts are broken, and others of shearing are usually visible. In more schistose varieties, sericite, biotite, etc. are plentifully developed.

-----the general structure at times suggested a tuffaceous origin for the rock, the shearing to which the rock has been subjected masking their true origin....

Whereas Young studied more massive rocks, Alcock (1941) was familiar with the more schistose types to the northwest where he recognized them as possible tuffaceous members. He states:

> The best sections .... exposed along the main Tetagouche and its chief tributary, the South Branch ...... the dark slates and limestones have associated with them banded, greenish rocks and zones of sericitic schist, which apparently represent volcanic tuffs. In thin section the massive green rocks are found to consist of a mass of secondary minerals .... They pass into chlorite schists .... These vary from hard, cherty types containing but little sericite to highly schistose types containing much. Many show crystals of feldspar, giving them a pseudomorphic appearance..... they are seen to consist largely of quartz and sericite with large, irregularly shaped crystals of orthoclase and plagioclase ..... Similar grey rocks with feldspar and quartz crystals developed as metacrysts also occur....

Smith and Skinner (1958) refer to the augen schists as 'porphyry' from their descriptions of massive rocks around the Brunswick properties. They state:

> Some of the less deformed types of 'porphyry' have an igneous fabric... Other thin sections show rounded and embayed quartz grains as well as euhedral feldspars in a hydrothermally altered groundmass of felsic material .... They are interpreted as shallow sills or flows derived from the same magma as the siliceous volcanic rocks.....
>
> .... other rocks containing conspicuous quartz and feldspar grains have a sedimentary fabric. Where undeformed they may be bedded and contain rock fragments. Their

> larger grains are angular, and the groundmass is poorly sorted and fine grained in contrast to the microcrystalline groundmass of the igneous type.
>
> .... The growth of large grains as porphyroblasts is of negligible importance in explaining the origin of the great bulk of rocks with conspicuous quartz and feldspar grains.
>
> Confusion over the nature of the 'porphyry' has arisen because in most cases the rock is deformed and genetic criteria are destroyed. In ordinary one-mile mapping it has not been possible to separate the various types in the field, and the name 'porphyry' has been used for the hybrid unit. In future detailed mapping, however, the name chosen for this unit should be based on local considerations in the area mapped rather than on analogy with other parts of the district. It is not reasonable to try to force a single name on the 'porphyry' unit as it is presently mapped.

Lea and Rancourt (1958) describe augen schists from the Brunswick area also, and describe a rock type they refer to as a chlorite schist, as:

> characterized by about 15 per cent of moderately coarse quartz crystals (up to 0.5 mm. in diameter) showing strong evidence of milling, cracking, and fracturing in metamorphism. These quartz grains are essentially the same as the quartz eyes of the quartz eye schists. The groundmass is approximately 60 per cent very fine quartz and 15 to 25 per cent deep-green chlorite in tiny flakes. It is suggested that these rocks are moderately aluminous fine grained sediments. They are strongly suggestive of a progressive sedimentational gradation from coarser and more impure greywacke toward more purely siliceous and finer grained material.

This rock type is later considered to be the metamorphic derivative of augen schists (Pearce, 1963).

McAllister (1960) points out the association of the augen schists with sulphide occurrences in the area.

Quote:

> Rocks characterized by the presence of euhedral crystals, angular fragments, or rounded grains of quartz and/or feldspar are associated with every massive sulphide deposit in the Bathurst-Newcastle camp....
>
> Flow structures and igneous contacts have certainly been identified in quartz-feldspar porphyries of the district. It is suggested that most of the rocks of known magmatic origin (i.e., not tuffaceous) of the district are hard, brittle and of blocky or conchoidal fracture.
>
> On the other hand most of the rocks in close association with the ore bodies show features suggestive of tuffaceous origin, such as bedding, associated agglomerate, presence of shards, glass, pumiceous texture, etc. Considerable variation is also found in the matrix of the tuffaceous members. Some are chloritic, some are fine grained and sericitic and some have a matrix resembling grey phyllitic argillite. The variation in matrix reflects, among other things, the variation of environments in which the tuffs were deposited. As compared to the rocks of known magmatic origin the tuffs are more schistose, having generally a matrix rich in soft sericite and/or chlorite ...... 'Porphyry-Tuff' ... is distinguished from rocks in the 'Acidic Volcanic unit ... mainly on a basis of grain size. In the (former) unit many of the rocks carry crystals of feldspar up to one-half inch in diameter. Many of the rocks of the 'Acidic Volcanic' unit are similar except for the much smaller size of the augen of quartz and feldspar.

Smith (1957) describes several types of augen schist that he was able to recognize from a regional mapping program. These include:

1. Rocks considered to be contemporaneous with the rhyolitic flows in the area. Such exist either as flows or as shallow sills and grade into rhyolites as the number and size of phenocrysts decrease.
2. Cross-cutting dykes, such as a body at the Nigadoo Mine, which cuts both Ordovician and Silurian rocks and which is thought to be related to the granite intrusions. A narrow quartz-feldspar porphyry dyke was mapped by Smith and McAllister (1956) on the P - 7 map sheet.
3. An arkosic or tuffaceous rock which appears to be highly sheared and which has a fine-grained rather than a microcrystalline matrix. This type also contains rock fragments.
4. A type containing 'blue' quartz eyes, in a matrix that appears to be sedimentary. It is questionable whether the eyes are sedimentary or metasomatic.

The foregoing discussion has been presented to bring attention to the ambiguity that exists in dealing with the augen schist sequence. The contention that detailed mapping will solve many of the problems has been true. The contention (Smith and Skinner, 1958) that the rock should be given an applicable name to fit specific occurrences may be valid, but since this sequence of rocks in its various forms had a similar origin, a common terminology is desirable. Variance in physical and chemical properties result from changes in the depositional environment, and in the local conditions of metamorphism. This area was one of great volcanism during Ordovician time (McAllister, 1960) and was relatively unstable. Rocks such as the different chemical iron facies, graphitic schists and greywackes are common associates and indicate that the area was one of shallow seas, deeper lagoonal basins, and terrestrial highlands. Such a physiographic setting testifies to the amount of diversification that should be expected in the rock assemblage.

Present Terminology

A controversy exists as to whether this particular rock assemblage should be referred to as porphyry or as augen schist. The classic definition of a porphyry in the past has been used to describe all rocks containing conspicuous phenocrysts in a fine-grained matrix. The resulting texture is described as being 'porphyritic.' This term is, at present, used to define any igneous or meta-igneous rock that has two or more distinct grain sizes. The term 'augen', in the classic sense, was used to refer to 'eye shaped' structures, especially in metamorphic rocks, and further the use of the word 'augen schist' implies a sheared rock characterized by the presence of recrystallized minerals in schistose streaks and lenticules. The term 'augen gneiss', furthermore, incorporates such rocks containing phacoidal crystals or aggregates, with the augen representing either uncrushed fragments or porphyroblasts.

The writer prefers the term 'augen schist' for the following reasons:

1. The term 'porphyry' denotes igneous rocks, whereas these rocks are metamorphic. They show recrystallization, with the development of abundant mica which imparts a schistosity to the rock.
2. Rocks that are massive may appear as 'porphyries' superficially; however, in thin section all of the rocks show augen development with mica minerals characteristically moulded around the phenocrysts.
3. Many of the rock types within the unit are not characterized by a porphyritic texture, but in thin section folia of eye shaped material is invariably present, sometimes even as mica aggregates.

Field Characteristics of the Augen Schists

Detailed mapping on the scale of 4 inches to the mile has allowed the writer to make observations and draw conclusions concerning the augen schist units.

1. Several types can be recognized in the field. They differ slightly in mineralogy, the amount of shearing, and their over-all physical appearance. The various types are representative of rocks derived from flows, tuffs or sediments.
2. Augen schist forms the dominant rock type of the intermediate stratigraphic unit of the Ordovician sequence (Plate VII).
3. Augen schists often form long sinuous beds whose stratigraphic lengths greatly exceed the thickness. For example, in the N - 6 area 100 to 200 foot thick beds can be traced laterally for over three miles. Since these rocks are rhyolitic, it is difficult to visualize such as flows, for magma of rhyolite composition is assumed to form short, thick, bulbous flows. This is considered as evidence that the rock units were deposited as air-deposited tuffs.
4. Augen schists are often considered to be a sediment of the greywacke-sandstone type. It is difficult to visualize the sedimentary environment needed to produce a rock containing large crystals of feldspar in an argillaceous matrix without including volcanic events.
5. The augen schists are not the intrusive equivalent

of rhyolites as suggested by Smith (1957) or Skinner (1956). The writer has not observed any instance where intrusive relations were indicated.

6. Augen schists vary from extremely massive to very schistose within local areas. This feature is associated with areas where local deformation has been quite variable.
7. Rocks of the augen schist family occur interbedded with all of the rock units in the Ordovician sequence, from the outer basic volcanics to the innermost acidic volcanic core rocks. The association of augen schist with such a wide variety of rocks, including graphite schists, greywackes, andesites, and rhyolites reflects a complex origin for this rock type.
8. Augen schists, with successive degrees of dynamic metamorphism, are converted to quartz-sericite schists.
9. Schistosity has developed parallel to the bedding planes. This feature has been used with considerable success in tracing out the trends of the lithologic units.

To arrive at a conclusion regarding the origin of the augen schists, several lines of evidence other than field criteria must be considered. All of the rocks have been affected, more or less, by metamorphism and weathering, but many still retain original features which are indicative of their origin.

## Petrography

### General Statement

Complete petrographic descriptions of the rock types studied are included in Chapter III, with emphasis on the development of augen schists.

This section includes a discussion of the mineralogy and texture of the augen schists and the significance that these features have in determining the original character of the rocks and in describing the metamorphic changes which have occurred. This is, then, a summary of the conclusions arrived at from the petrographic study of Chapter III.

### Texture

Low grade metamorphism has, for the most part, destroyed the original fabric of the rocks. Where metamorphism has been most intense the resulting texture is typical of schists with segregated bands of mica-rich and quartz-rich material. Mica-rich bands flow around augen of quartz and feldspar in typical fashion. In areas where dynamic metamorphism has been lower the rocks are massive and in many cases tend to retain their original texture or fabric.

During the mapping program the writer was able to make subdivisions within the gross augen schist unit partly on the basis of the texture observed in outcrop. For example, augen schists could be distinguished from porphyritic rhyolites, and volcanic members of the augen schist sequence could be distinguished from pyroclastic derivatives.

Metamorphic and igneous textures are both prevalent in the matrix material, whereas an igneous texture predominates in the phenocrysts.

Matrix

Recrystallization has tended to increase the total grain size and to produce a clear metamorphic assemblage. The matrix is invariably a mosaic of anhedral grains of quartz and feldspar with varying amounts of sericite, depending on the degree of schistosity developed in the rock. The anhedral grains display vivid serrated boundaries and where in contact with larger phenocrysts the contacts become vague or gradational with interfingering between the two in typical lace-work fashion (Figure 12, Plate X). This feature is often advanced in support of porphyroblast growth, but is the normal result of recrystallization of the rock components. Evidence to support secondary addition of material to the grains is present. Many large quartz phenocrysts display clear unstained metamorphic borders, and many feldspar phenocrysts exhibit clear untwinned rims.

Recrystallization of the matrix and metamorphic differentiation supplies excess silica for redistribution as veins within the rocks and as fracture fillings in the phenocrysts.

The rocks of the augen schist series are unique in that they show many features that are not evident in the massive rhyolite intrusives and flows of the same volcanic suite. The nature of the matrix implies a tuffaceous origin. The most prevalent feature is the development of abundant sericite and the apparent ability of the rock to be easily recrystallized. This feature is indicative of the augen schists in the northwest and indicates that they were originally composed of a material that was easily altered and reconstituted. It is the writer's contention that the sericite content is not only dependent on the amount of shearing but is also indicative of the amount of water contained in the original rock. Fyfe, Turner and Verhoogen (1958) state that tuffs can contain up to 10 percent water within the mineral structure (clays, sericite). In this respect the rocks in the northwest could represent air-blown and water deposited tuffs, in contrast to the more massive types closer to the volcanic source (southeast and central regions).

Evidence of original glass has been observed and recorded, with examples, in Chapter III.

Phenocrysts

Metamorphism has been low grade and dynamic resulting in the original phenocrysts having been crushed and strained to varying degrees, with most suffering fracture and separation. The degree of destruction varies from areas where shearing is low and the phenocrysts are merely strained to areas of extreme shearing where the phenocrysts have been completely obliterated and smeared along planes of shearing (Contrast Figure 63, Plate XXXVI with Figure 66, Plate XXXVII).

Although metamorphic effects are pronounced, the original texture and origin or the rock is illustrated by several features.

Deep and rounded embayments within the phenocrysts, and especially quartz, are indicative of a volcanic origin. Embayments in the quartz grains are generally tunnel-shaped with smooth curved edges that do not appear rough and jagged (Plate XIX). Embayment features have been observed in quartz phenocrysts from the augen schists, "dacites" and pyroclastics from the whole area and have been noted in grains that have been almost completely destroyed by cataclasis (Figures 57 and 58, Plate XXXIII). The material which fills the embayments consists of a microcrystalline mass of quartz, sericite and feldspar, which represents the composition of the original magma. Embayed quartz grains have been seen not only in the augen schist, but also in the massive intrusive rhyolites of the area (Figure 19, Plate XIV). Many large potash feldspar phenocrysts also contain deep embayments (Figure 43, Plate XXVI) similar to those seen in quartz grains. Survey of the literature has shown that embayed structures are indicative of igneous porphyries and crystal tuffs (Figure 19, Plate XIV and Figure 31, Plate XX).

The shapes of the phenocrysts are indicative of igneous rocks. Study of tuffs and flow rocks from various areas and a survey of the literature indicates that euhedral and subhedral phenocrysts are common and similar to the phenocrysts in the augen schists of the Bathurst-Newcastle area. The size and shape of the quartz and feldspar phenocrysts indicates that both were growing simultaneously in the magma. Furthermore, the presence of abundant fractured and angular grains of both quartz and feldspar, of the same composition as the larger euhedral phenocrysts, indicates a common origin. That is, all of the phenocrysts, both euhedral and fragmental, have originated in a magma and reached their present position through the action of forceful extrusion.

In many instances the texture of the rock is indicative of a pyroclastic (Plate XXII and Figure 47, Plate XXVIII). The rocks consist of small angular quartz grains and rock fragments, notably shale and rhyolite in various stages of rounding, set in an argillaceous matrix. The angular quartz has not formed in situ through deformation. In many instances this rock has been included, during mapping, with the augen schists from surface appearance,and often microscopic analysis is necessary for recognition of the original rock.

The massive texture of the rhyolite porphyries is fundamental in establishing the intrusive and unaltered nature of this rock (Plate XII). Igneous quartz and feldspar phenocrysts are present and the matrix does not show features of tuffaceous origin. The relationship between massive rhyolites is obvious from the nature of the phenocrysts.

Conclusion

Meagre as the textural evidence is at this stage its very nature is strongly suggestive that most of the augen schists are tuffaceous. It was observed that the tuffaceous nature in any one area is further enhanced by the presence and development of abundant sericite. From a gross textural aspect it is concluded that many of the massive rocks are indicative of ash flows whereas the highly schistose "dacites" in the same region are more indicative of original bedded glassy tuffs. Similarly many of the rocks mapped as rhyolite tuffs show relic textures that are more indicative of bedded tuffs than are the more massive types derived from flows.

Mineralogy

As emphasized in Chapter III, the rocks of the acid volcanic sequence are mineralogically simple. All of the components are salic, with femic members forming minor constituents. The rocks are composed largely of quartz, low temperature alkali feldspars and sericite, with minor chlorite, biotite, and accessory zircon, epidote, apatite, calcite, garnet and iron minerals. The mineral assemblage is indicative of rhyolites, with the exception of low temperature feldspars.

The wide occurrence of a mineralogically similar rock series lends added support to the hypothesis that the augen schists and associated rocks represent a volcanic sequence which owe their textural differences largely to original deposition. The differences imposed on the rock sequence is thought to be a reflection of the original composition, that is, whether the rock is a flow, ash flow, airborne ash, or subaqueous deposit of some nature.

Quartz forms the dominant mineral of the augen schists, both as phenocrysts and in the matrix. There can be little doubt that the quartz of the phenocrysts is igneous. Matrix quartz of the schistose rocks has been recrystallized, whereas in the massive flow rocks the quartz appears relatively unaltered and igneous.

Sericite is very common as a matrix component and as an alteration product of feldspar grains. In general sericite is indicative of low grade metamorphism and is common in the metamorphic products of acid volcanic rocks. The abundance of sericite in the augen schists in this area is variable over very short distances and is a product of variances in the original water and glass content of the rocks combined with extremes in local deformation. During shearing stresses water-rich rocks are very susceptible to recrystallization and the production of sericite. Sericite is especially abundant in the "dacites," both massive and sheared.

Probably of most significance is the presence of abundant phenocrysts of low temperature perthitic feldspar in all of the acid volcanic rocks. Such a feature is not indicative of fresh rhyolites or tuffs. On the other hand such a mineralogy is indicative of plutonic rocks, and it may be the reason why some writers consider the augen schists to be intrusive equivalents of the rhyolites (Skinner, 1956). This interpretation cannot be seriously considered in view of the overwhelming evidence to support a tuffaceous texture and origin. Loudon (1960) classifies the augen schists as quartz keratophyres, indicating tuffs and flows of pre-Tertiary age that exhibit low temperature feldspar mineralogy. The feldspar is recognized in keratophyres as not having originated in a magma but as resulting from metasomatic action (mainly albitization) after consolidation of the rock. An example of this type of feldspar is the patch perthites and chequerboard albites.

Perthitic feldspars form the dominant phenocrysts of the volcanic suite. The various types, with descriptions, have been included in Chapter III. A controversy exists over the origin of the perthitic structures exhibited by the feldspars. Four possibilities exist:

1. The classic theory of exsolution of a high temperature form on cooling and through metamorphism.
2. Replacement of perthitic potash feldspar by albite.
3. Replacement of albite by crypto-perthitic K-feldspar.
4. Simultaneous crystallization of albite and K-feldspar in crystals in the magma.

The first case is the easiest to explain and represents the most common acceptance of perthite formation. However, the last three cannot be discounted. Emmons, _et al_.(1953) recognizes the various ways by which perthitic structure can be formed and discusses it at some length, and following are quotations from this work (page 56):

> The formation of some perthitic textures by unmixing in the solid state of the plagioclase fraction of an originally homogeneous

> potash-soda feldspar was first proposed by Vogt .... The fine, regular perthitic intergrowths are still explained in this way .... (page 58) The secondary or replacement origin received little attention in the early studies of perthite but now is being considered an increasingly important process in the development of certain perthitic textures..... The mobility of sodic feldspar materials is well illustrated by its selective concentration in feldspar fractions and its absence in areas adjacent to such fractures. The obvious interpretation is that the fracture became an area of low pressure to which mobile material - unmixing plagioclase was drawn ...... If the fractured crystals constitutes a a locally closed system, a perthitic crystal results. If, however, the fracture is one of a connected series of fractures, the aggregate of fractures becomes a drainage system by which the mobile sodic plagioclase materials may be channeled away, possibly to be ponded elsewhere ..... Perthites characterized by plagioclase occurring as films and shadow may be the result of a hydrostatic pressure change during the last stages of crystallization, whereas by contrast those of the many other varieties (vein, plume, patch) may result from differential pressures and the consequent migration of sodic material. Even where fracturing is not evident the plagioclase lamellae may penetrate the contiguous crystals.

Many of the perthitic structures seen in the augen schists from the Bathurst-Newcastle area are recognized as patch types, and it is the writer's opinion that they probably formed through the remobilization of the soda complement of original cryptoperthitic feldspar through the agencies of metamorphism. The feldspars of the rocks have been fractured and staining processes have greatly aided in exemplifying the patch nature of the sodic material. Whereas Emmons, et al. (1953) considers the sodium molecule to be the mobile material, Battey (1955) considers that the formation of perthitic structures in keratophyres results from the replacement of albite by potash cryptoperthite. Battey (1955) states (page 107):

> The phenocrysts of the keratophyres are remarkable also for the stages they show of replacement of albite by orthoclase-cryptoperthite .... of variable optical properties. A complete series of examples can be found in New Zealand rocks, and replacement around the margins and along cracks to almost complete, and finally complete elimination of the islands of albite remaining in the potash feldspar.

This description may also be applied to the feldspars from the acid volcanics of the Bathurst-Newcastle area, but it requires that one prove the presence of potash metasomatism over the area. At the present time no such evidence is available. The former case is the easiest to apply and is the one favored by the writer.

Whereas K-feldspars are common, Na-feldspar is less common as phenocrysts. It occurs in two forms. First, as rounded phenocrysts that have characteristic twin lamellae running across their full extent and, secondly, as a type referred to in the literature as "chequer-board" albite. The latter type is commonly referred to in modern terms as "chess-board" albite.

The convential albite forms the more common type, and the chequer-board type forms the lesser fraction. Chequer-board albite is characterized by the type of twinning which it exhibits. Twin lamellae, unlike that of normal plagioclase feldspar, do not pass completely through the grains. Battey (1955) describes the chequer-board albites from the northern New Zealand keratophyres as (page 105):

> those with well-developed chequer structure, which are usually of water-clear albite. The chequer-albite is twinned on the albite-law, but with short lamellae which, after continuing for a little greater than their width, either wedge out or are abruptly truncated by planes parallel to (001); such short lamellae, in the same orientation but offset from one another, occupy the whole area of the phenocrysts and, in sections cut normal to (010) when one part of the twin is at extinction, produce a chequered pattern.

Battey (1955) ascribes a primary origin to the chequer-board albites, envisioning it as a process of accumulation and welding together of individual albite laths. Others ascribe chequer-board structure to irregular deposition of albite during the growth of a crystal or to the processes of unmixing, metamorphism and soda-metasomatism.

Few examples of chess-board albite (Figure 32, Plate XX) were seen in the writer's area, and any attempt to conclude the origin seems to be of little value at this time. However, since this feature is exhibited in rocks which show wide variances in perthitic structures, a common origin for the two would seem to be in order. In this respect it seems most logical, from the standpoint of total history of the rock, to attribute all perthites to a combination of high temperature formation and subsequent exsolution, combined with later effects of metamorphism and local metasomatism.

All of the rocks of the Bathurst-Newcastle district lie within the greenschist facies as outlined by Turner and Verhoogen (1960). Within the main facies they recognize three subfacies based on the presence of biotite, epidote and almandine in rocks of a stable metamorphic assemblage. It is the writer's contention that the three subfacies cannot be recognized in the augen schists of the Bathurst-Newcastle district, but that an increase in metamorphic intensity can be recognized.

The presence and relative abundance of chlorite, biotite, epidote and garnet in the acid volcanic rocks may be used to indicate increasing metamorphic intensity. The rock assemblage has not reached equilibrium, and the intensity of metamorphism is related to the amount of shear in the area and the response of the rock type in producing a new mineralogy under shear conditions.

Whereas massive rhyolites show an absence of biotite and almandine, they fall generally within the quartz-albite-muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1960). All of the other rock assemblages, showing biotite and almandine, are placed in higher subfacies representing higher conditions of temperature and pressure.

In summary it may be stated that a study of the mineralogy and texture has been useful in determining something of the history of metamorphism and that the two features form strong evidence that the augen schists represent a continuing metamorphic series of volcanic flows and tuffs.

## Metamorphism

### General Statement

Dynamic metamorphism (deformation and shearing) has been responsible for the production of augen schists, and finally quartz-mica schists, from rhyolite flows and tuffs. This process is described and documented in Chapter III.

In the section on mineralogy, above, it has been emphasized that the presence and relative abundance of biotite and almandine in particular enables one to recognize different intensities of metamorphism from one rock sample to another. In this respect, several generalities can be made:

1. The mineral assemblages have not reached equilibrium.
2. The rocks in the northwest part of the area are more schistose and show greater abundance of almandine than

do the massive rocks in the southeast. Therefore, metamorphism (shearing) has been more intense in this area, and there may be an intensity gradient from southeast to northwest.

3. "Dacites" contain the greatest abundance and largest individuals of almandine. This indicates that the composition of these rocks was such that they reacted more rapidly to the shearing stresses than did the other rock types.

Metamorphism has been responsible for changes in the phenocrysts and matrix which tend to obscure the origin of the rocks. All of these changes, with illustrations, have been discussed in Chapter III. In summation, under conditions of dynamic stress and low confining pressure:

1. Quartz phenocrysts have failed by brittle means, such as strain, crushing and smearing along shear planes.
2. Feldspar phenocrysts failed by unmixing, fracture and chemical alteration through promotion of mobile action of both $Na_2O$ and $K_2O$.
3. The matrix is affected by devitrification, recrystallization and alteration with production of schistosity.

The reader is referred to Chapter III for a comprehensive discussion of each.

Phenocrysts and Matrix

It seems evident that the main effect of metamorphism has been to reduce the size of the phenocrysts and to increase the grain size of the matrix constituents. This tendency was discussed by Pearce (1963), who considers it a case of mylonitization, and states (page 45):

> The rocks of this study have undergone extreme brecciation, volume increase, recrystallization under directed stress and chemical alteration. The preferred orientation of the major minerals in the most sheared rocks suggests that these features were developed under similar stress conditions and hence were at least partly contemporaneous. That is, brittle deformation, plastic deformation and metasomatism took place concurrently in the same rock.
>
> .... it becomes plausible if we consider the size difference between the large quartz grains (5 mm. diameter) and the small grains in the groundmass (0.02 mm.). Since some physical and chemical properties are a function not only of the intensive properties of a material but also the amount (size) of the material, it follows that large and small grains will behave differently under the same conditions of stress. For example, the rate of reaction is proportional to surface; therefore, given equal weights of the two grain sizes mentioned above, the small grains will react 250 times more rapidly than the large grains, all other things being equal. In addition, the free energy of the small grains will be greater than that of the larger grains and they will tend to be more chemically reactive (unstable). Because of the square-cube law, the greater grains will be weaker than the smaller grains by a factor of 250 and hence will be more readily fractured under applied stress. Thus as mylonitization proceeds and grain size is reduced, a certain critical grain size will be reached below which failure by fracture does not take place .... instead failure is by plastic deformation (recrystallization). Coherance of the rock as a whole would be maintained by the plastic deformation of the fine grain sizes which are affected by cataclastic deformation. Once this critical grain size is reached further compression or shear

> stress will not tend to disrupt the rock but to make it more coherent by aiding recrystallization. Any grains which result through fragmentation and have a grain size smaller than the critical size will have a tendency to grow larger by recrystallization with other grains or with material introduced from other sources and hence reduce the free energy. If by crystal growth and recrystallization the critical size is exceeded, the grains will be subject to reduction in size by granulation. Thus the critical size is the only mechanically and chemically stable grain size for a given mineral under a given set of conditions, and is determined by the strength of the mineral, the maximum rate of recrystallization, the confining pressure and the magnitude and rate of application of the directed stress.

This statement sums up concisely what is evident from thin section analysis. The amount of mechanical breakdown and the amount of recrystallization of the matrix are both seen to increase with transformation of massive flows and tuffs into augen schists and mica-rich schists. The presence of water in these rocks greatly facilitates the reaction and the production of micaceous minerals.

The writer has seen local areas where massive augen schist has been transformed into quartz-sericite schist over a stratigraphic distance of approximately 2000 feet. Such an occurrence is represented by the samples N - 7 - 1 to N - 7 - 4 and is illustrated by Figures 63 to 66 of Plates XXXVI and XXXVII. In this case the development of mica schist is different from those described earlier in that a slip cleavage is seen to develop at a sharp angle to the bedding and schistosity. Figure 63 represents the augen schist as this series appears in its most massive form. It is characterized by rounded to euhedral feldspar phenocrysts that reach a length of 8 mm, generally aligned roughly parallel to the schistosity. Quartz eyes are much less common, subhedral, smaller, and, in most cases, crushed.

Sample N - 7 - 2 (Figure 64) was taken approximately 800 feet east of N - 7 - 1. In hand specimen this rock shows more shearing than the previous rocks. The large feldspar phenocrysts have been fractured and separated by a shear that has developed at right angles to the long direction of the grains. The outcrop represents one of the rare instances where cleavage is seen to cut the primary bedding (Figure 54, Plate XXXI). In thin section the rock is extremely deformed and flowage has occurred within the matrix where sericite and biotite are common components. Individual mica bands flow around quartz mosaics and fractured feldspar phenocrysts. A notable feature of Figure 64 is the tendency of the long feldspar phenocrysts to be rotated into the plane of the newly developing slip cleavage. Similar to the feldspar phenocrysts quartz mosaics, evident in the previous slide, have been partially rotated into the plane of the newly developing cleavage with an apparent coarsening of grain.

Figure 65 represents a thin section of the rock sample N - 7 - 3, which was collected at a distance of 650 feet east of N - 7 - 2. In the outcrop bedding and cleavage are seen to be almost at right angles and both well-developed (Figure 54, Plate XXXI). The bedding is accentuated by the occurrence of alternating dark and light bands of chlorite-rich and feldspar-rich layers respectively. The newly developed slip cleavage is prominent as closely spaced planes. Whereas in the former two cases feldspar grains were seen to transect the cleavage planes, such is not the case here. In thin section (Figure 65) feldspar phenocrysts have been almost completely destroyed and are made to stand out through staining. Individual fragments appear to be randomly oriented and show features suggestive of albitization. In contrast to the feldspars, quartz shows a high degree of reconstitution (Figure 65), and vein type segregations are starting to be prevalent along the slip cleavage planes.

Sample N - 7 - 4 (Figure 66) was collected 550 feet east of N - 7 - 3 and represents the maximum schist development seen in the sequence. The schistosity is exemplified by the presence of abundant chlorite, sericite, and biotite. Small fragments of feldspar and quartz are abundant with their long directions parallel to the schistosity, and to the direction of the slip cleavage.

PLATE XXXVI : PHOTOMICROGRAPHS OF QUARTZ-MICA SCHIST DEVELOPMENT.

Figure 63. Stained thin section.Crossed nicols.Sample N - 7 - 1, from near Television tower. Massive type augen schist. Abundant perthitic K-feldspar(black) and embayed quartz phenocrysts(grey and white). The original bedding parallels the schistosity from left to right. Matrix has been recrystallized and feldspar phenocrysts have been fractured.

Figure 64. Same sequence as Figure 63. Sample N - 7 - 2. Stained. Crossed nicols.Rock has been deformed by a slip cleavage developed at right angles to the original bedding. Bedding: east-west.Cleavage: north-south. Large K-feldspar phenocrysts are fractured,separated,and are being rotated into the plane of the cleavage.

# PLATE XXXVI

Figure 63 4·2 x

Figure 64 4·2 x

PLATE ~~XXXVII : PHOTOMI~~CROGRAPHS OF QUARTZ-MICA SCHIST DEVELOPMENT.

Figure 65. Same sequence from Figures 63 and 64. Stained thin section. Crossed nicols. Sample N - 7 - 3. Slip cleavage planes are pronounced(east-west). Movement along the slip cleavage is indicated by the sericite band parallel to the bedding (north-south). The large feldspar phenocrysts from Figures 63 and 64 have been reduced to small fragments (dark). Quartz phenocrysts have also been highly crushed and separated. Matrix is starting to segregate into quartz-rich and sericite-rich bands.

Figure 66. Same sequence as Figures 63,64 and 65. Stained thin section. Crossed nicols. Sample N - 7 - 4. Near final stage in production of a quartz-sericite schist from an augen schist by dynamic metamorphism.Slip cleavage is north-south. Bedding completely destroyed. Slip cleavage planes are closely spaced. Relic feldspars (black) and quartz(white) phenocrysts lie with their long direction parallel to the schistosity planes.

# PLATE XXXVII

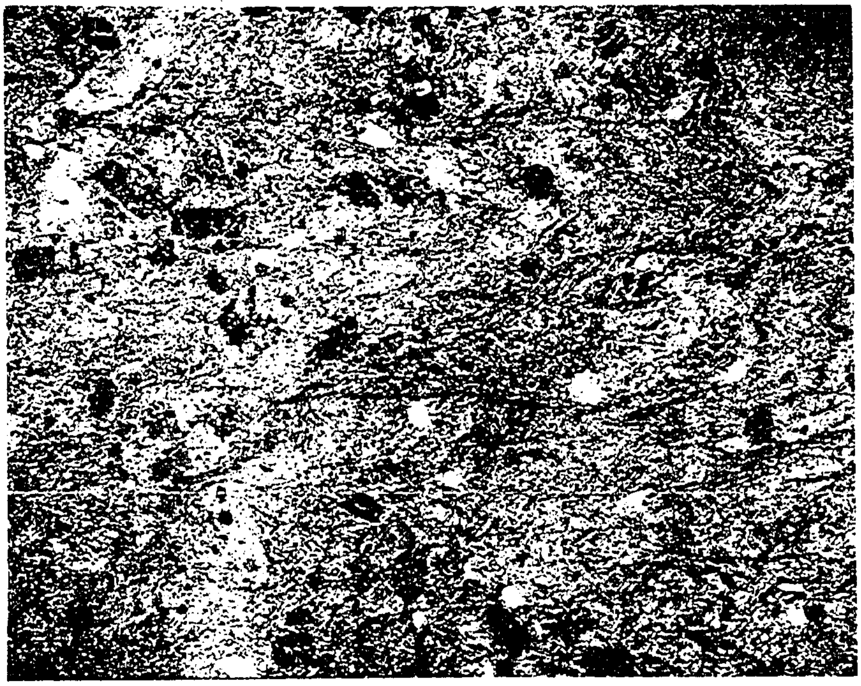

Figure 65 4·2 x

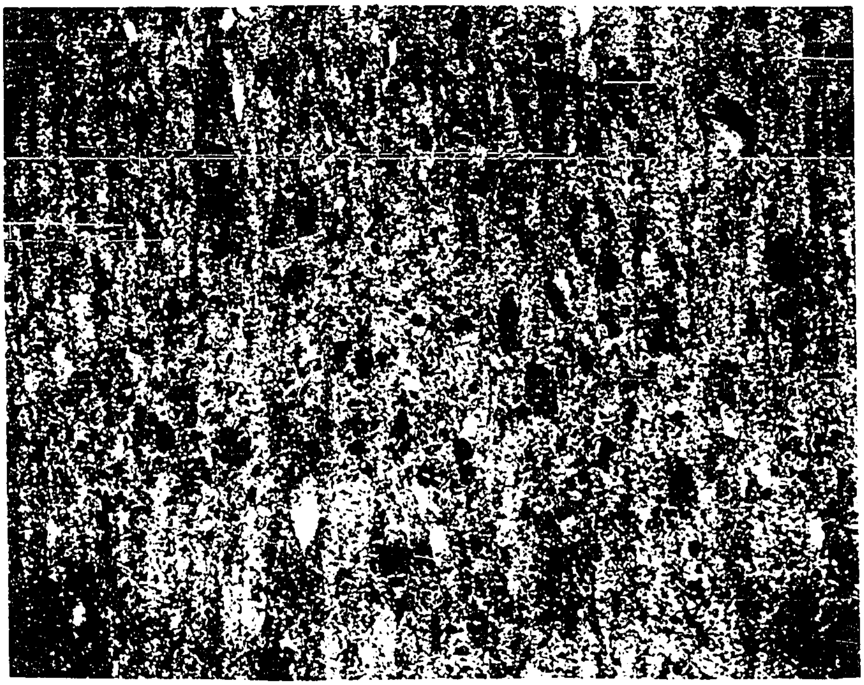

Figure 66 4·2 x

Quartz and mica minerals have been segregated in the matrix and the rock approaches a quartz-sericite schist.

In this action the tendency has been much as described by Pearce (1963), with phenocrysts being reduced in grain size through mechanical breakdown, and the matrix being coarsened through neo-crystallization.

Porphyroblasts

Albite is the stable sodium-bearing mineral in the greenschist facies. Within the more highly sheared rocks, metamorphism has promoted the development of small albite porphyroblasts in association with quartz augen (Figure 59, Plate XXXIV). These have formed either as a response to the breakdown of former feldspar phenocrysts or from the crystallization of albite in areas of low chemical potential. In the same rocks, biotite also forms porphyroblasts as elongated and platy structures parallel to the planes of schistosity.

Metasomatism

Thin section evidence indicates that metasomatism has been active on a small scale. The abundance of secondary quartz is one of the best criteria. Quartz is prevalent in low pressure areas, such as cracks in the phenocrysts, in shadow areas of augen, and in areas of rotational movement. On a larger scale, metamorphic differentiation has promoted the development of quartz veins in the rocks.

Alteration of feldspar, with the production of micas, is pronounced. In this process potasium moves into the mica structures from the perthitic feldspars, with release of silica and sodium. The redistribution of silica is well documented, but the redistribution of sodium is less well known. However, sodium is seen forming stable albite grains and forming rims around larger potash grains.

It has been postulated by other observers that the sodium has migrated from the volcanic augen schists into the pyroclastic rocks. It is then interesting to note the dominance of potassium over sodium in most augen schists which appear in chemical analyses (Loudon, 1960; Pearce, 1963). It would then appear that much of the soda may have migrated out of the rocks, but this has not been documented by chemical analysis.

It should also be pointed out that the abundance of chequer-board albite is also indicative of soda migration, providing a metasomatic origin is accepted for the mineral.

The differential retention of potassium compared to sodium is to be expected in view of their relative mobilities which is a reflection of the smaller ionic radius of sodium (0.98Å) to potassium (1.33Å). Orville (1962) indicates that during a rise in temperature and the establishment of a thermal gradient that potassium will migrate ~~to the cooler areas of a rock~~ mass and sodium will migrate to the hotter areas.

Conclusion

In summary, the significance of dynamic metamorphism has been to produce a low temperature mineral assemblage from a high temperature assemblage, to develop the augen schists, and to finally destroy the augen schists by further shearing, with the development of quartz-mica schists. Metasomatism has occurred on a local scale, and the evidence gained from the petrographic study indicates that the effects have been local.

## Conclusions

As a result of this study several conclusions are made concerning the origin of the augen schists as related to acid volcanic rocks. These conclusions and observations are summarized below.

1. Textural evidence indicates that the majority of rocks of the augen schist unit are representative of tuffs. Differences in rock type, differences in original depositional environments, surface weathering and varying degrees of dynamic metamorphism account for the variations seen within the rocks classed as augen schists.

2. Metamorphism is dynamic and representative of shearing stresses set up during ~~periods of deformation.~~ Various rock units have reacted differently to the stresses.

3. Massive augen schists in the area around the Brunswick properties and the Heath Steele properties are thought to be indicative of ash flow origin, whereas the more schistose types in the N - 6 map area are indicative of airborne ash deposits. This conclusion is further substantiated by the local geology, where the centers of extrusion are in close association with rocks of the southeast area.

4. Textural and mineralogical evidence and metamorphic history indicates that the augen schists mapped as "dacites" might be representative of subaqueous flows.

5. The preponderance of potassium over soda in the augen schists (Loudon, 1960; Pearce, 1963) results either from a primary potassium-rich magma, melting of sediments forming the magma, potassium metasomatism, weathering prior to burial, or removal of sodium by metamorphic differentiation.

6. Intrusive rhyolites are recognized as the centers of extrusion. Mineralogical evidence indicates a close tie between these rocks and the augen schists. Massive augen schists may be derivatives.

7. Minor metasomatism has occurred in response to the dynamic metamorphism and the production of quartz-sericite schists from rhyolite flows and tuffs.

8. Metamorphism has been responsible for the exsolution of high temperature feldspars to low temperature forms, typical of quartz keratophyres. Subsequent minor mobiliation of potassium, sodium and silica within the feldspar grains, and in the immediate surroundings led to the production of patch perthitic structures.

9. The original textures of most of the augen schists have been destroyed and metamorphic textures are prevalent.

10. Textural studies of certain augen schists show that these particular rocks were of an original pyroclastic nature. The original rock is thought to have originated as a pyroclastic flow, or from the deposition of ash material washed into shallow basins from surrounding highlands.

11. During extreme shearing albite phenocrysts are destroyed by crushing and alteration. However, since albite is the only stable sodium mineral in the greenschist facies, it forms small pophyroblasts.

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## LEGEND

**PALÆOZOIC**

**PENNSYLVANIAN**

9 — *(Undivided)*

**DEVONIAN**

*Mafic intrusive rocks*

*Felsic intrusive rocks*

**SILURIAN**

**MIDDLE SILURIAN**

**CHALEUR BAY GROUP**

6 — *(Undivided)*

**ORDOVICIAN**

**MIDDLE ORDOVICIAN**

**TETAGOUCHE GROUP (1-5)**

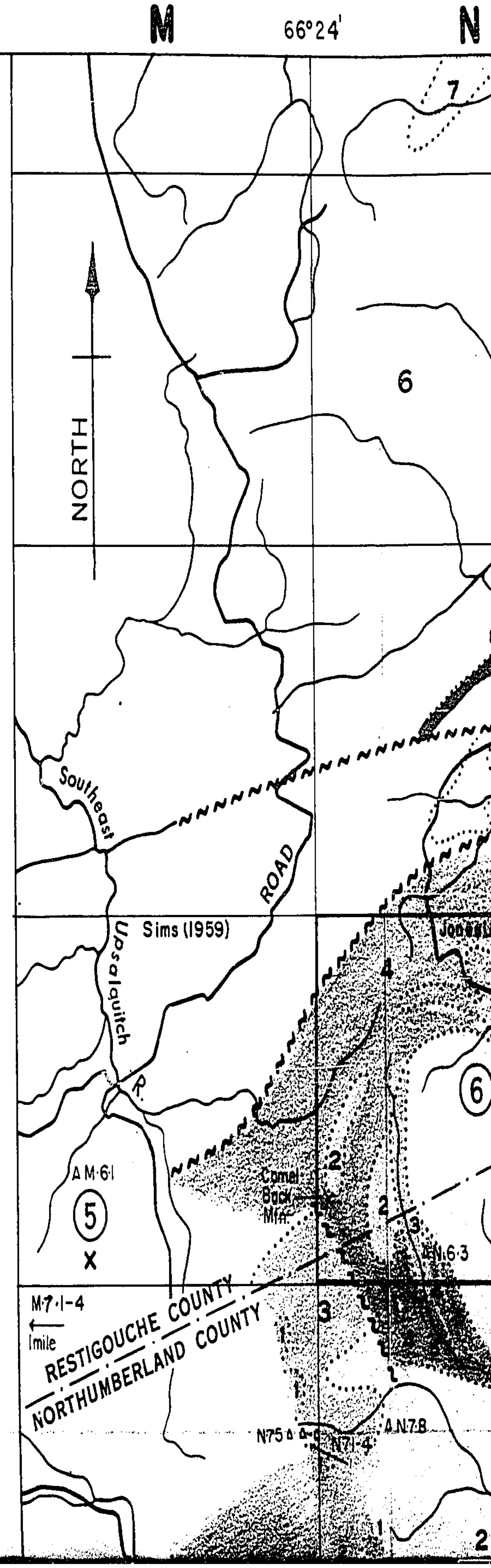
*Slate division*

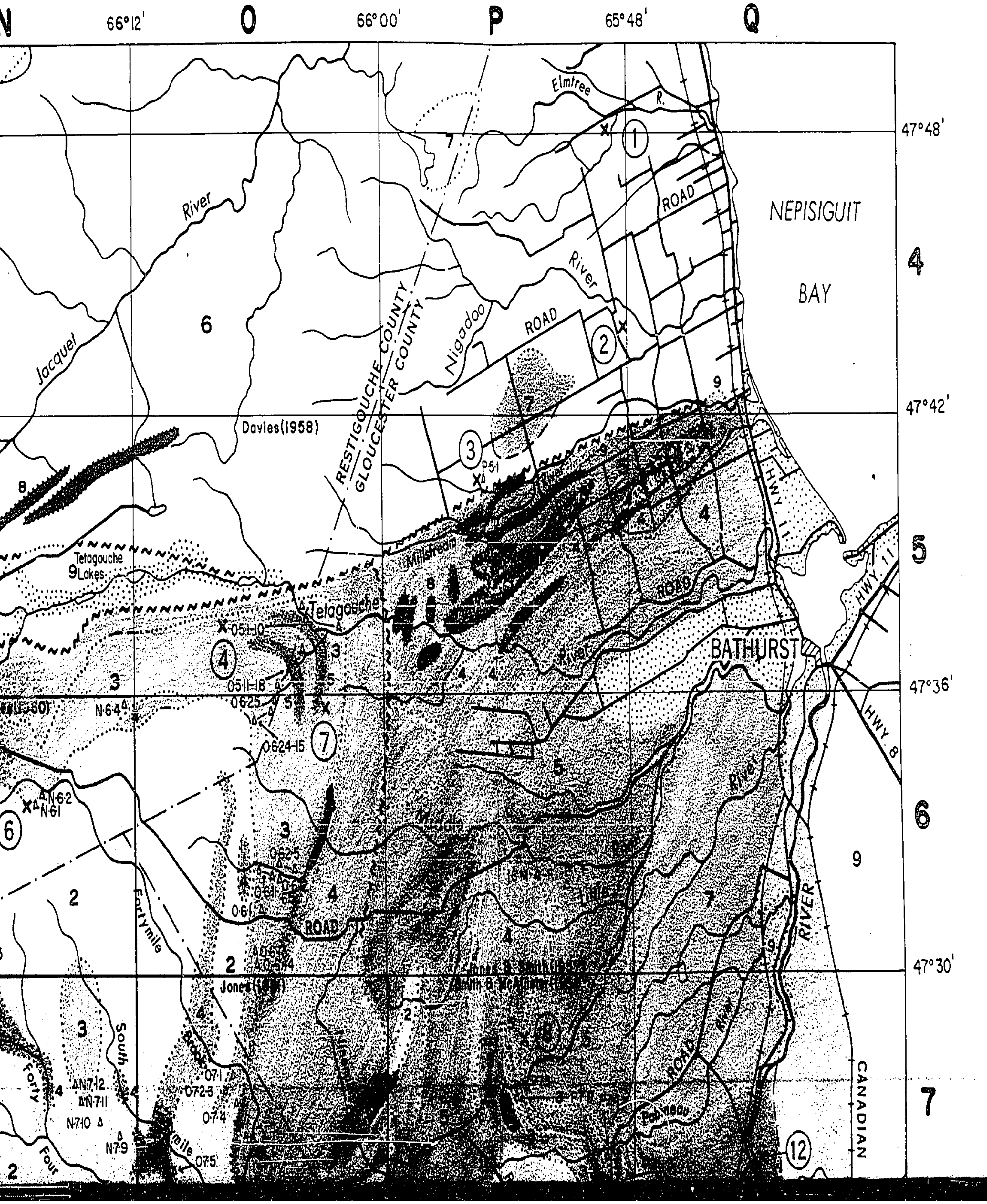
4 — *Greenstone division*

3 — *Porphyry division*

2 — *Felsic volcanic division*

1 — *Siliceous metasedimentary rocks*

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66°12'
O
66°00'
P
65°48'
Q
47°48'
47°42'
47°36'
47°30'
4
5
6
7
Elmtree
R.
ROAD
NEPISIGUIT
BAY
River
Jacquet
River
Nigadoo
River
RESTIGOUCHE COUNTY
GLOUCESTER COUNTY
Davies(1958)
Tetagouche
Lakes
Millstream
Tetagouche
HWY 11
HWY 8
BATHURST
Middle
Fortymile
South
Forty
Four
Pabineau
RIVER
CANADIAN

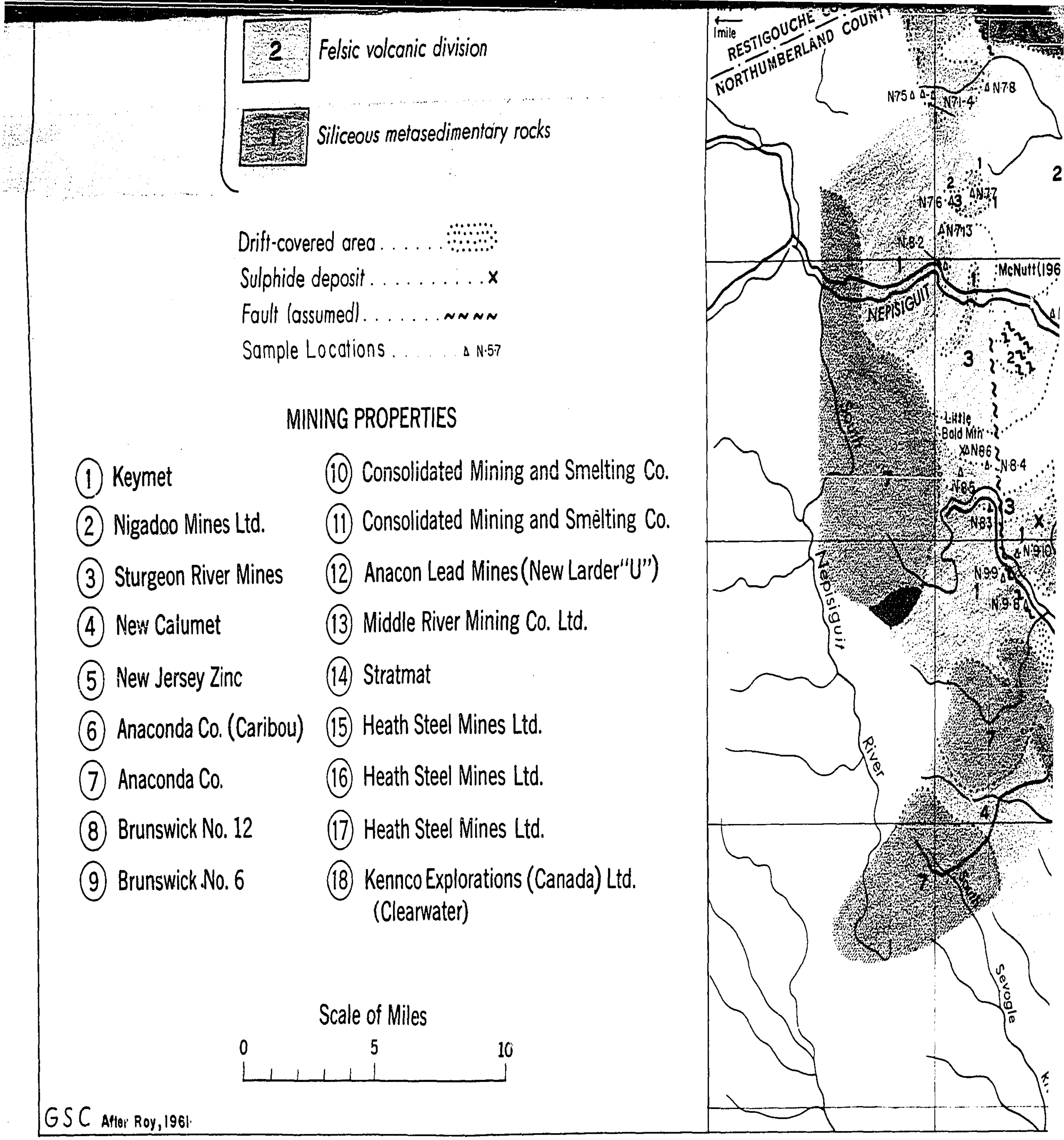
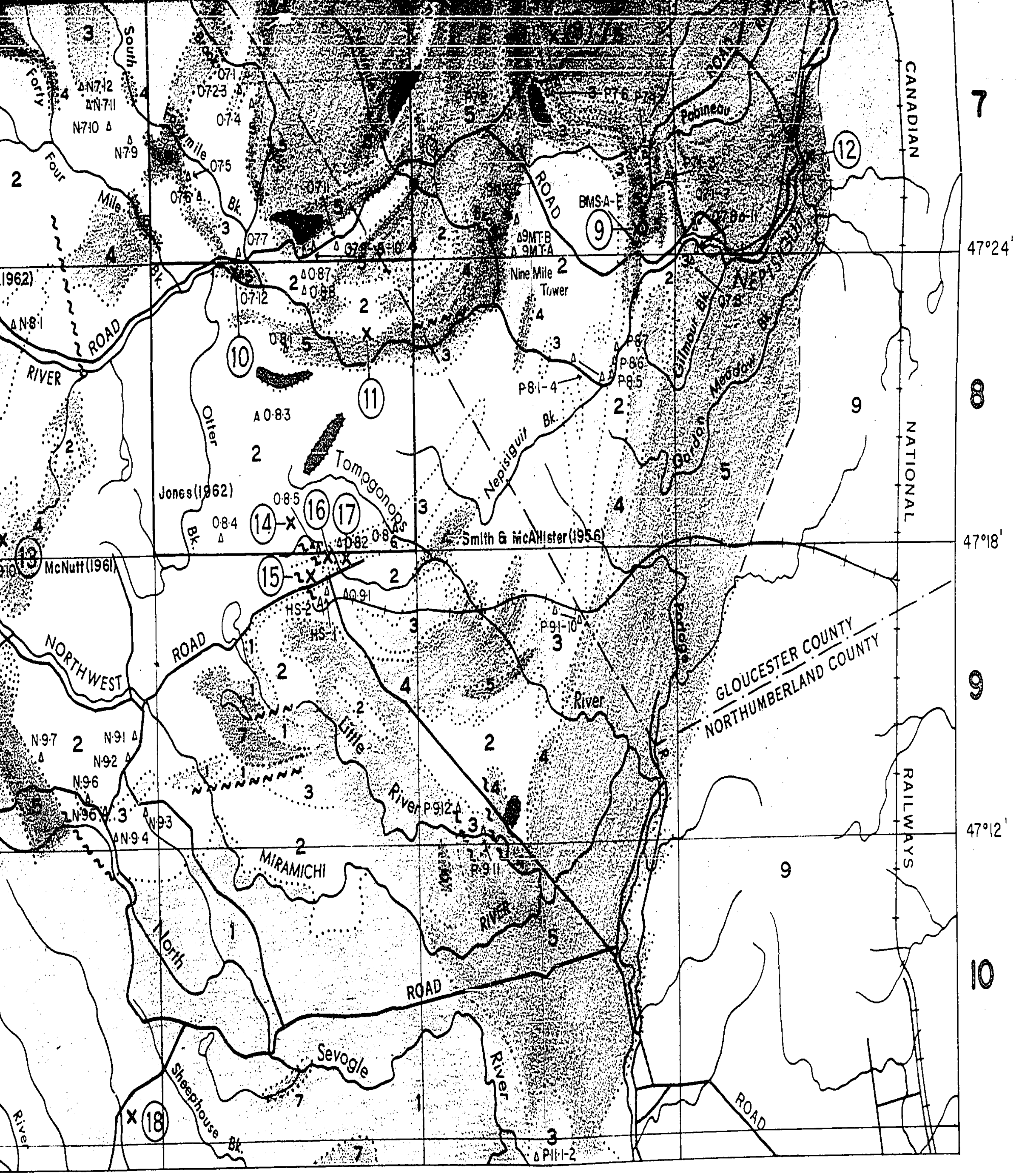



PLATE I: General




al Geology of the Bathurst — Newcastle District of New Brunswick

# PLATE II

## LEGEND

### SILURIAN and/or DEVONIAN

GABBRO

### SILURIAN

PRINCIPALLY SEDIMENTARY ROCKS

5

- A CONGLOMERATE
- B LIMESTONE
- C GRAYWACKE, MINOR TUFFACEOUS ROCKS

### ORDOVICIAN

PRINCIPALLY QUARTZ TRACHYTE

4

- A QUARTZ TRACHYTE
- B ANDESITE, BASIC TUFF
- C GRAPHITIC SCHIST, MINOR SEDIMENTARY ROCKS
- D RHYOLITE, PORPHYRITIC RHYOLITE
- E JASPER

PRINCIPALLY RHYOLITE, PORPHYRITIC RHYOLITE

3

- A RHYOLITE, PORPHYRITIC RHYOLITE
- B QUARTZ SERICITE SCHIST
- C CHLORITIC AND SERICITIC QUARTZ AND/OR FELDSPAR AUGEN SCHIST
- D ANDESITE, BASALT
- E COARSE BASIC VOLCANIC ROCKS
- F GRAPHITIC SCHIST, MINOR SEDIMENTARY ROCKS

PRINCIPALLY CHLORITIC AND SERICITIC QUARTZ AND/OR FELDSPAR AUGEN SCHIST

2

- A CHLORITIC AND SERICITIC QUARTZ AND/OR FELDSPAR AUGEN SCHIST
- B GRAPHITIC SCHIST, MINOR SEDIMENTARY ROCKS
- C ANDESITE, BASALT, BASIC TUFFACEOUS ROCKS
- D RHYOLITE, PORPHYRITIC RHYOLITE
- E CHLORITIC AND SERICITIC SCHIST, PHYLLITE
- F CHLORITIC AND SERICITIC SEDIMENTARY ROCKS
- G RED SLATES

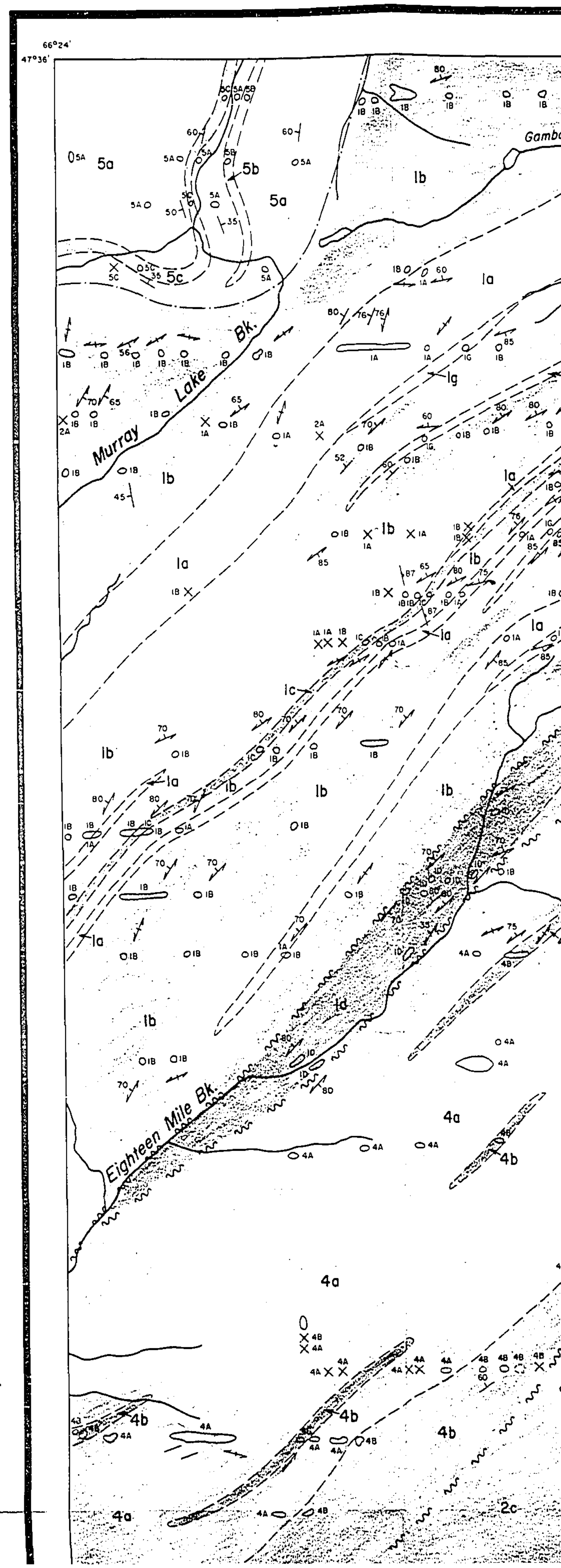
PRINCIPALLY BASIC VOLCANIC ROCKS, CHLORITIC AND SERICITIC SEDIMENTARY ROCKS

1

- A CHLORITIC AND SERICITIC SEDIMENTARY ROCKS, MINOR TUFFS
- B ANDESITE, BASALT, BASIC TUFF, MINOR COARSE GRAINED BASIC VOLCANIC ROCKS
- C COARSE GRAINED BASIC VOLCANIC ROCKS
- D GRAPHITIC SCHIST, MINOR ARGILLITE, SILTSTONE
- E CHLORITIC AND SERICITIC SCHIST, PHYLLITE
- F RHYOLITE, PORPHYRITIC RHYOLITE
- G RED MANGANIFEROUS AND HEMATITIC SLATES
- H IRON FORMATION

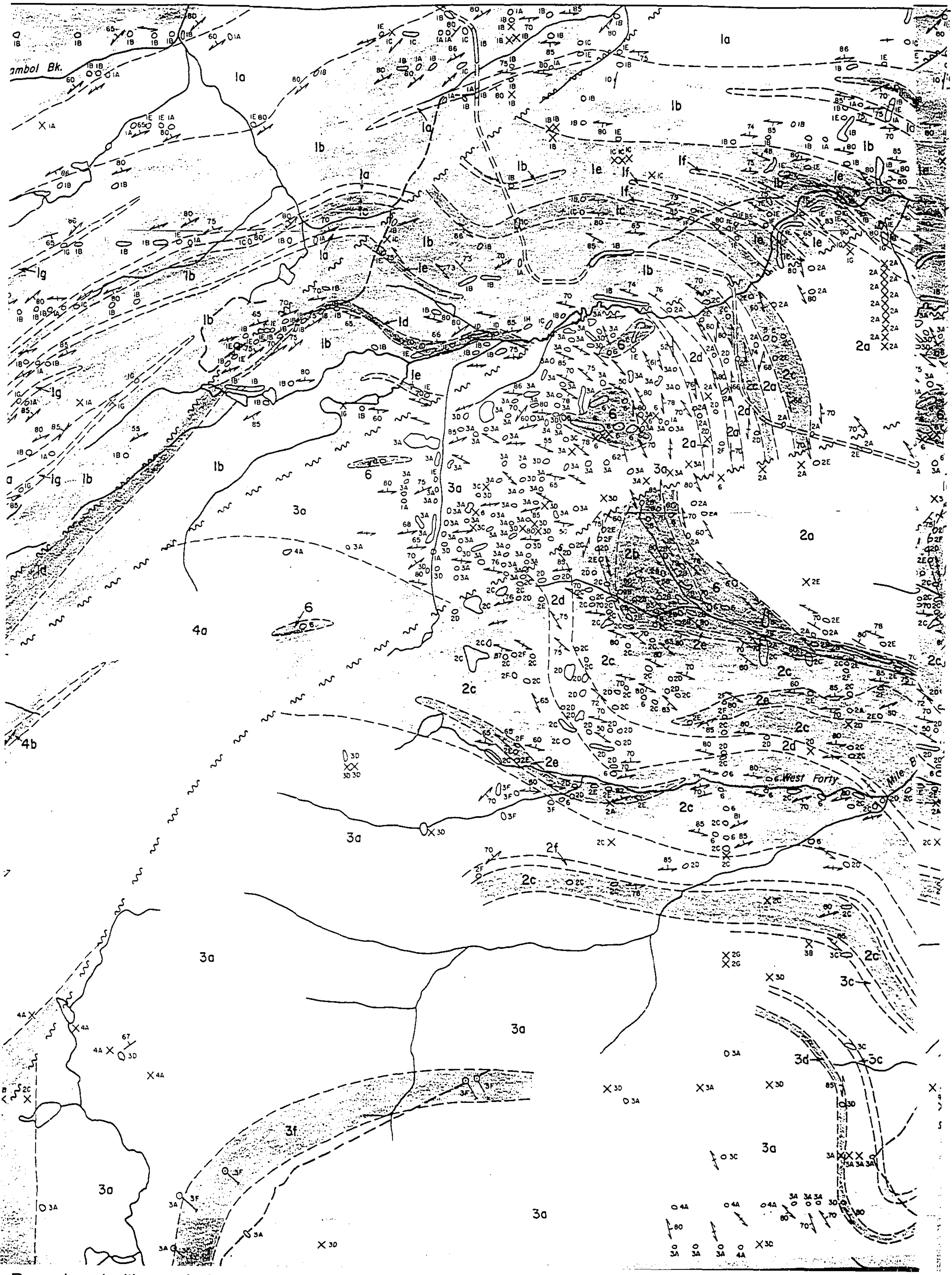
## SYMBOLS

- O3A ◌3A — ROCK OUTCROP (DEFINED, PROBABLE)
- X3A — FLOAT
- 45 — SCHISTOSITY (INCLINED, VERTICAL, DIP UNKNOWN)
- 45 — BEDDING (INCLINED, VERTICAL, DIP UNKNOWN)
- 45 — JOINTING (INCLINED, VERTICAL)
- 45 — DRAGFOLD (PLUNGE KNOWN, PLUNGE UNKNOWN)
- ASSUMED GEOLOGICAL CONTACT
- UNCONFORMITY



MI

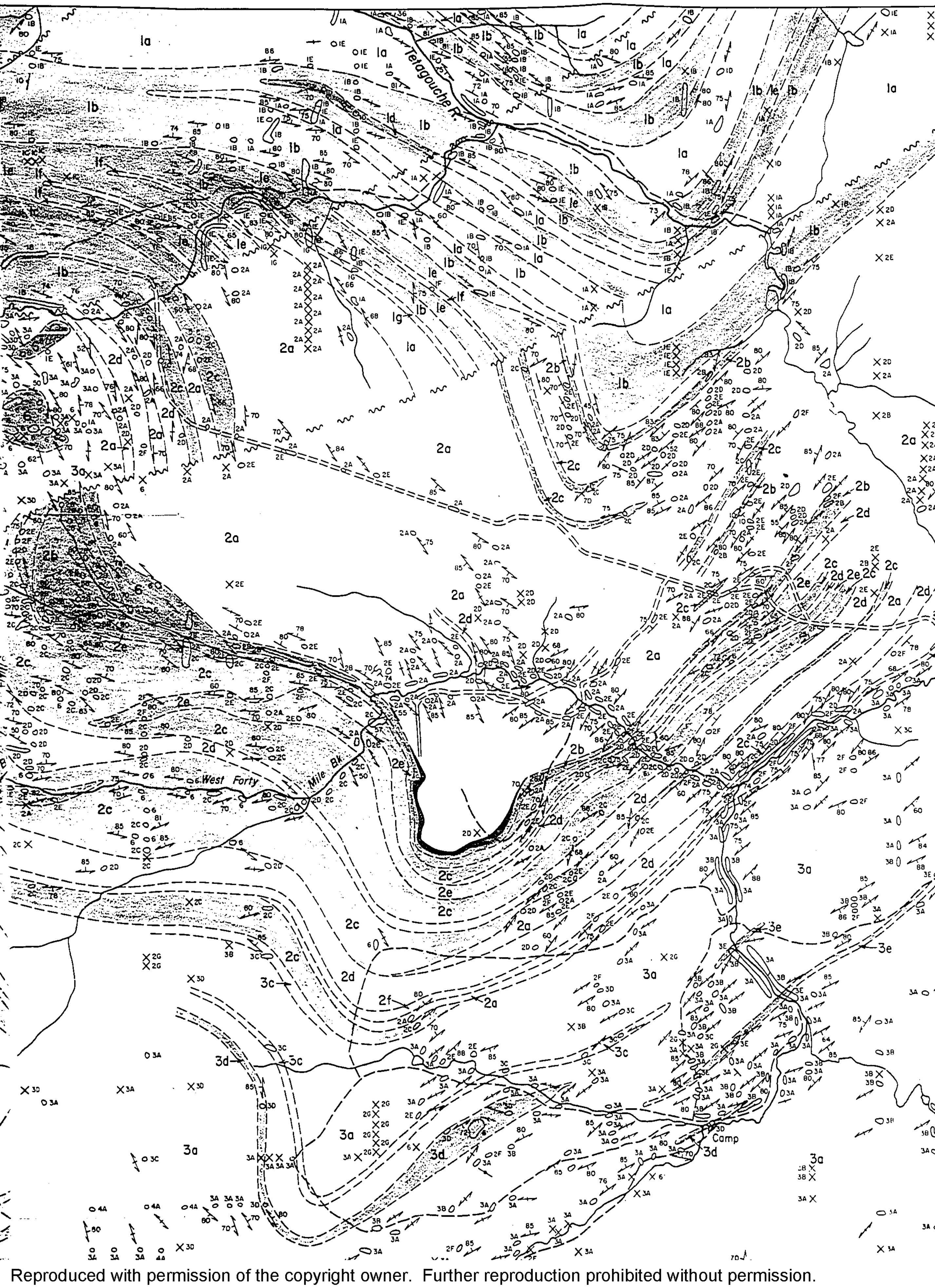
DEPAR

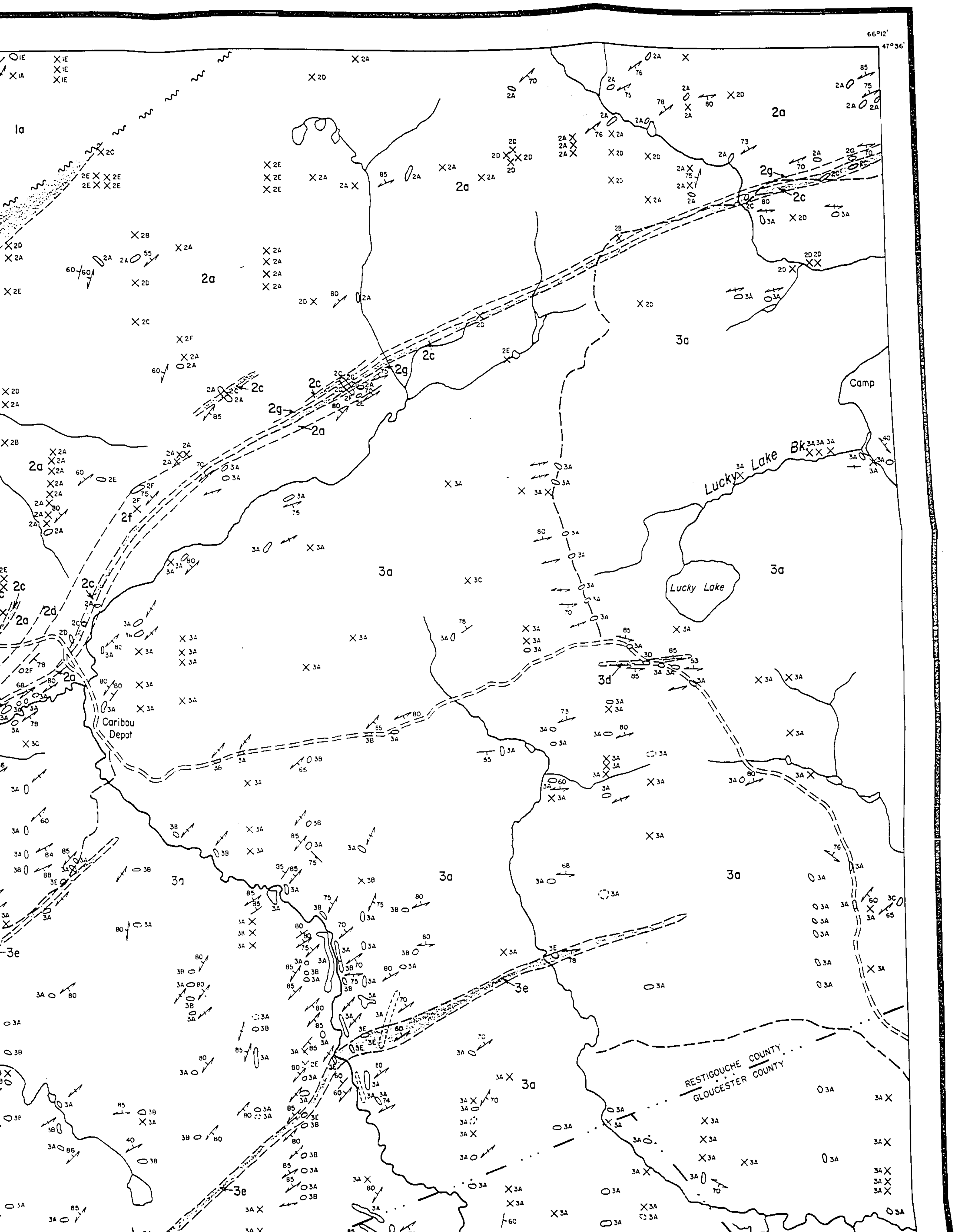


NEW BRUNSWICK

# MINES BRANCH

DEPARTMENT OF LANDS AND MINES




66°12'
47°36'
1a
2a
2c
2g
2f
2d
3a
3d
3e
Camp
Lucky Lake Bk
Lucky Lake
Caribou Depot
RESTIGOUCHE COUNTY
GLOUCESTER COUNTY

UNCONFORMITY

ASSUMED FAULT

MASSIVE SULPHIDE BODY

3A TRENCH

ADIT

DIAMOND DRILL HOLE

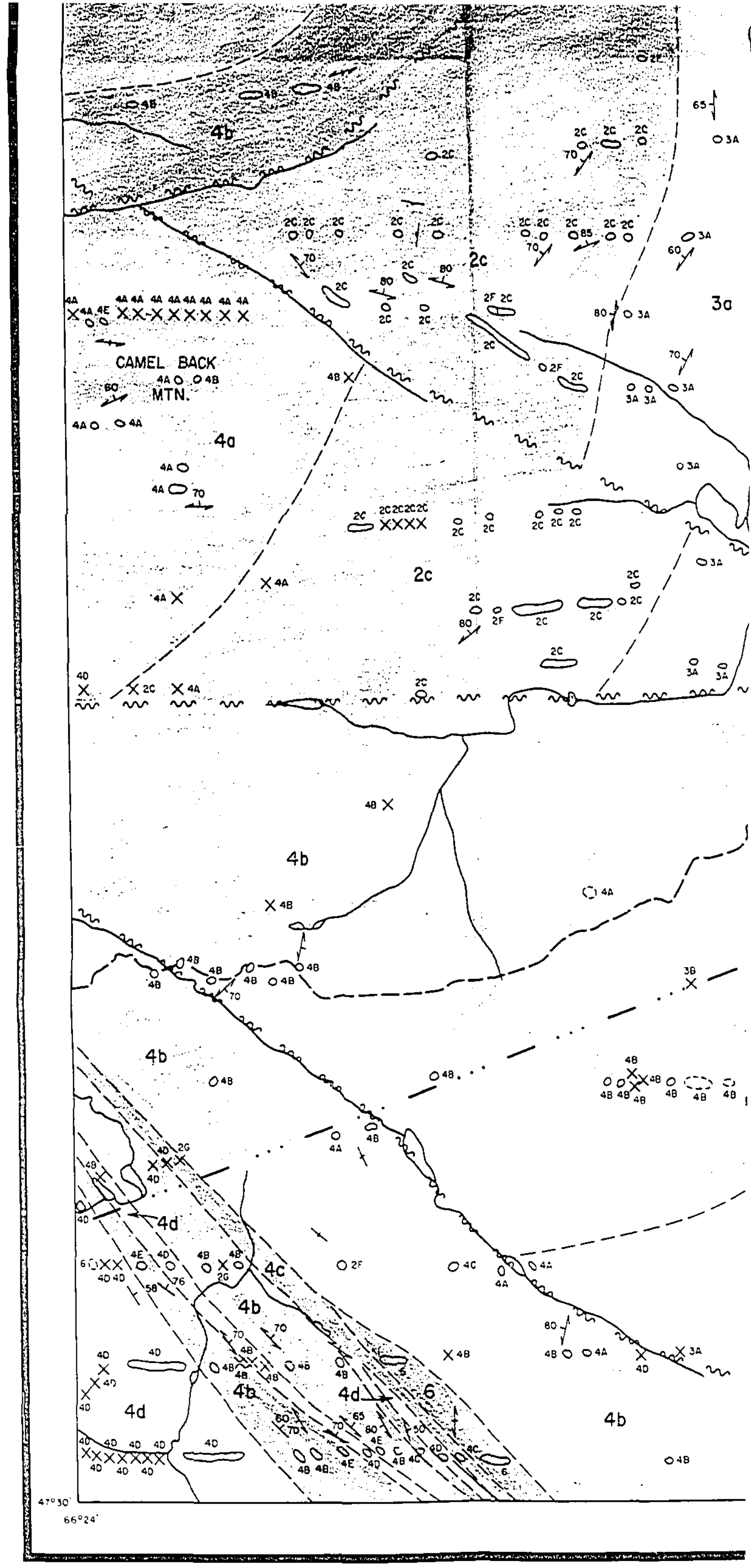
GEOLOGY BY:

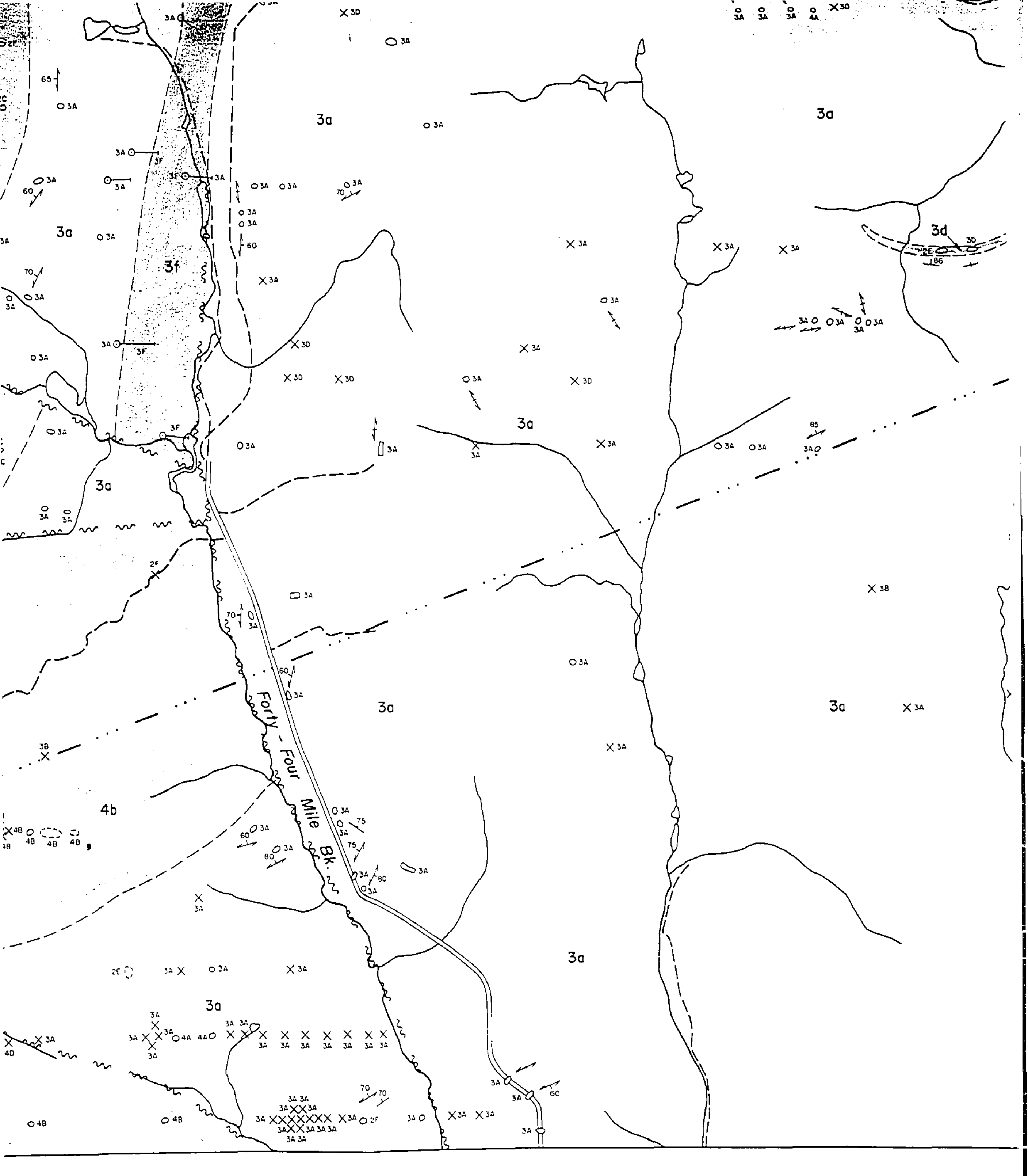
R. A. JONES (1960)
MINES BRANCH
DEPARTMENT OF LANDS AND MINES
PROVINCE OF NEW BRUNSWICK

APPROXIMATE MAGNETIC DECLINATION 23° 30'

PUBLISHED 1961

P.M. 60-3

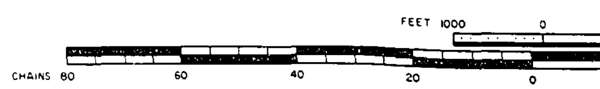


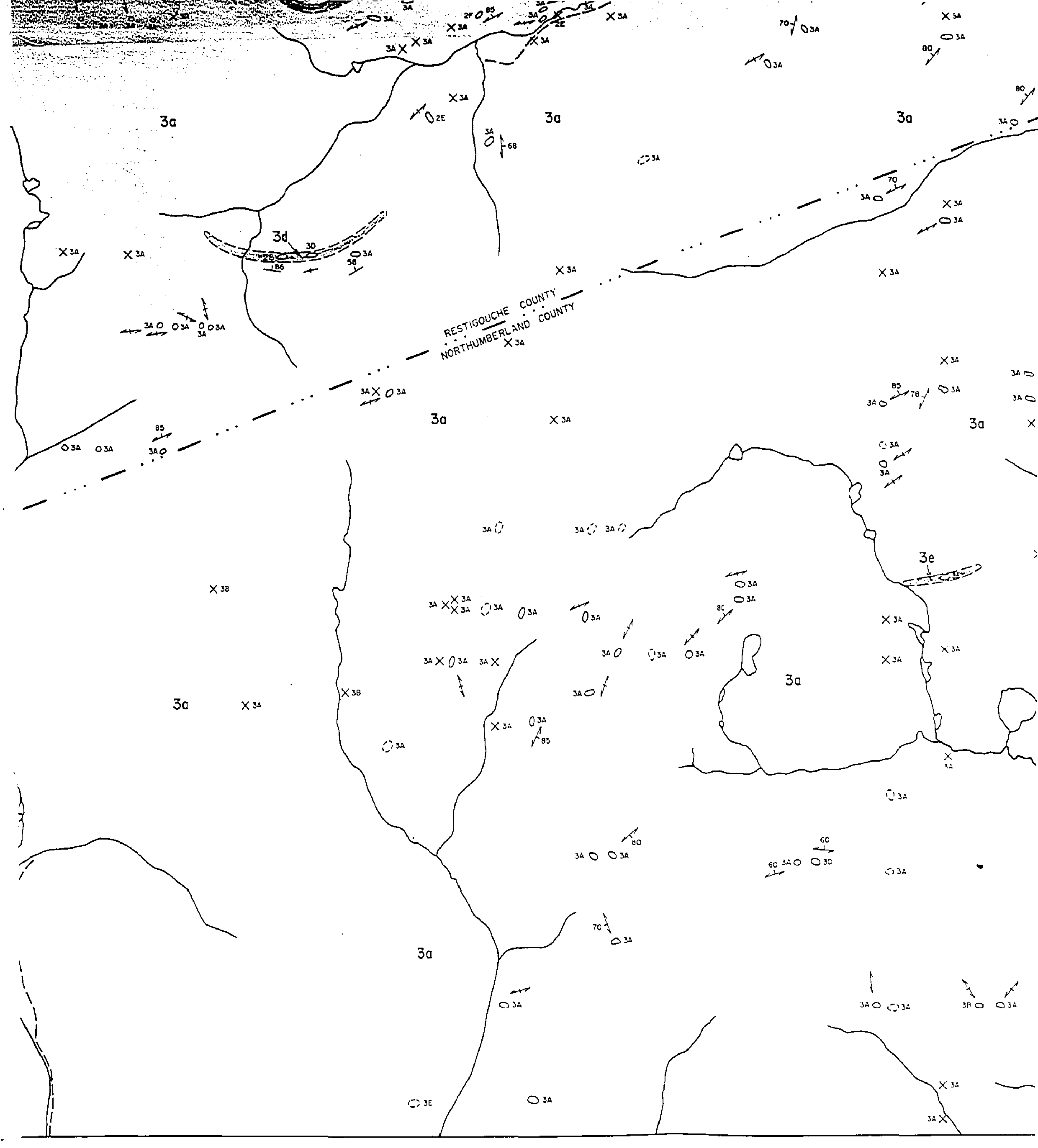



# HEAD OF FORTY MILE

## RESTIGOUCHE A

SCALE:





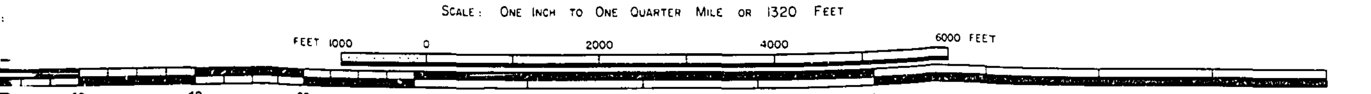

MAP AREA N - 6

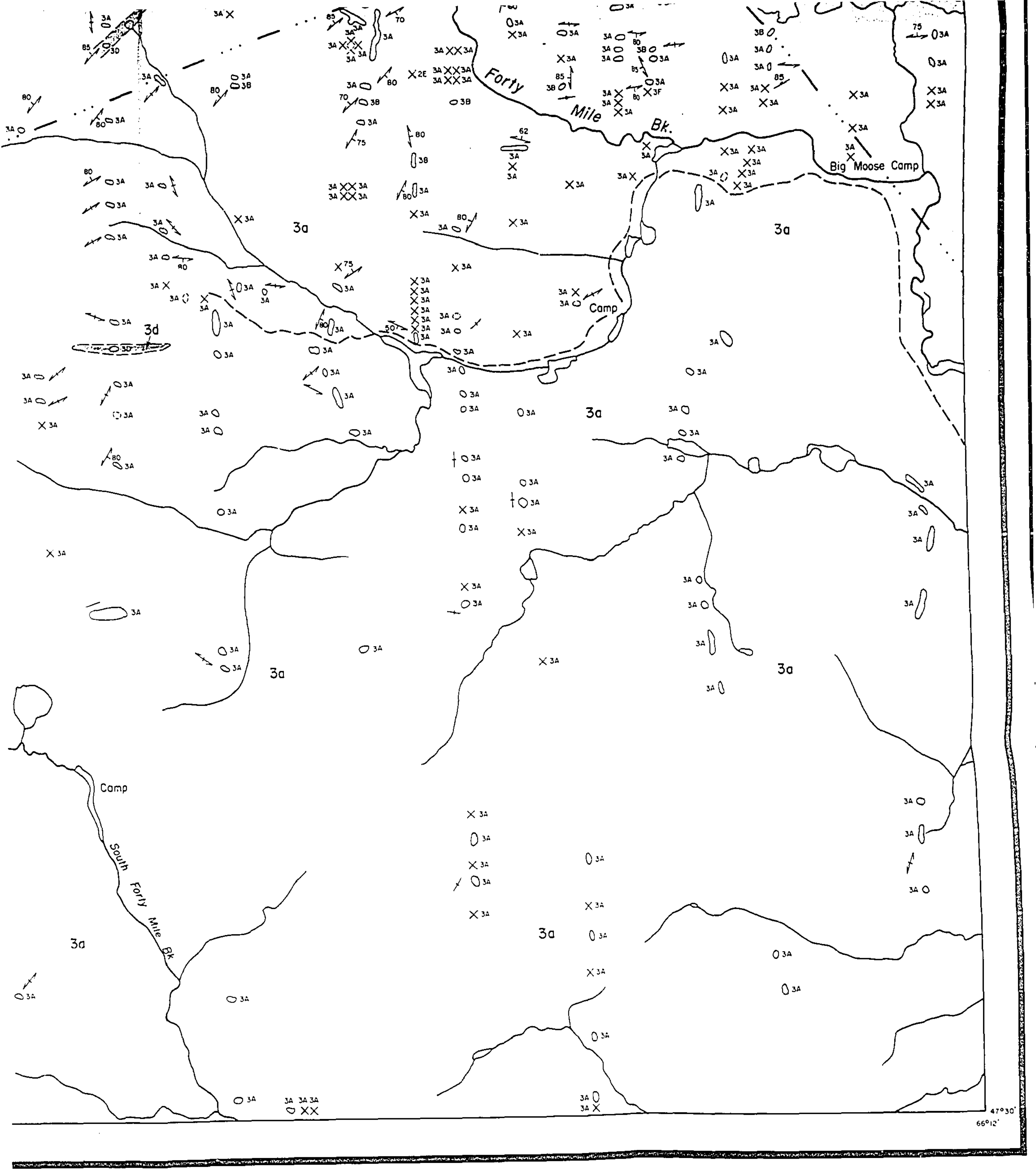
# OF FORTY MILE BROOK AND TETAGOUCHE RIVER

RESTIGOUCHE AND NORTHUMBERLAND COUNTIES

NEW BRUNSWICK

SCALE: ONE INCH TO ONE QUARTER MILE OR 1320 FEET




Forty Mile Bk.
Big Moose Camp
Camp
Camp
South Forty Mile Bk
3a
3d
47°30'
66°12'

ER

P.M. 60-3

# PLATE III

## LEGEND

### PRE - SILURIAN

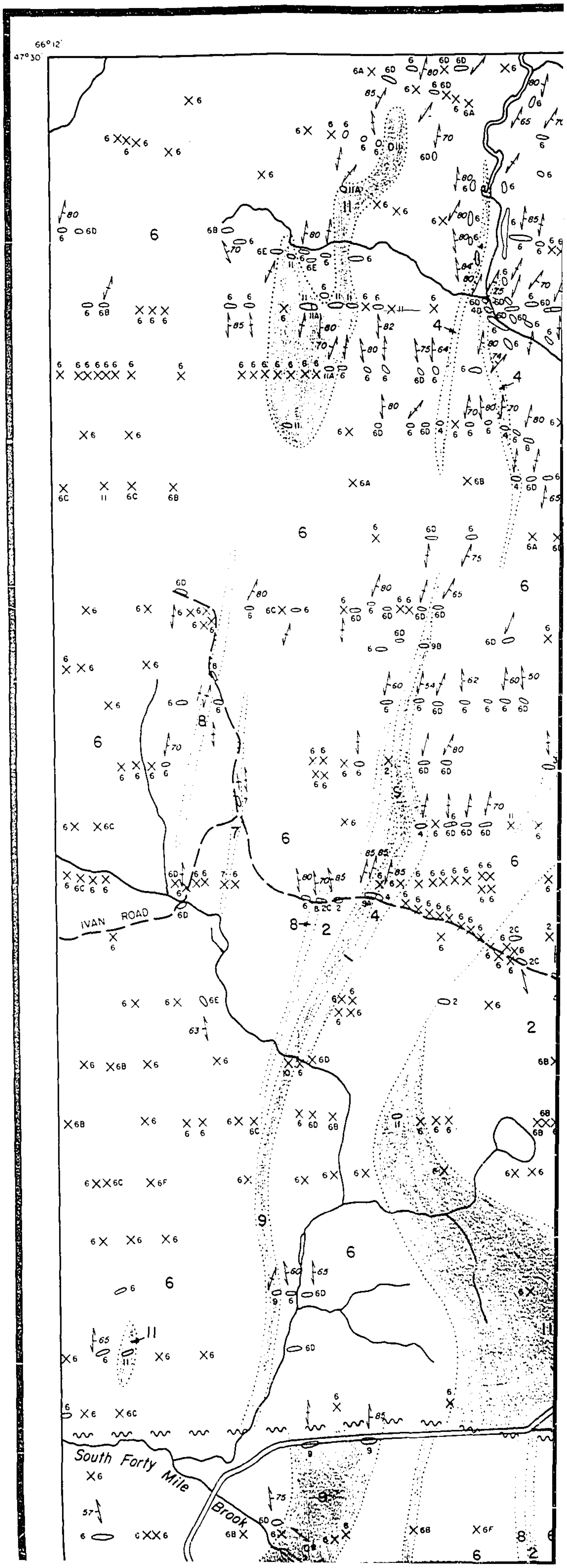
| | |
|---|---|
| 1 | *BASALT* |
| 2 | *INTERMEDIATE VOLCANIC ROCKS*<br>2A *Green felsite*<br>2B *Mafic tuffs*<br>2C *Coarse mafic volcanic rocks*<br>2D *Chloritic and/or sericitic schist*<br>2E *Basalt*<br>2F *Chert* |
| 3 | *LIGHT GREEN FELSITE*<br>3A *Andesite*<br>3B *Rhyolite and rhyolite porphyry*<br>3C *Siliceous tuffs*<br>3D *Chloritic and/or sericitic schist*<br>3E *Quartz and/or feldspar augen schist* |
| 4 | *COARSE GRAINED MAFIC VOLCANIC ROCKS*<br>4A *Andesite*<br>4B *Gabbro equivalents* |
| 5 | *CHLORITIC AND/OR SERICITIC SCHIST*<br>5A *Quartz and/or feldspar augen schist*<br>5B *Rhyolite and rhyolite porphyry* |
| 6 | *RHYOLITE AND UNDIFFERENTIATED SILICEOUS VOLCANIC ROCKS*<br>6A *Siliceous tuffs*<br>6B *Rhyolite porphyry*<br>6C *Quartz and/or feldspar augen schist*<br>6D *Chloritic and/or sericitic schist*<br>6E *Light green felsite*<br>6F *Intermediate volcanic rocks* |
| 7 | *CHLORITIC AND SERICITIC QUARTZ AND/OR FELDSPAR AUGEN SCHIST*<br>7A *Porphyritic rhyolite*<br>7B *Rhyolite*<br>7C *Quartz - sericite schist* |
| 8 | *ARGILLITE*<br>8A *Graphitic schist*<br>8B *Sericitic schist* |
| 9 | *GRAPHITIC SCHIST*<br>9A *Argillite*<br>9B *Sericitic schist* |
| 10 | *RED MANGANIFEROUS AND/OR HEMATITIC SLATE* |
| 11 | *GABBRO AND DIABASE*<br>11A *Coarse mafic volcanic rocks*<br>11B *Intermediate volcanic rocks* |

### RECENT

| | |
|---|---|
| 12 | *GLACIAL DRIFT* |

## SYMBOLS

| | |
|---|---|
| 6B | *Observed rock outcrop* |
| X 6B | *Observed float* |
| | *Schistosity (inclined, vertical, dip unknown)* |
| | *Bedding (inclined, vertical, overturned)* |
| | *Jointing (inclined, vertical)* |
| | *Attitude of dragfold* |



M

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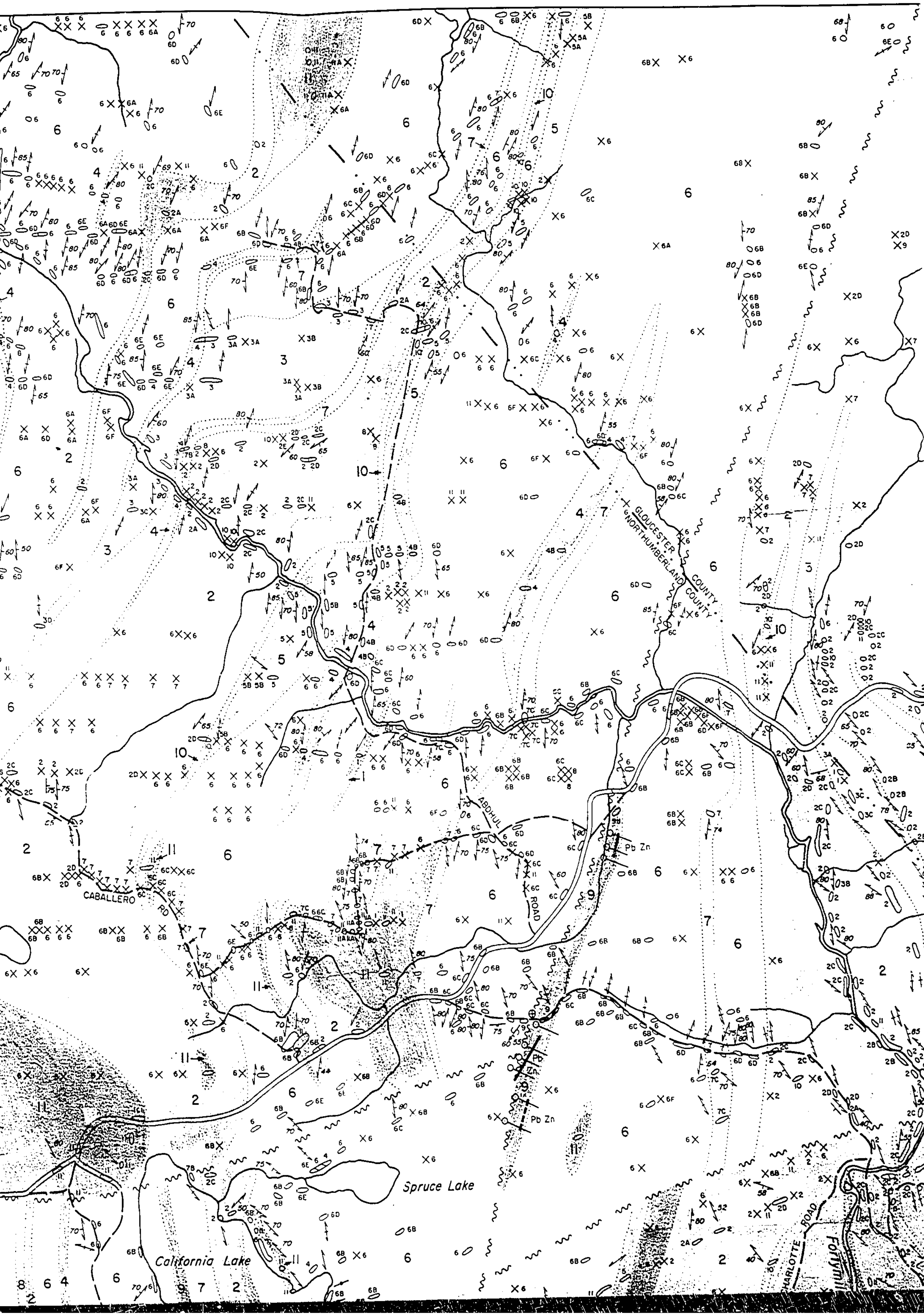
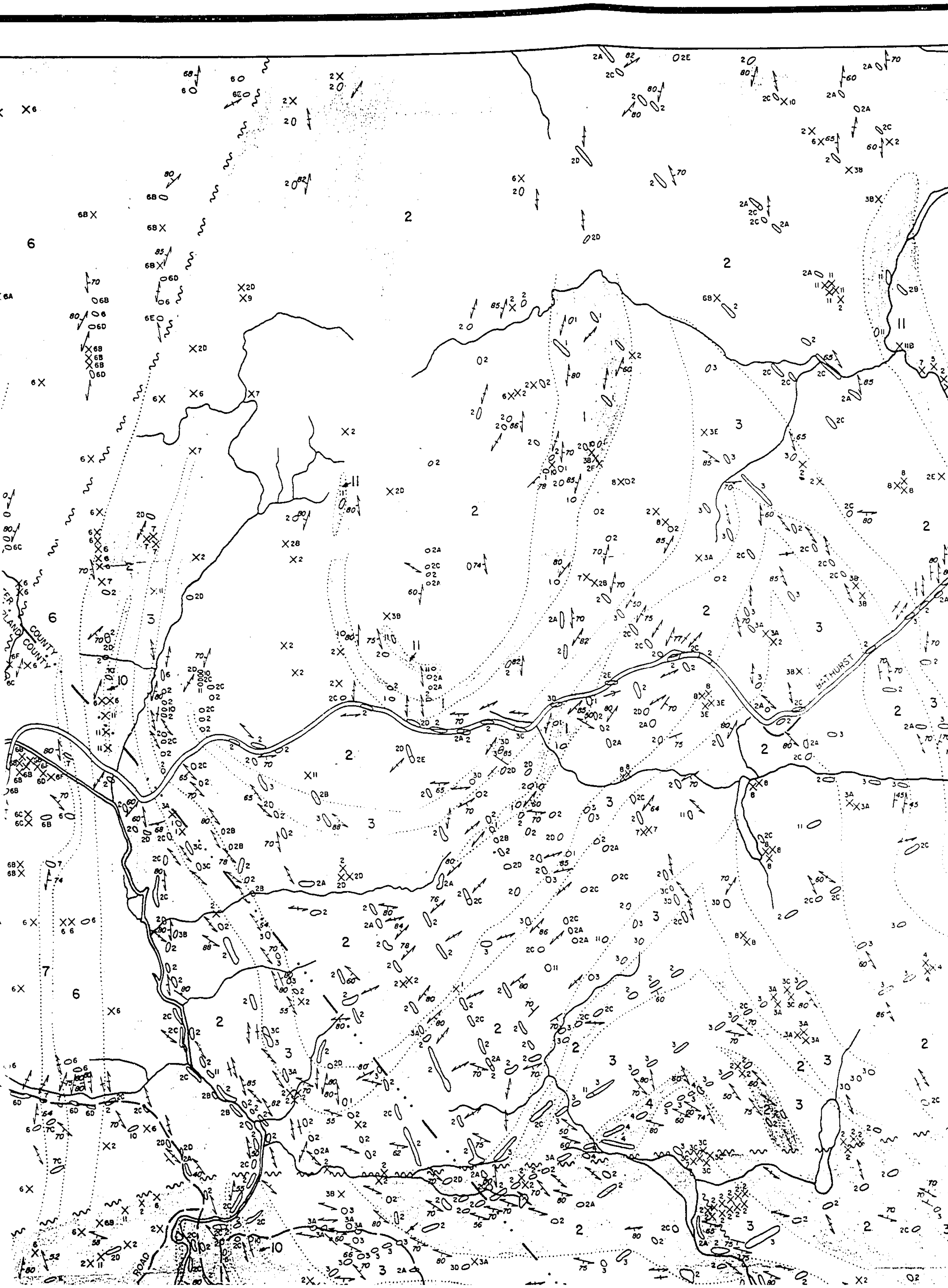


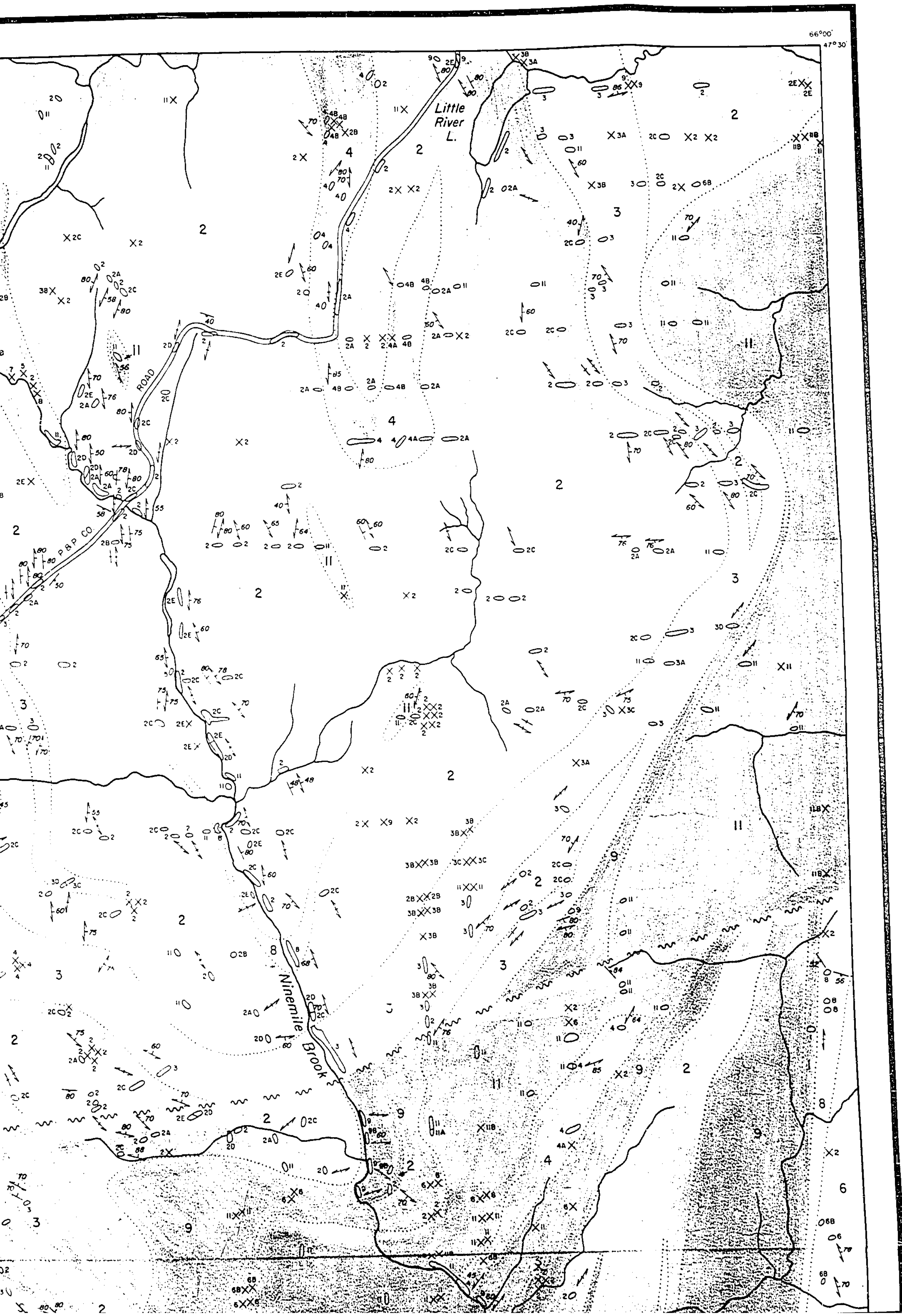
GLOUCESTER COUNTY
NORTHUMBERLAND COUNTY
ABDHUL ROAD
CABALLERO RD
Pb Zn
Spruce Lake
California Lake

NEW BRUNSWICK

# MINES BRANCH

DEPARTMENT OF LANDS AND MINES




66°00'
47°30'
Little River L.
ROAD
P & P CO.
Ninemile Brook

Jointing (inclined, vertical)

Attitude of dragfold

Assumed geological contact

Assumed fault

Glacial striae

Diamond drill hole

Sulphide body

Mineral occurrence

| | |
|---|---|
| Pb | Lead |
| Zn | Zinc |
| Fe. | Iron |

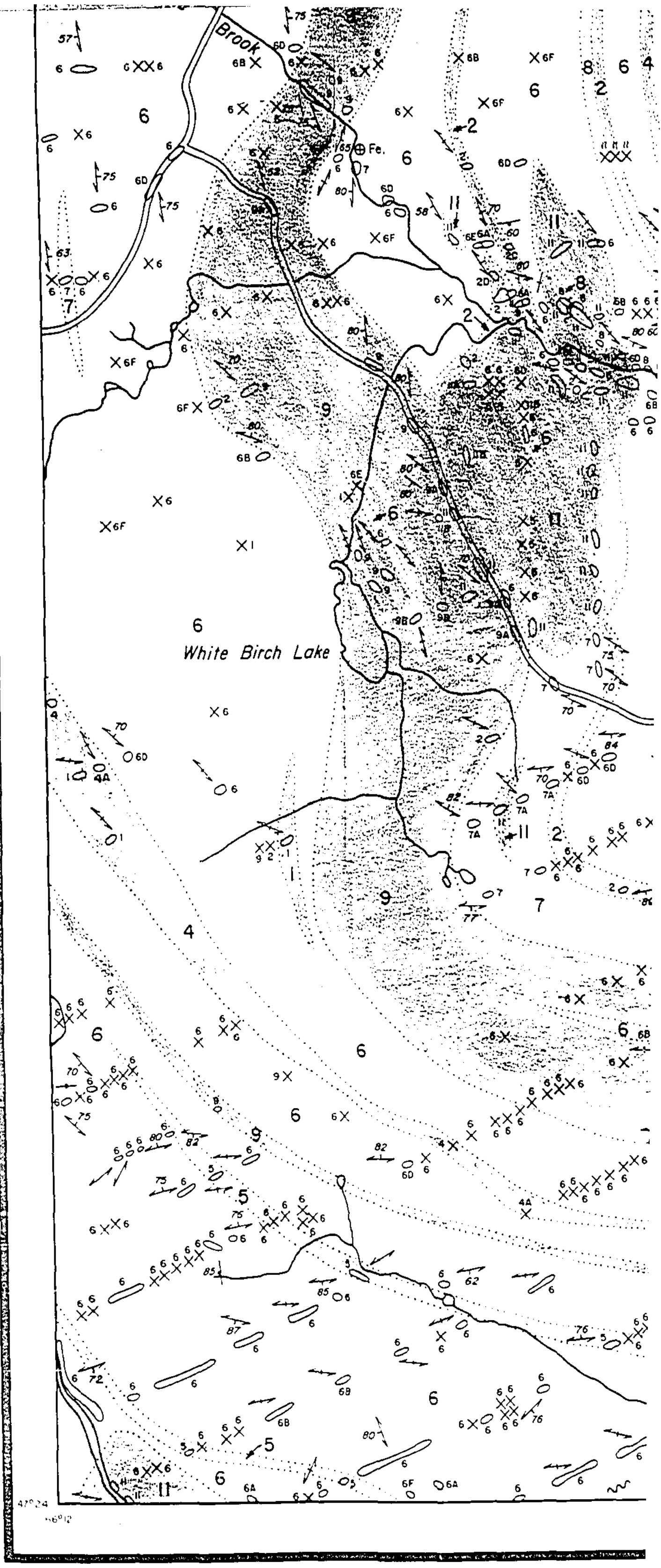
GEOLOGY BY:

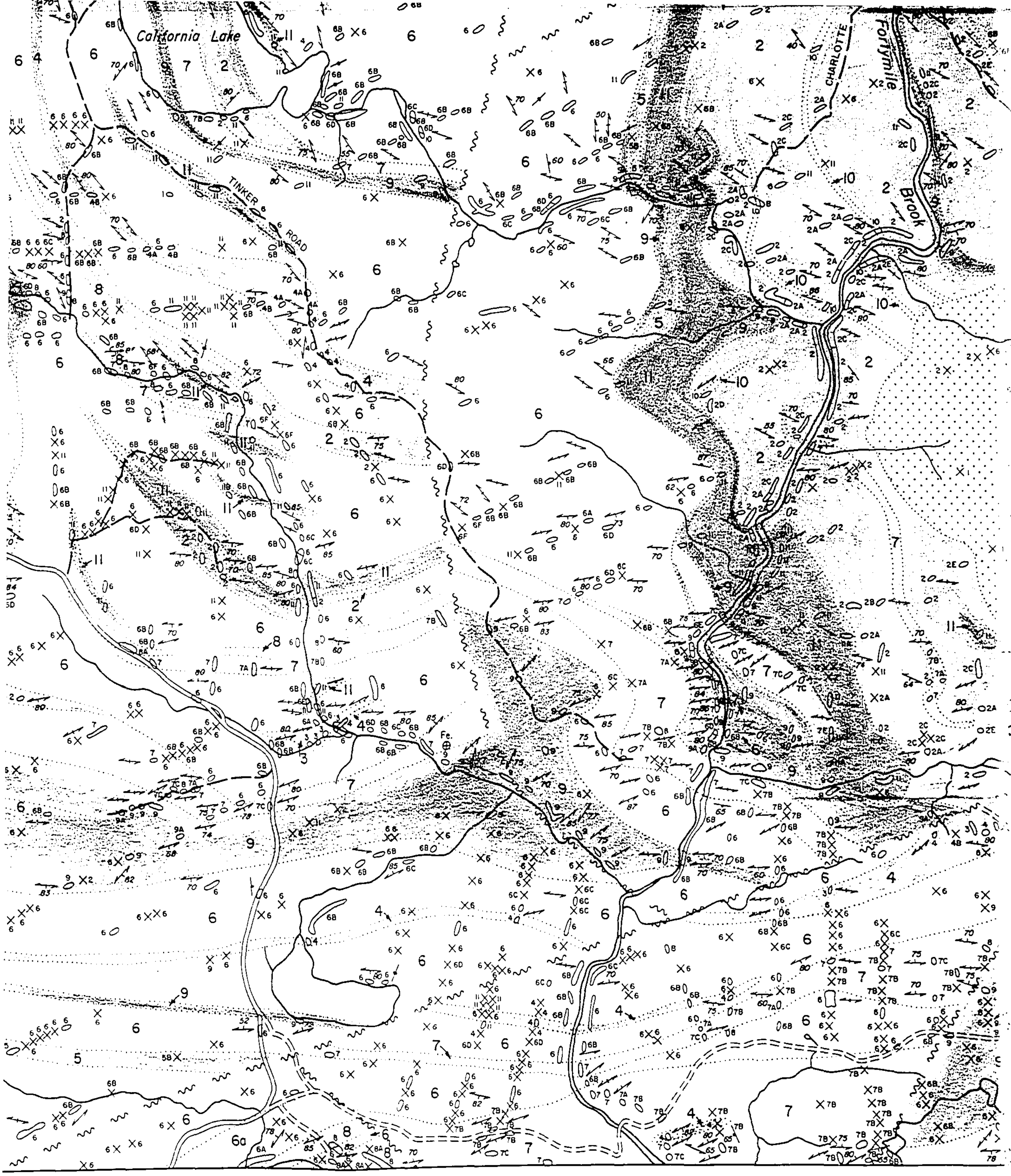
R.A Jones (1961)
Mines Branch
Department of Lands and Mines
Province of New Brunswick

Approximate Magnetic Declination 23°24' West

PUBLISHED 1963

P.M. 61-1






# PARTS OF FORT

GLOUCESTER

SCA

FEET 1000 0

CHAINS 80 60 40 20 0


MAP AREA O-7

# TS OF FORTY AND NINE MILE BROOKS

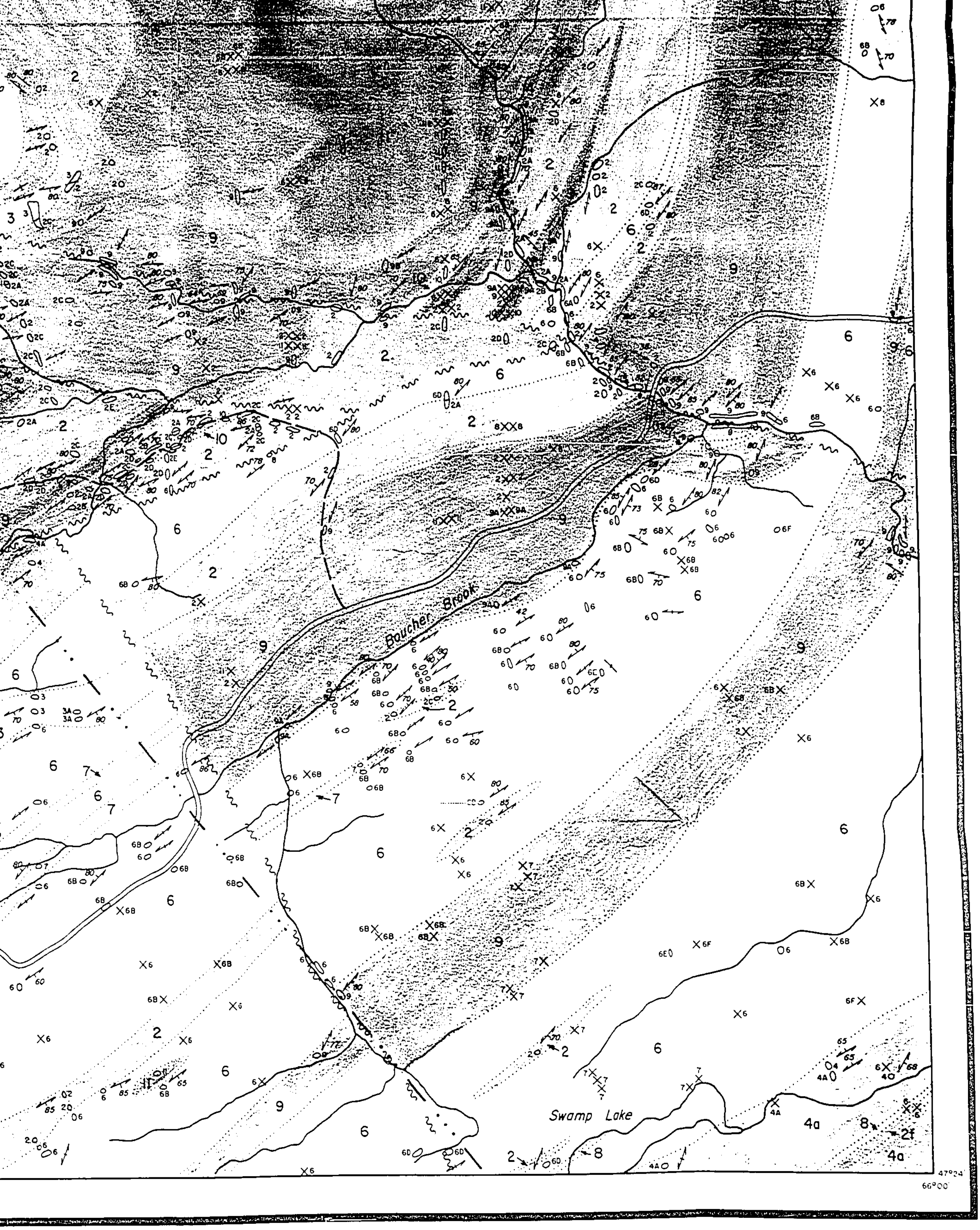
## GLOUCESTER AND NORTHUMBERLAND COUNTIES

## NEW BRUNSWICK

SCALE ONE INCH TO ONE QUARTER MILE OR 1320 FEET

FEET 1000 0 2000 4000 6000 FEET

40 20 0 1 2 MILES




P.M. 61-1

# PLATE IV

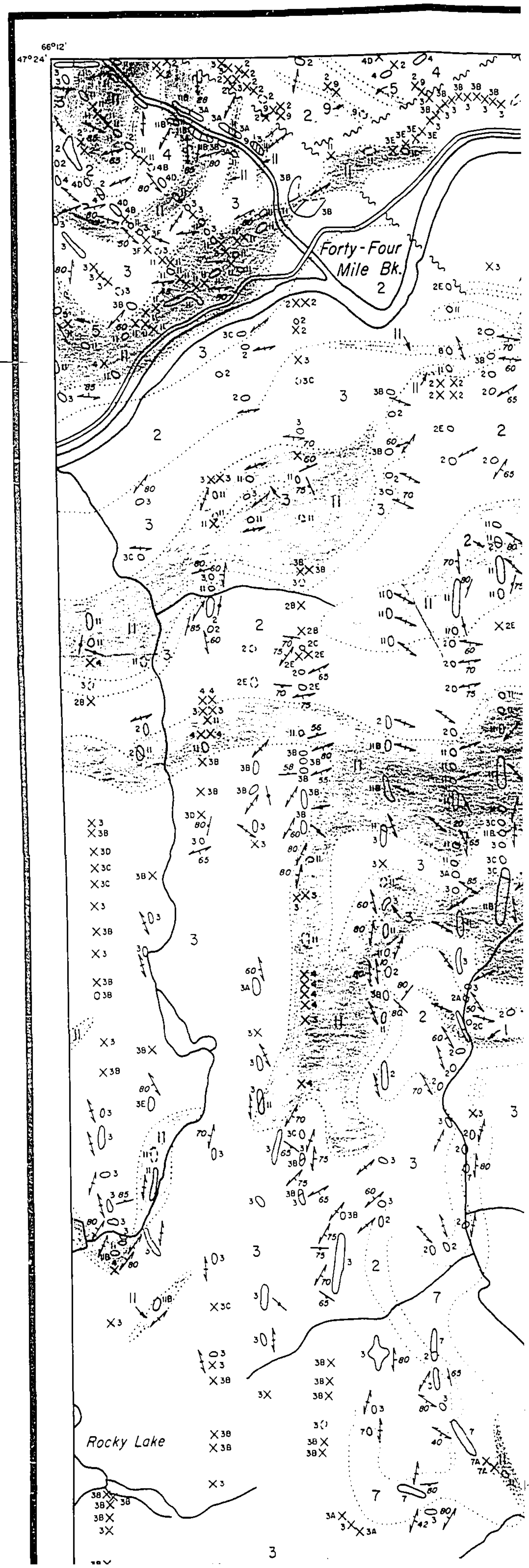
## LEGEND

### PRE-SILURIAN

| | |
|---|---|
| 1 | *INTERMEDIATE VOLCANIC ROCKS*<br>1A Basalt<br>1B Dacite and light green felsite<br>1D Coarse grained mafic volcanic rocks<br>1E Gabbroic equivalents |
| 2 | *DACITE AND DACITE PORPHYRY*<br>2A Quartz and/or feldspar augen schist<br>2B Rhyolite<br>2C Rhyolite porphyry and porphyritic rhyolite<br>2D Quartz - chlorite - sericite schist<br>2E Siliceous tuff |
| 3 | *SILICEOUS TUFFACEOUS ROCKS*<br>3A Dacite<br>3B Rhyolite<br>3C Porphyritic rhyolite and rhyolite porphyry<br>3D Quartz and/or feldspar augen schist<br>3E Quartz - chlorite - sericite schist<br>3F Intermediate volcanic rocks |
| 4 | *SILICEOUS VOLCANIC ROCKS*<br>4A Porphyritic rhyolite and rhyolite porphyry<br>4B Siliceous tuffaceous rocks<br>4C Quartz and/or feldspar augen schist<br>4D Quartz - chlorite - sericite schist<br>4E Dacite<br>4F Intermediate volcanic rocks |
| 5 | *QUARTZ - CHLORITE - SERICITE SCHIST*<br>5A Quartz and/or feldspar augen schist<br>5B Dacite<br>5C Rhyolite<br>5D Siliceous tuffaceous rocks<br>5E Argillite |
| 6 | *QUARTZ AND/OR FELDSPAR AUGEN SCHIST*<br>6A Dacite<br>6B Porphyritic rhyolite and rhyolite porphyry<br>6C Rhyolite<br>6D Quartz - chlorite - sericite schist<br>6E Siliceous tuffaceous rocks |
| 7 | *POSSIBLE SILICEOUS INTRUSIVE ROCKS*<br>7A Rhyolite<br>7B Quartz and/or feldspar augen schist<br>7C Siliceous tuffaceous rocks<br>7D Quartz - chlorite - sericite schist |
| 8 | *GRAPHITIC SCHIST*<br>8A Argillite<br>8B Greywacke<br>8C Quartz - chlorite - sericite schist |
| 9 | *RED MANGANIFEROUS AND HEMATITIC SLATE* |
| 10 | *CHERTY IRON FORMATION*<br>10A Red hematitic slates |
| 11 | *GABBRO AND DIABASE*<br>11A Coarse mafic volcanic rocks<br>11B Intermediate volcanic rocks |

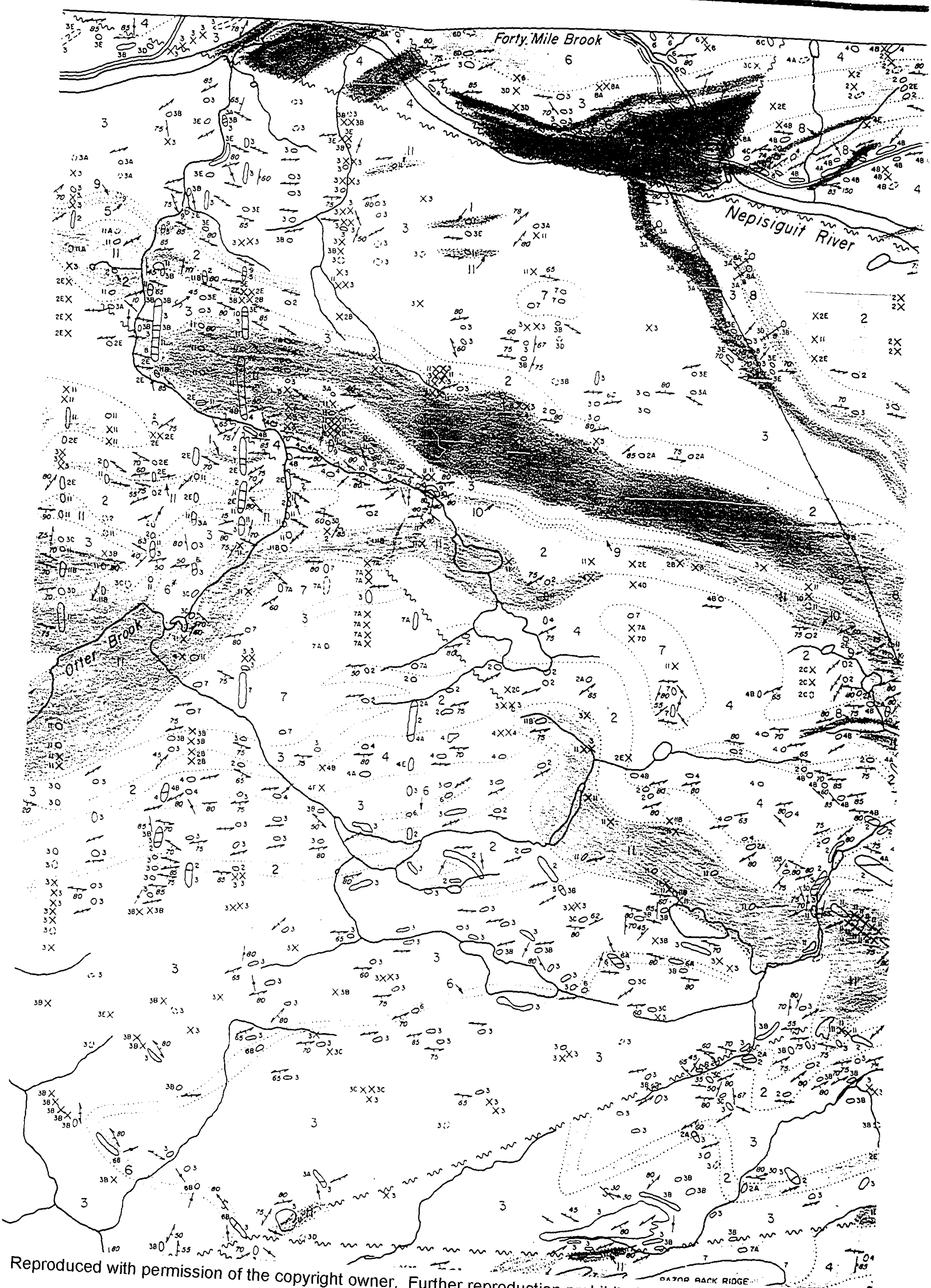
## SYMBOLS

| | |
|---|---|
| O3B ◌3B | *Observed rock outcrop (defined, assumed)* |
| X3B | *Observed float* |
| | *Schistosity (inclined, vertical, dip unknown, with lineation)* |
| | *Bedding (inclined, vertical)* |
| | *Jointing (inclined, vertical)* |



M

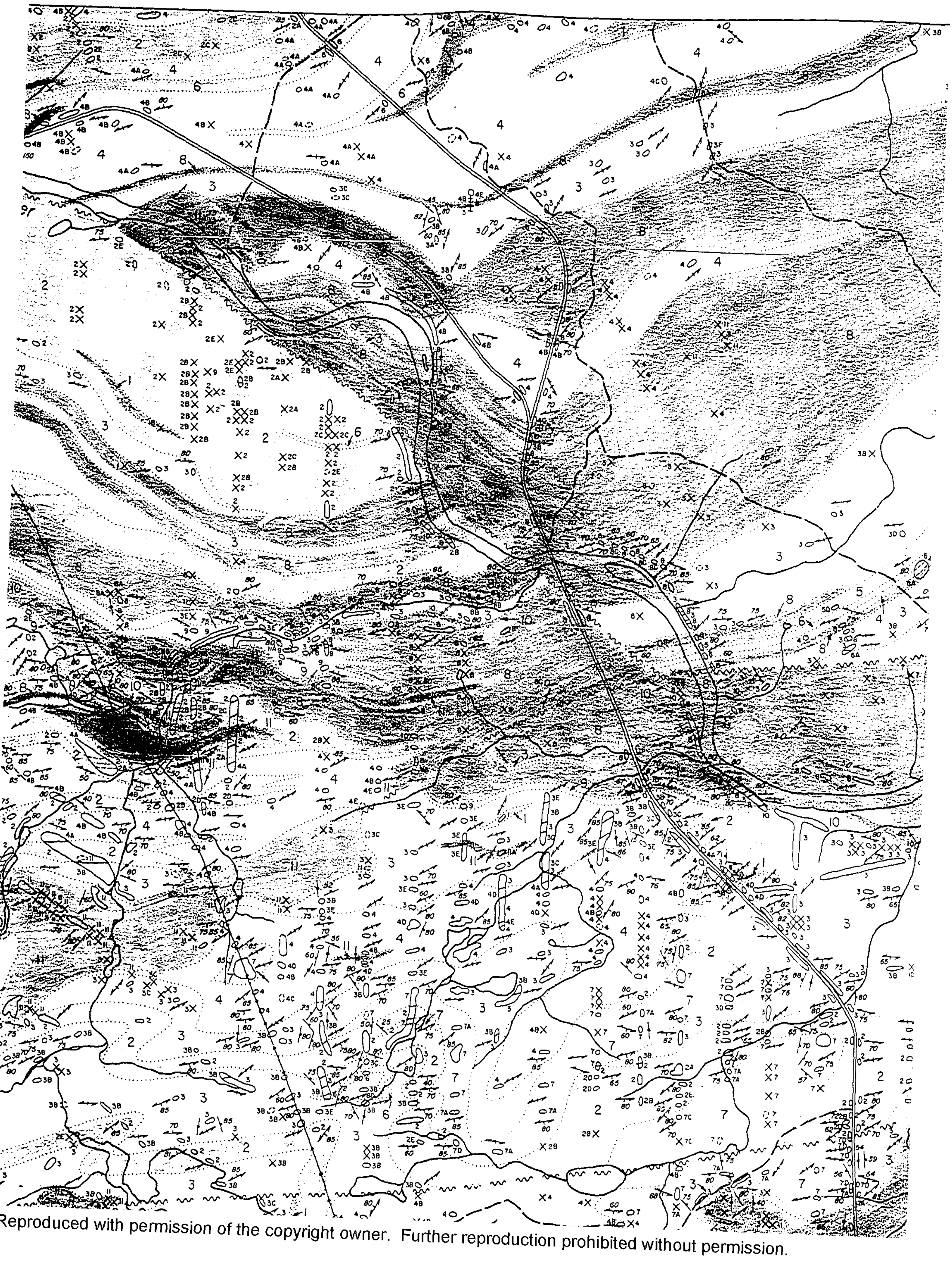
DEPAR

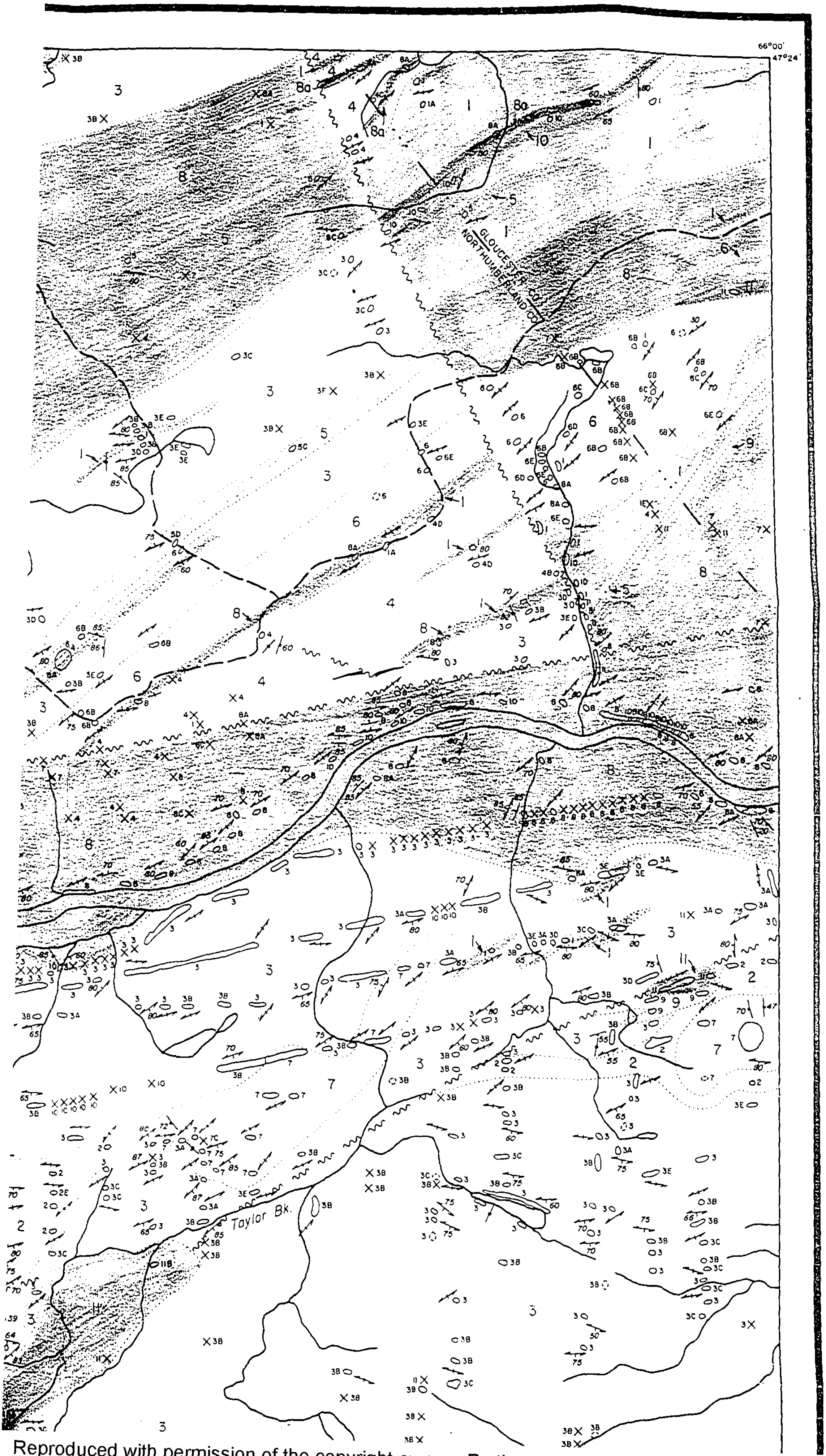

Forty Mile Brook
Nepisiguit River
Otter Brook
RAZOR BACK RIDGE

NEW BRUNSWICK

# MINES BRANCH

DEPARTMENT OF LANDS AND MINES




66°00'
47°24'
GLOUCESTER CO.
NORTHUMBERLAND CO.
Taylor Bk.

Bedding (inclined, vertical)

Jointing (inclined, vertical)

Attitude of dragfold

Assumed geological contact

Assumed fault

Diamond drill hole

Sulphide body

Mineral occurrence

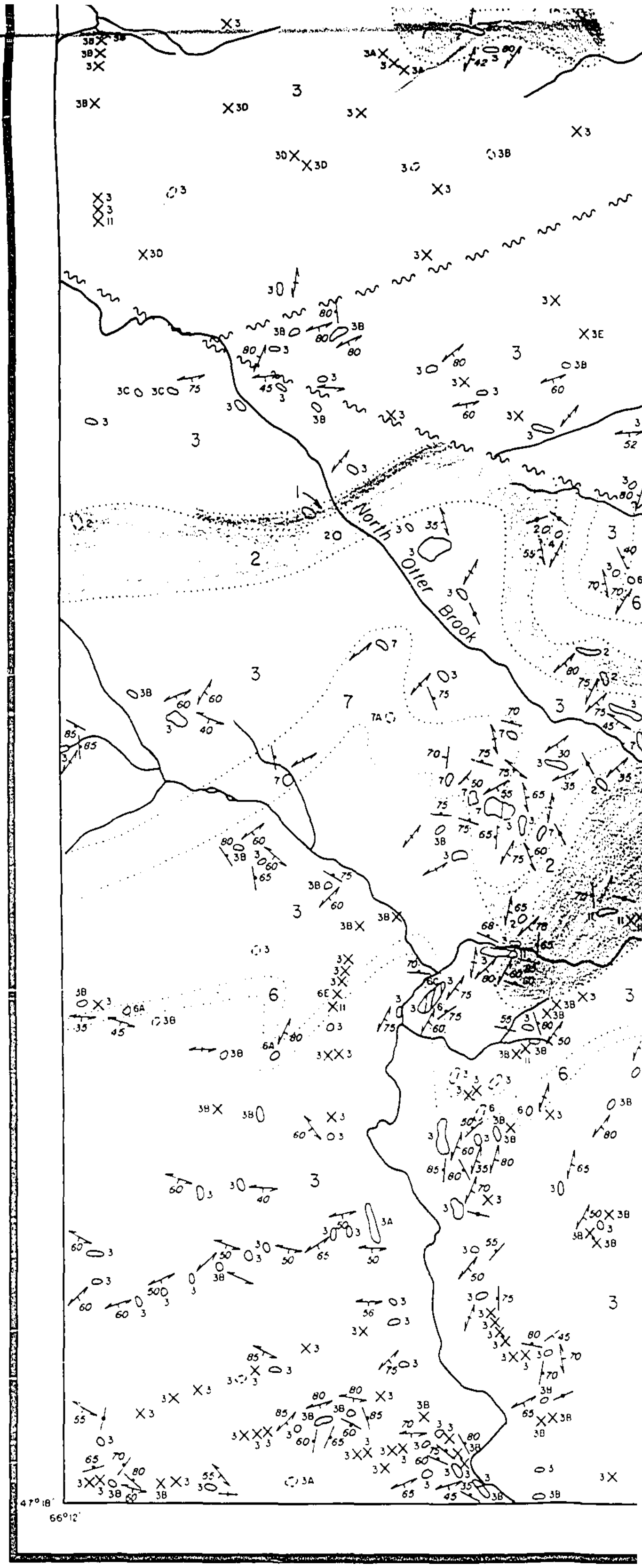
GEOLOGY BY

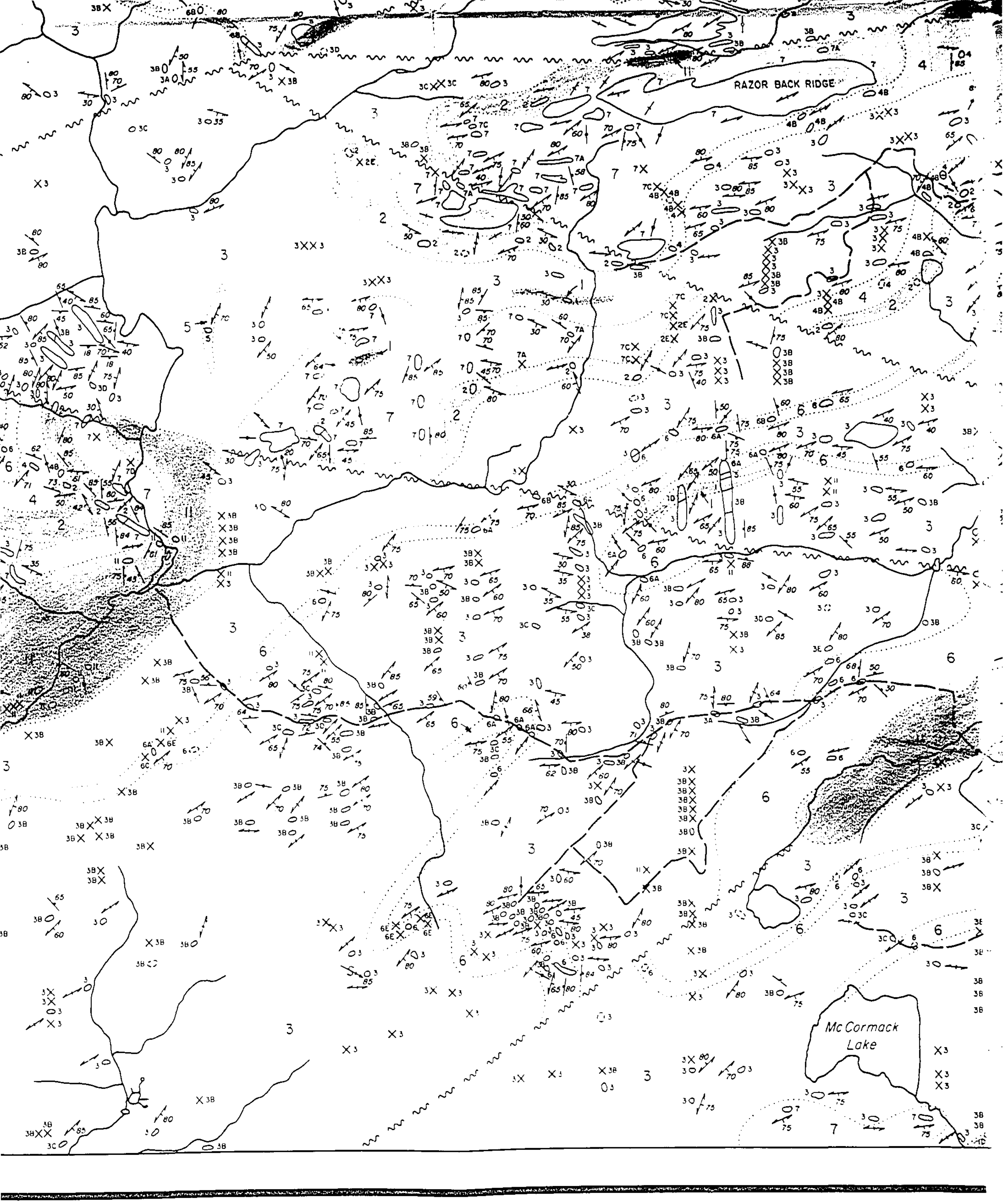
R A Jones (1962)
Mines Branch
Department of Lands and Mines
Province of New Brunswick

Approximate Magnetic Declination 24° West

PUBLISHED 1964

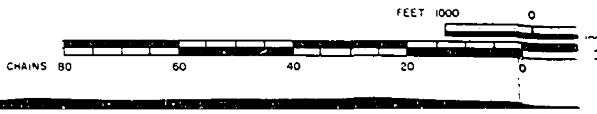
P.M. 62-1

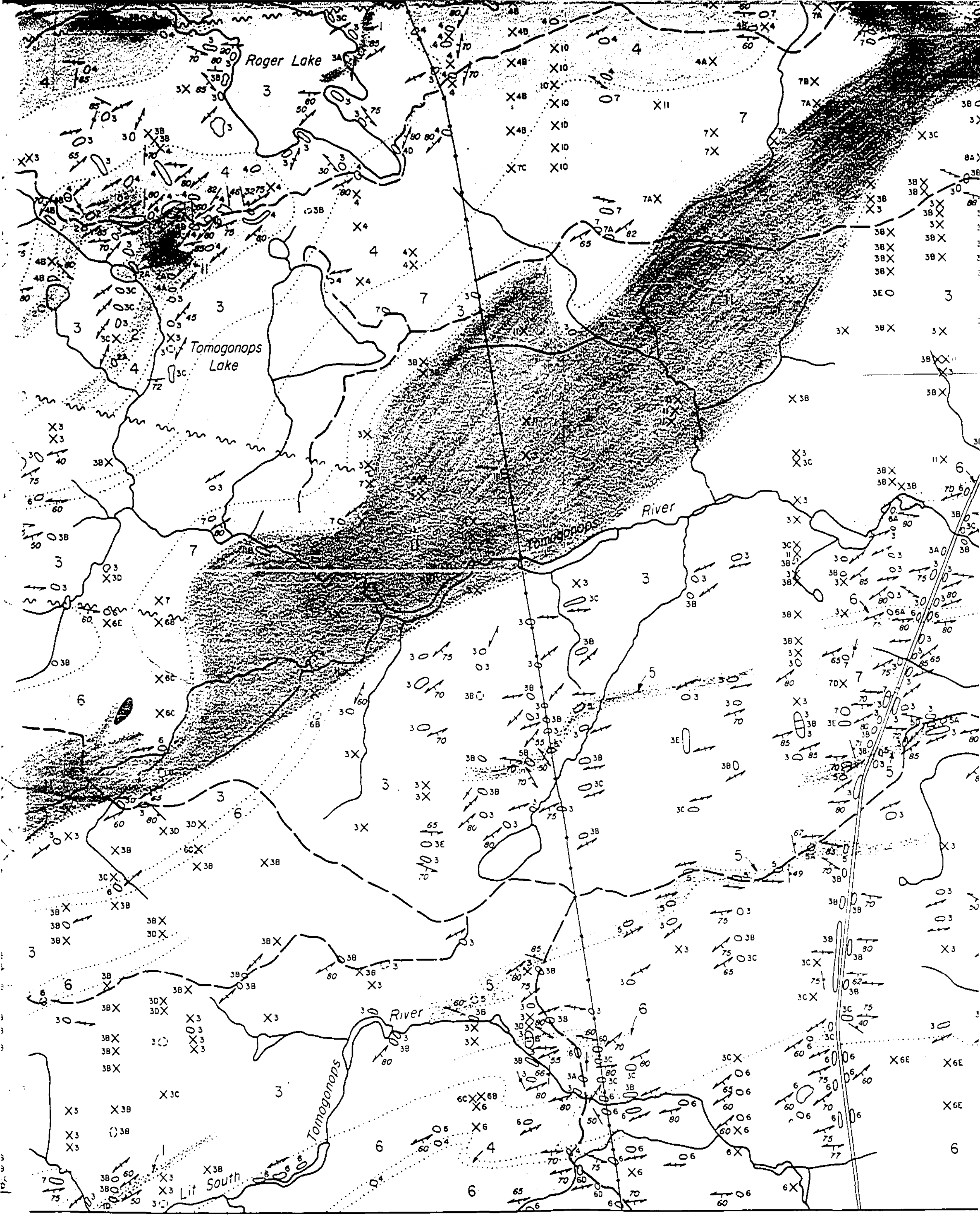





NEPISIGUIT

GLOUCESTER






MAP AREA O-8

# 'JIT RIVER - OTTER BROOK

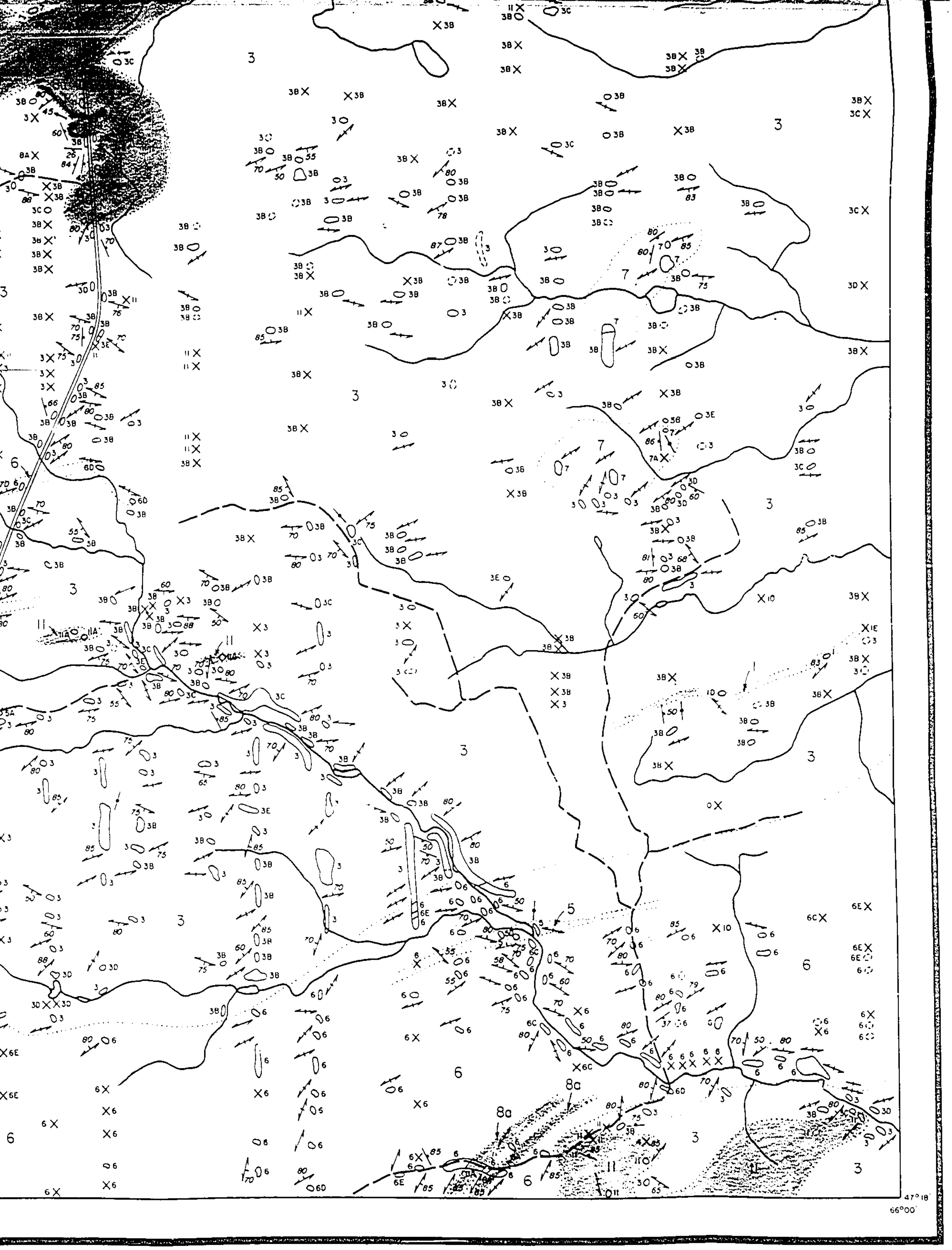
STER AND NORTHUMBERLAND COUNTIES

NEW BRUNSWICK

SCALE: ONE INCH TO ONE QUARTER MILE OR 1320 FEET

0 2000 4000 6000 FEET

0 1 2 MILES



P.M. 62-1