GEOLOGY OF THE NOEL PAUL'S BROOK AREA, CENTRAL NEWFOUNDLAND

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BY

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Abstract

This thesis is concerned with a study of the general geologic features of the Noel Paul's Brook area in Central Newfoundland, with emphasis on the systematic description and classification of rock types.

In the gently rolling terrain the remnants of two Cenozoic erosion surfaces may still be recognized. As a result of Pleistocene glaciation the countryside has been left with a thick mantle of boulder clay, but because of two conflicting lines of evidence no definite conclusion as to the direction of glacial ice motion could be reached.

The bedrock geology is characterized by narrow - often persistent - bands of clastic sedimentary rocks and volcanic formations striking approximately northeast. Their total thickness, if the possibility of repetition through isoclinal folding is disregarded, is over 30,000 feet. With the exception of one conglomerate member the sedimentary rocks are fine grained. The volcanic rocks consist of metamorphosed acid and intermediate flows and tuffs. The intermediate rocks are associated with thin bands of slightly metamorphosed limestone, limy shale and greenstones of sedimentary origin.

A large granite batholith lies along the southern boundary of the map area, and smaller intrusive stocks, sills and dikes, ranging in composition from diorite to micropegmatite also occur.

No fossils were found in the sedimentary rocks, but by lithological correlation with rocks beyond the thesis area the formations mapped are believed to range in age from Middle Ordovician to post-Ordovician.

It is believed that the rocks were deformed by two major orogenies: one in the late Ordovician, the other late in the Devonian period. The conglomerate member mentioned above may have formed in connection with the late Devonian upheaval.

The sedimentary rocks have steep dips, generally in a southeasterly direction, but the beds are often overturned. These high dips are indicative of tight, isoclinal folding, and observation of minor folds tends to support this assumption. Faults are not conspicuous, but shearing and brecciation of outcrops in some areas suggest that faulting has taken place in the vicinity of these outcrops.

The great thickness of the stratigraphic sequence and the abundance of volcanic rocks, some of which show pillow structure, indicate a eugeosynclinal environment. However, most of the sedimentary rocks have characteristics which suggest deposition in a deltaic or terrestrial environment.

CHAPTER I

INTRODUCTION

Area and materials studied

Tally Pond, in the center of the Noel Paul's Brook area, lies 24 miles in a southwesterly direction from the town of Buchans in Central Newfoundland (fig. I in text and fig. 2 in pocket, at back), and the coordinates 56°29' west longitude and 48°38' north latitude intersect at a point in the pond.

The boundaries enclose an area of over 100 square miles; the average width is approximately five miles and the distance between the southwest and northeast corners is over 22 miles.

This thesis deals with a description of the general geology of the area, with emphasis on the systematic description and classification of rock types, and is the result of two summers' field work and a study of over 600 hand specimens and 130 thin sections during two academic years at Memorial University of Newfoundland.

Purpose of the investigation

One of the larger base-metal deposits in Canada is that found at Buchans in Central Newfoundland. For many years the American Smelting and Refining Company (ASARCO), Buchans Unit, attempted to extend the area of known mineralization in their 7000 square-mile Concession Area, which included much of the central and southern portions of the island, by means of a well organized mineral exploration program. In 1958 the lease on the Concession Area expired, but ASARCO applied for, and was granted, an extension of 5 years on 1000 square miles with the provision that 200

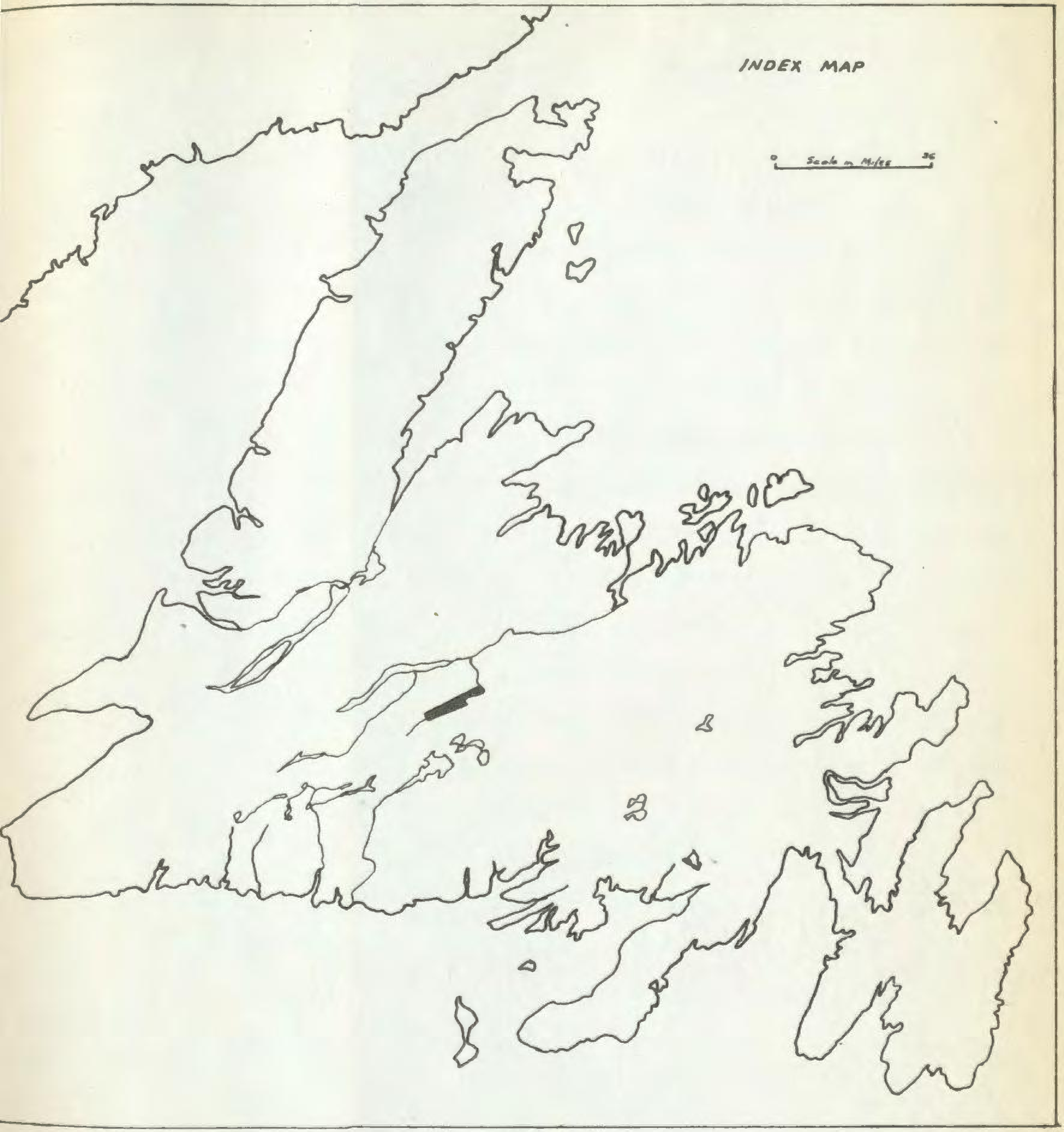

FIGURE 1

square miles be surrendered each year.

On the strength of previous geological mapping, the discovery of a number of mineralized boulders, and the encouraging results of several preliminary geochemical soil traverses, it was decided that resumption of exploration in the Noel Paul 's Brook area was warranted. As a result, a detailed geochemical prospecting program was launched in the spring of 1959, and a party of 12 men under the supervision of the writer was assigned to the area. Work was resumed in the spring of 1960 with a party of 17 men, and continued through to October of that year.

The program consisted of methodical sampling of B-horizon soils and analysis of the samples in a field laboratory for zinc and copper content, in order to detect abnormally high values which might indicate the presence of base metal deposits in the underlying bedrock. The geochemical program was supplemented by prospecting for mineralized outcrops and boulders. In addition, the writer carried out detailed mapping, which involved a thorough search for outcrops and a study of the geology of the area, in order to determine the existence of any geologic structures that might be favorable for the localization of base metal deposits.

Field work

Field work occupied the summers of 1959 and 1960, a total of about 7 months. Mapping was done with the aid of aerial photographs on a scale of 1000 feet to the inch, and field work was plotted on uncontrolled base maps of the same scale. Traverses between outcrops were made by means of pace and compass.

Acknowledgements

The writer wishes to express his sincere gratitude to all those who assisted him in any way during the preparation and writing of this thesis. He is especially indebted to the following: to Memorial University of Newfoundland for awarding him two graduate fellowships, without which this work would not have been possible; to the American Smelting and Refining Company for giving the writer a free hand in mapping the area, providing thin sections, and for the loan of the base maps; and to Dr. W. D. Brueckner under whose supervision this thesis was written and who gave valuable advice and criticism. The writer also wishes to thank Dr. Paul Clifford and Dr. R. D. Hughes of the geological faculty, Memorial University; Dr. Clifford read the manuscript and checked the petrology, and Dr. Hughes was always willing to discuss problems and to offer opinions and advice. Messrs. E. A. Swanson and R. L. Brown of the geological staff, American Smelting and Refining Company, gave freely of their time and were a never-ending source of information on the geology of Central Newfoundland. John Allcock, a student from the Royal School of Mines in London, was responsible for some of the mapping during the summer of 1960, and James Dawson, a geology student from the Memorial University of Newfoundland, assisted the writer during much of the 1959 field season.

Thanks are also due to Mrs. Edith Peach for her careful preparation of the first typewritten draft, and to Miss Ruby Garland for typing several chapters.

Accessibility

The area is accessible both by automobile and small, float-equipped aircraft. By road it is 41 miles from Buchans to Lake Ambrose via the Buchans Highway, the Millertown Road and Anglo-Newfoundland Development Company woods road. The latter begins on the west side of Exploits Dam where the Exploits River leaves Red Indian Lake, the dam being crossed by a rail ferry operated by the A. N. D. Company.

From Lake Ambrose, the road continues south to Haven Steady on Noel Paul's Brook. At Haven Steady it branches: one branch follows the river in a northeasterly direction for 20 miles, with a side road to Tally Pond; the other follows the river in a southwesterly direction to Snowshoe Pond, a distance of 14 miles.

Previous work

Unlike the coastal areas which have attracted many workers in the field of geology because of the ease of accessibility and extensive exposures of bedrock, the interior of Newfoundland has been practically ignored.

A. H. Murray, former Newfoundland Government Geologist, journeyed from the south coast to the Bay of Exploits by way of Noel Paul's Brook in 1882, but he made few notes of the geological features which he encountered.

About 70 years later Norman Brown of McGill University was employed by the Buchans Mining Company, Limited, to map an area extending from Buchans Junction in the north to Lake Douglas in the south. Brown spent the summers of 1951 and 1952 in this area, and the results of his work were outlined in an unpublished M.Sc. thesis (1952).

In the summer of 1953 Raymond C. Murray of the University of Wisconsin was employed by the Buchans Mining Company, Limited, to map the eastern half of the present thesis area. Murray's base map shows that he discovered only a few scattered outcrops, and he wrote nothing about the geology of the area apart from a discussion on the direction of glacial ice motion (Journal of Geology, vol. 63, no. 3, May, 1955).

General outline of geology

The overall distribution of the rocks in the thesis area and the relative positions which they occupy may best be understood by reference to the accompanying geological map (plate I, in pocket). It shows alternating bands of sedimentary and volcanic rocks, a large granite batholith along the southern boundary, and two smaller intrusives in the southwestern and northeastern corners, respectively. Other intrusive rocks were mapped in the field and are described in this thesis, but their dimensions are so small that they can only be shown on the geological map by means of a symbol or line.

If a general dip direction exists it might be said to be toward the south, but most of the dips approach the vertical and often the beds are overturned toward the north. It is therefore plausible that the sedimentary rocks have been subjected to tight, isoclinal folding, which the more competent volcanic rocks were able to resist.

Proceeding from North to south across the thesis area 8 formations have been identified. In the extreme northeast corner the Burnt Pond formation outcrops for approximately 3000 feet along Burnt Pond Brook.

It consists of a tightly folded sequence of black shales, with some siltstones and thin tuff bands, which have been dated as Middle Ordovician on the basis of correlation with similar rocks nearby.

Immediately to the south of the Burnt Pond formation, and extending as far west as Tally Pond, are the aphanitic flow rocks with thin tuff and mudstone bands which constitute the Tally Pond volcanics. Although exposures are poor in the eastern extensions of the formation, it is apparently folded into an open syncline which converges south of Tally Pond.

The West Tally volcanic formation, consisting of felspar porphyry, acid tuff, and lesser agglomerate or flow breccia, outcrops on the west side of Tally Pond and also protrudes as islands in the pond. Its boundaries have not been accurately determined because of the paucity of outcrops, and its exact relationships with the Tally Pond formation on the opposite side of Tally Pond and the Chickadee lava formation to the south are somewhat obscure.

Intermittent exposures of the Chickadee lava formation, the most northerly rock unit in the western part of the area, have been found to extend westward for about 6 miles from the shore of West Tally Pond. Originally the flows must have had a composition approaching basaltic andesite, but they have been drastically altered by chloritization, carbonatization and epidotization. Several outcrops exhibit pillow structure, suggesting that at least some of the flows were extruded on the sea floor.

The Lake Ambrose formation extends unbroken across the whole length of the map area, a distance of over 20 miles. Throughout its western half the formation consists of a reddish, mixed-pebble conglomerate member to the north and a fine-grained, grey-weathering sandstone member to the south. In its eastern half, however, the formation is composed predominantly of sandstone, and conglomerate exposures are rare.

The Pine Falls formation, which is composed mainly of intermediate flows and tuffs, is the only other unit occurring north of the river. Like those of the Chickadee lava formation the flows have been subjected to alteration: chloritization, serpentinization and epidotization, and to a lesser extent uralitization. Occasional exposures of slightly metamorphosed limestones, limy shale and greenstones of sedimentary origin are also found within this formation.

Three separate units of black siltstones, slates and phyllites, in addition to those in the Burnt Pond formation, were mapped in the area north of the brook. These units are so limited in extent that they do not deserve formational names, but will be grouped and described together in the final section of the chapter on sedimentary rocks.

The area south of Noel Paul's Brook is underlain by the Loon Brook formation and the Carter Lake volcanics. The former unit can be separated into two divisions: a Northern Division of grits, slates, phyllitic shales and quartzites, and a Southern Division consisting mainly of massive quartzites with numerous thin bands of phyllitic shale and schist. The Carter Lake volcanics are composed primarily of massive tuffs, with quartz and felspar eyes, which are quite similar in composition and appearance to those of the West Tally formation mentioned above. These volcanic rocks are apparently conformable with the sedimentary rocks of the Loon Brook formation, because although the Northern and Southern Divisions are separated by over 2000 feet of the Carter Lake volcanics to the east, only thin, conformable bands of tuff are interbedded with the sediments to the west in the vicinity of Veneer Brook.

The area was heavily glaciated during the Wisconsin stage of the Pleistocene period, so that most of the bedrock is concealed beneath a thick blanket of boulder clay, and erratic boulders are scattered throughout the countryside. Murray (1955) established that the ice approached the contact between the Boyd's Pond batholith and the Loon Brook formation from a direction of S54W, but the present writer discovered red conglomerate boulders from the Lake Ambrose formation far to the south, as well as to the northeast, of their site of deposition. The significance of this discovery will be discussed in chapter 2.

In the subsequent chapters of this thesis the chief physiographic features and Pleistocene geology are first described. Then follows a description, emphasizing mineralogical compositions and textures, of the sedimentary, volcanic and intrusive rocks, in chapters 4, 5 and 6 respectively. The final 3 chapters deal, in turn, with the structural geology, geologic history and economic geology of the area.

CHAPTER II

PHYSIOGRAPHY, GLACIAL GEOLOGY AND PRE-GLACIAL GEOMORPHOLOGY

Drainage

Generally speaking, the area is poorly drained. This condition is due partially to the fact that most of the land is covered with a mantle of drift left by the ice sheet which advanced over the area at the end of the Pleistocene, but another contributing factor, particularly in the northern part of the area, is the low relief of the land. Boggy areas are prevalent here, and it appears from a study of aerial photos that some of them are the remnants of lakes which have filled up since the ice sheet retreated. In testing this assumption, the writer collected samples from the edges of several of these bogs with an auger, and in many cases the samples were found to be a greyish quartzose sand, probably deposited on the beach of the original lake. This assumption is also supported by the fact that the shorelines of some small ponds follow almost exactly the configuration of the outer edge of the surrounding bog.

The only major drainage feature within the immediate boundaries of the map area is Noel Paul's Brook (plate 2, in pocket). The river has its origin in Blizzard Pond, which lies close to the divide between the White Bear River - Grey River waters draining to the south coast and the Exploits River waters draining to the Bay of Exploits in Notre Dame Bay. From Blizzard Pond the river empties into Snowshoe Pond, then flows in a north-northeasterly direction through its lower reaches until it widens into Lake Douglas. North of Lake Douglas the course of the river changes in direction, and from Haven Steady to Noel Paul's Steady, a distance of some 23 miles, its direction of flow is east-northeast. Reference to a small scale map reveals that to this point the river follows a somewhat arcuate course which is roughly parallel to the south shore of Red Indian Lake. From its outlet at Noel Paul's Steady until it joins with the waters of Exploits River, 13 miles below Exploits Dam, Noel Paul's Brook follows the entirely different direction of N15E.

For most of its course the river flows through a wide valley with a gentle gradient (fig. 5), but rapids do occur at several localities, the most notable of which is at Pine Falls. Between Blizzard Pond and the outlet of Noel Paul's Steady, the Anglo-Newfoundland Development Company has built a series of seven dams to control the flow of water in the river. The two largest dams hold back the waters of Lake Douglas and John Paul's Steady respectively.

In the remainder of the map area only five other streams of any consequence are found, and are important in that better bedrock exposures are found in them than anywhere else in the area. These are the southward flowing West Tally Brook and the northward flowing Rosie, Veneer, Loon and Carter Lake brooks.

Relief

Generally speaking, the area has low relief. North of the brook lies a gently undulating, plateau-like region, having an average elevation of 1000 feet above sea level and sloping gently southward toward Noel Paul's Brook, which has an average altitude of about 700 feet (plate 2 and fig. 4, in pocket). This monotonous landscape is interrupted by occasional ridges and hills which have formed on the more resistant rocks of the Tally Pond, West Tally and Pine Falls formations.

South of the brook the terrain is more highly dissected. The land rises fairly steeply away from the valley of Noel Paul's Brook to a central ridge which roughly bisects the area between the brook and the granite along the southern boundary. At its summit the ridge has an average height of 1000 feet and a maximum height of 1339 feet. The micropegmatite dike which rises abruptly above the southern shore of Haven Steady is probably the southwestern extension of the ridge; it attains a height of over 1300 feet above sea level.

Structural control of physiographic features

The major relief features, stream courses and lake basins of the thesis area were ultimately shaped by the work of the Pleistocene glacier. The general trend of the features, however, is for the most part dependant on the strike of the underlying bedrock formations. Their strike is about N50E to N60E in the area under investigation as well as in many parts of Central and South-Central Newfoundland which the author has visited. This result is not in agreement with the statement made by Twenhofel (1912, later quoted by Snelgrove, 1928), that the general structural trend approximates a direction of N28E and this latter figure cannot, therefore, be regarded as typical.

Glacial geology

In the Noel Paul's area practically all the land is covered by a fairly thick mantle of glacial drift. Good exposures are found in many gravel pits and road cuts, and in one location along West Tally Brook a section approximately 25 feet thick can be seen (fig. 7). Sections of drift were also revealed east of Veneer Brook in several trenches which were excavated in the course of exploratory work. It was found that the bedrock in the vicinity of these trenches is covered to an average depth of 1 to 3 feet, with local accumulations, up to 5 feet thick, which fill depressions in the bedrock surface.

This drift is composed mainly of clay and sand, but boulders up to several feet across are common constituents. It has a characteristic light greyish-brown color when dry, turns dark brown when moistened, and has a very fresh appearance suggestive of a youthful age.

All but one of the deposits examined by the writer were composed of typical boulder clay (fig. 6). The lone exception was found in a gravel pit 6½ miles east of Five Mile Camp on the Noel Paul Road; at this point the material appears to be outwash gravel, as the pebbles show a fair degree of sorting and clayey material is almost entirely absent. Considerable amounts of outwash sand were also found by Brown (1952) just outside the thesis area, about two miles northeast of Lake Ambrose.

Much of the area underlain by the Carter Lake volcanics supports only sparse vegetation, and the overriding effects of the ice sheet are expressed and even emphasized by the ubiquitous outcrops and the many enormous boulders, torn from the underlying bedrock, which dot this particular part of the countryside (fig. 8).

Examination of a glacial deposit 300 feet south of the dam on Noel Paul's Steady led Murray (1955) to conclude that "approximately 80 percent of the fragments larger than 2 inches in diameter were carried less than 10,000 feet by the ice." Murray and his associates also mapped granite boulders north of the contact between the granite and the sedimentary rocks in the area south of Noel Paul's Brook, and Murray concluded from the distribution of the erratics that the ice had moved in a direction of N56E. E. A. Swanson (oral communication, 1960) also believes that the ice moved northeasterly in the area south of Red Indian Lake, because ore boulders from the Victoria Mine area have been found some distance to the northeast of known outcrops.

The present writer found evidence indicating southerly movement of the ice and therefore conflicting with Murray's and Swanson's findings. Firstly, boulders of the typical red conglomerate of the Lake Ambrose formation are scattered over much of the southern portion of the map area (i.e. to the south of the conglomerate outcrop), and some of these boulders have been carried southward for at least 11,000 feet. Secondly, glacial striae of a general north-south direction were observed. On an outcrop about 2 miles south of Lake Ambrose these striations are striking north-south; on a quartzite surface east of Veneer Brook, where stripping operations had bared the bedrock, a direction of the striae of S5E was measured.

The author's observations agree more closely with those of Brown (1952), who stated that "the generally southern direction of glacial movement is indicated by boulders of red conglomerate occurring only to the south of the conglomerate." To a lesser degree, however, conglomerate boulders were evidently also carried northeastward over the intrusive stock on the eastern boundary of the map area.

Owing to the lack of sufficient facts, the actual significance of these conflicting observations defies interpretation, and further studies are needed before the problems of the direction of glacial ice motion in the Noel Paul's Brook area can be properly understood.

Pre-glacial geomorphology

Twenhofel and MacClintock (1940, pp. 1718-1723), from their studies of the surface of Newfoundland, recognized 3 peneplains of pre-glacial origin in the western mountains although only two are recognized elsewhere(fig. 3). The highest upland surface of slight relief, the Long Range Peneplain, is found on the west coast and ranges in elevation from about 2000 to 2600 feet. This erosion surface may be represented in West-Central Newfoundland by the summits of the highest hills but is absent in East-Central and Eastern Newfoundland. According to Twenhofel and MacClintock, the second peneplain has an elevation ranging from 1300 to 1700 feet in Western Newfoundland, from 1200 to 1600 feet in the western part of the interior, and falls gradually eastward until on the Avalon Peninsula it lies at an elevation of 700 to 800 feet. This surface has been named the High Valley Peneplain.

The writers point out that a third erosion surface, represented by the dissected upland surface and wide, mature valleys, is found at elevations from 500 to about 1000 feet. In Central Newfoundland and on the Avalon Peninsula this third surface is between 500 and 1000 feet high.

The southern part of the High Central Plateau (which includes the present thesis area) was interpreted by Twenhofel and MacClintock as follows:

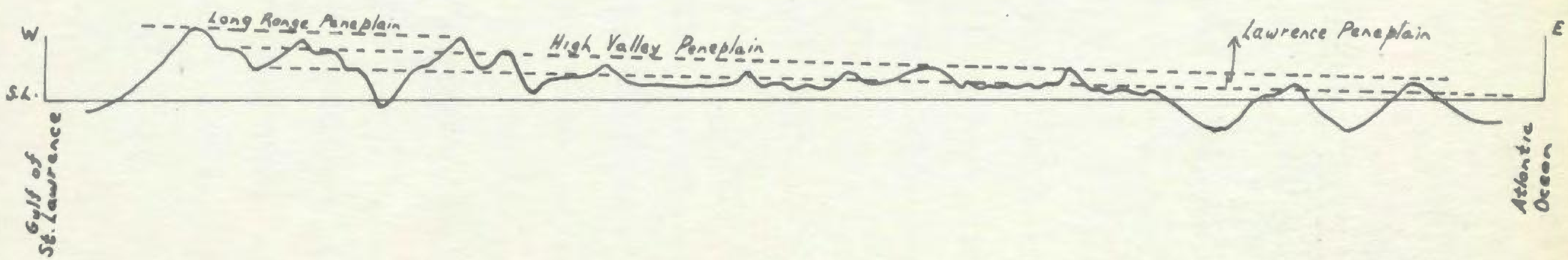

Figure 3   Profile from the Gulf of St. Lawrence south of Bonne Bay to the Atlantic Ocean at St. John's. (After Twenhofel and MacClintock, 1940. Exaggerated x 2).

Three surfaces of erosion may be present in the southern part of the High Central Plateau: the highest points of land (i.e. above 1500 feet) represent monadnocks; surfaces of 1400 to 1500 feet and less represent the peneplain surface of the High Central Plateau; and surfaces with an elevation of 1000 feet or less correspond to the Hind's Lake Flats in the Grand Lake - White Bay Basin. In the Red Indian Lake - Exploits River Valley - Notre Dame Bay region the writers postulated two erosion levels: the higher level is represented by monadnocks which have an elevation of about 1200 feet in the Red Indian Lake region; the lower level corresponds to the upland east of Red Indian Lake at an elevation of 500 to 700 feet.

The writer suggests the following correlation for the relief features of his area with the erosion levels of Twenhofel and MacClintock:

(1) The summits of the highest hills, which range in height from 1000 to 1300 feet (fig. 4a, b, d), may correspond to a high level of peneplantation which can be compared with the High Valley Peneplain of Twenhofel and MacClintock. It can be correlated with the second highest erosion surface in the southern part of the High Valley Plateau which was discussed above, and is probably the same peneplain as that in the Red Indian Lake region which was reported to have an elevation of about 1200 feet.

(2) A more or less flat, slightly dissected plain, which lies between 800 and 900 feet above sea level (fig. 4e), and slopes gently southward toward Noel Paul's Brook, and northward toward Red Indian Lake and the Exploits River Valley where it is only 500 feet high. This surface can be correlated with the Lawrence Peneplain of Twenhofel and MacClintock, which they describe as lying between 500 and 700 feet in the upland east of Red Indian Lake.

CHAPTER III

SEDIMENTARY ROCKS

General statement

The sedimentary rocks of the Noel Paul's Brook area are found mainly in three formations - the Lake Ambrose, Burnt Pond and Loon Lake formations - which comprise about 50 percent of the stratigraphic sequence, the remainder being of volcanic origin. The Pine Falls formation also contains several limestone bands and some greenstones of sedimentary origin, but the greater part of the formation consists of sheared and altered, intermediate to basic, volcanic rocks.

These sediments have a persistent northeasterly strike and are steeply dipping throughout the whole area. A statistical analysis of hundreds of attitudes shows that the general dip direction is southeast, but often the beds dip vertically or at high angles to the northwest. Top and bottom determinations are difficult - if not impossible - to make, because of the absence of primary features, but the writer suspects that the rocks have been isoclinally folded.

Lake Ambrose formation

a. Separation into members

The Lake Ambrose formation consists of two divisions: the lower (northern) division is described here as the conglomerate member, and the upper (southern) division as the sandstone member. The term "member" is used here as a matter of convenience in discussing the two units, for in its most accurate sense it designates "comparatively unimportant and more or less local rock units included within formations . . ." (Weller, 1960, p. 434). As both the conglomerate and sandstone are fairly thick and widespread, they will be described in some detail in succeeding pages.

b. Name and type area

There is no single place where the formation is sufficiently exposed to say that it has a precise type "locality". Immediately to the south and southeast of Lake Ambrose there are possibly more frequent and extensive exposures, both of conglomerate and sandstone, than elsewhere; hence, this general area may be called the type "area" of the formation, and the name is derived from the large lake nearby.

c. Conglomerate number

(1) Chief rock types: occurrence and boundaries

The lower member of the Lake Ambrose formation is a massive, reddish to purple conglomerate consisting of small pebbles in a gritty matrix which comprises only a small amount of the rock in any given outcrop (fig. 9).

The conglomerate is traced easily from the southern end of Lake Ambrose for some ten miles eastward. South of Lake Ambrose it reaches a thickness of about 5200 feet, and a tongue of thinly bedded, pink sandstone interfingers with the conglomerate through an intermediate zone of pebbly sandstone. The maximum extent of this sandstone tongue is not known because it extends westward out of the map area. Within the mapped portion it has a thickness of approximately 1200 feet.

Eight miles northeast of this zone the conglomerate again attains a thickness of about 5200 feet, but between the two areas of maximum preservation it averages only 2400 feet in thickness. The 5200-foot thickness to the east also includes some 1600 feet of thickly-bedded, pink siltstone, as well as pink and grey sandstone, which outcrops in a band about $2\frac{1}{8}$ miles long. This fine-grained band may belong to the sandstone member, for, in the 10 or 11 miles remaining till the boundary of the area is reached, only a few widely separated exposures of red conglomerate were seen. Two of these outcrops were found interbedded with the sandstone member, close to the top of the formation. Because of its very limited occurrence in the eastern half of the map area the conglomerate has not been distinguished as a separate unit here. Boulders of it are widespread, however, and their distribution eastward indicates that the coarser member persists throughout the area underlain by the Lake Ambrose formation, but probably only as small lenses interbedded with the dominant sandstone member.

(ii) Structures

Primary structures are not common: the only suggestion of bedding is a rough alignment of the pebbles, and even that is lacking in many outcrops. Red sandstone bands, 1 to 4 inches thick, are seen in a few exposures (fig. 9) and less frequently bands of pebbles, much smaller than those in the main conglomerate, can be found. There are usually sharp contacts between these different layers, but at least one example of graded bedding was observed. About 2 miles southeast of Chickadee Pond, rising in a mound out of a bog, a steeply dipping outcrop in which a 30-foot section of the conglomerate is exposed, exhibits a gradation from conglomerate at the bottom to a sandstone, containing a few small pebbles, at the top.

Outcrops of the contact between the two formations were not observed anywhere, nor of that with the underlying formations with the one exception: on the northern edge of the large bog which lies on the east side of the Tally Pond Road patches of conglomerate were found filling depressions in fine-grained, acid volcanic rocks of the Tally Pond formation. If this conglomerate is of the same age and composition as the main body of conglomerate in the Lake Ambrose formation, as it appears to be from visual inspection, then sedimentation must have proceeded on the eroded surface of the Tally Pond formation, and an unconformity could be assumed to exist between the conglomerate and the volcanic rocks.

(iii) Conglomerate of different composition

There also exists a somewhat different type of conglomerate. Less than two miles from the mapped eastern end of the formation and close to the contact with the Pine Falls formation is an occurrence of sheared, green conglomerate which outcrops intermittently for 700 feet. This conglomerate is very poorly sorted, and the constituents range from pebbles less than 1 inch in diameter to boulders a foot across. In addition to the andesite fragments which give this rock its greenish cast are pebbles of red sandstone and siltstone, vein quartz, red chert and grey limestone.

A thousand feet to the west of this outcrop is an exposure of grey conglomerate, consisting mainly of pebbles of a grey weathering greenish sandstone in a grey, gritty matrix. Boulders up to 15 inches across are found in this conglomerate, which is probably a facies of the green conglomerate just described.

(iv) Composition of the main conglomerate

The pebbles making up the conglomerate are moderately well-rounded and rarely exceed 2 inches in diameter, although in several outcrops pebbles as long as five inches were observed and, in an outcrop on the shore of Chickadee Pond, boulders 2½ feet long are present.

The chief constituents of the conglomerate are fragments of red shale and sandstone, although in some outcrops pebbles of light-green andesite constitute a large percentage of the rock, and elsewhere quartz porphyry is the dominant constituent. Less common are fragments of grey sandstone, vein quartz, grey limestone and quartz-felspar porphyry. The matrix, which comprises only a small percentage of the rock, is composed of angular quartz and felspar grains, and flakes of sericite. Some of the constituents are almost completely covered with hematite, but as adjacent fragments are comparatively fresh it may be assumed that this coating, rather than being selective, took place prior to deposition. Apparently the hematite is secondary, because it is present in many pebbles without regard to their original composition. Calcite occurs in irregular grains and in veinlets cutting through some of the pebbles, and often the mineral replaces the quartz.

(v) Origin and environment of deposition

Twenhofel (1947) has said that because coarse clastics are deposited under many environmental conditions, a conglomerate has no environmental significance beyond the fact that the transporting agent was competent enough to place its constituents where they were found. However, the same writer states that the thickness of beach gravels may be as great as 50 feet and is less than that in most places, and only a very rapid rise of sea level could bring beach gravels below the level where they could not be eroded. A deposit of glacial origin would not be expected to have such a narrow range between the sizes of the largest and smallest fragments, and it would have a much higher ratio of matrix to pebbles than is found in the Lake Ambrose conglomerate; neither would a gravel deposit likely accumulate to any great thickness in the bathyal nor abyssal environments.

The extreme thickness, moderate degree of sorting, and the nature and composition of the components in the conglomerate member, limit both its source area and its environment of deposition to a very few possibilities. These characteristics, together with the wedge-like outcrop pattern and absence of fossils, are indicative of deposition in either a terrestrial or transitional environment. Pettijohn (1957, p. 253) has stated that:

> Under conditions of low relief the gravel yield is both small and mature i.e., the materials are chemically inert residues. Only vein quartz, quartzite, and chert remain; the bulk of the source rocks are reduced to sands and clays. High relief and rapid erosion produce coarse, immature gravels.

Although the small size of the pebbles which make up the conglomerate is indicative of low relief in the source area, their extreme diversity is characteristic of an immature gravel. A slowly rising terrain such as is provided by gradual uplift can therefore be invoked to account for this seemingly conflicting set of conditions, and, as pebbles of crystalline basement rocks in the conglomerate are extremely rare, a thick cover of sedimentary and volcanic rocks must have existed over the source area.

The conglomerate thickens toward the southwest and uplift was probably most intense in that direction, but the presence eastward of pebbles which were probably derived from the West Tally, Chickadee lave and Pine Falls formations indicates that a more gentle regional uplift was going on at the same time.

It will be shown in a later section of this thesis that after the Burnt Pond formation was deposited a whole geologic period may have elapsed before the resumption of sedimentary processes resulted in deposition of the Lake Ambrose formation.

What was the transporting medium from which the original gravel was deposited? A terrestrial or transitional environment has already been established, and the subrounded outlines presented by many of the pebbles suggests transportation by a fluid medium. The author is of the opinion that the gravel was transported along a river course by fast-flowing water and deposited in a deltaic environment.

d. Sandstone member

(i) Occurrence and chief rock types

The sandstone member of the Lake Ambrose formation extends across the map area from southwest to northeast, a distance of over 20 miles. Where the conglomerate member is thickest the overlying sandstone comprises only 2000 feet of the formation, but elsewhere the conglomerate thins or is absent and the sandstone attains thicknesses up to 8000 feet.

The term "sandstone" is not used here in its strict sense, but as a descriptive term for an assemblage of sediments which is composed largely of sandstones but also contains interbedded shales and mudstones. The entire division has been subjected to mild metamorphism so that some of the finer-grained sediments show development of mica along bedding planes, and they may be more accurately described by the metamorphic terms "schist" or "phyllite".

The rocks of the sandstone member weather to a distinctive light-grey or buff color (fig. 10), and are grey to green on the fresh surface. Where weathering has penetrated to any depth below the surface the rock is often pitted with small, rusty spots which sometimes are large enough so that the term "spotted sandstone" can be applied. South of Tally Pond, and lying to the north of the conglomerate member, is a small occurrence of black to grey siltstone which may be connected with the sandstone member. This unit will be discussed, together with two other similar occurrences, in the final section of this chapter.

(ii) Structures

Like the conglomerate which underlies it, the sandstone is remarkably devoid of primary features. No ripple marks, graded bedding or mud cracks were observed, and only a couple of relatively obscure examples of current bedding on a very small scale were seen. Interpretation of this current bedding indicates that the top of the Lake Ambrose formation is toward the south.

Although some of the mudstones and sandstones are thickly bedded, their usual range in thickness is from 0.1 inches to 1 inch with 0.2 inches being the mean. In a single outcrop beds of sandstone 8 inches thick alternate with green mudstone bands and thinner sandstone bands ranging in thickness from 0.1 to 0.3 inches. The bedding planes are sharp and no gradation can be seen from the coarser to the finer bands.

Two outcrops were observed in which bands of green mudstone, one 12 inches wide (fig. 11) and the other 6 inches wide, are interbedded with the sandstone. In both cases the finer-grained rock has a cleavage which strikes at an angle of about 20 degrees to the strike of the enclosing sandstone bed. The whole rock mass probably suffered deformation but the more resistant sandstone was not impressed with any noticeable planar feature such as was developed in the finer-grained bands.

Another small-scale feature observed in the field consisted of a lineation, trending across siltstone bands, from 0.3 inches to 1 inch wide. The strike of this lineation also differs by about 20 degrees from that of the bedding, but there is evidently no connection with the cleavage described above. The lineation is caused by yellowish-green stringers, and probably represents some structure which originated when the beds were still uncompacted.

(iii)Grain size

Measurement of the maximum grain size in the rocks which can be identified megascopically as sandstones reveals that it averages about 0.2 mm., falls as low as 0.09 mm., and never exceeds 0.35 mm. Classification on the basis of the Wentworth scale therefore places these rocks into the category of very fine-to medium-grained. The mudstones contain some clastic quartz grains but they are never larger than the silt grade.

(iv) Composition and textures (see table 1)

The chief detrital mineral is quartz, which comprises from 36 percent to 55 percent of the rock (fig. 12). The majority of the grains exhibit angular to subangular outlines: because of their small size there was little abrasion during transportation. A few minute liquid globules may be seen in most of the quartz grains, while many of them display undulatory extinction and evidently have been subjected to strain effects.

Felspar is the next most common detrital mineral but it never exceeds 7 percent of the rock. Most of it is orthoclase, but plagioclase, microline and an occasional grain of perthite are also present in most of the thin sections. As a general rule the felspars are remarkably unaltered and only their low birefringence and a slight turbidity distinguishes the untwinned felspar from quartz.

Leucoxene is usually present in a measurable percentage and in MI5I (table 1) it comprises 4 percent of the rock. This mineral occurs as irregular disseminated grains and is probably detrital in origin. Tourmaline and zircon are the only stable accessories which were identified in thin sections.

The content of matrix in these sandstones ranges from 23 percent to 40 percent, and is composed mainly of detrital silt which was welded together during diagenesis. Any argillaceous material which was present has recrystallized to sericite and chlorite, and with the highest power tiny composite crystals of alternating colorless muscovite and light-green chlorite may be seen. Occasionally the extremely fine-grained material of the matrix has reacted with the detrital constituents, and cases are seen where the borders of quartz grains are being penetrated by tiny needles of chlorite and sericite. Not all the mica in these rocks is authigenic, however, and both chlorite and muscovite occur in tabular

TABLE I

Mineralogical composition of sandstones in Lake Ambrose formation.

	M151	M119A	M162C	M111	M162C
Quartz	41.6	36.7	60.2	55.6	54.2
Orthoclase	4.0	8.0	3.0	6.0	Tr
Na-felspar	Tr	Tr	1.0	1.0	7.2
Limonite	9.0	7.0	6.0	-	11.0
Leucoxene	4.0	1.0	1.0	-	-
Muscovite	2.0	7.0	5.0	-	-
Chlorite	Tr.	2.0	1.0	2.0	-
Matrix	39.6	35.6	22.5	25.3	27.7
Rock fragments	-	3.0	-	-	-
Calcite	-	-	-	9.0	-
Zircon	Tr	Tr	Tr	1.0	Tr
Tourmaline	Tr	Tr	Tr	Tr	Tr
	100.2	100.3	99.7	99.6	100.1

and elongated crystals which are detrital in origin.

One of the most interesting aspects of these sandstones is that although some of them contain a fairly high percentage of carbonate others are carbonate-free. Two different minerals appear to be present: (a) ordinary calcite and (b) a ferruginous carbonate which could be either an iron-bearing calcite, or ankerite, the iron-bearing mineral of the dolomite group. The calcite occurs in clear, irregular grains and may have had its origin in the recrystallization of calcareous mud contained in the matrix; or it may have arisen through the destruction of calcium-bearing minerals of which no trace may now be seen; or have been precipitated from calcium-bearing solutions percolating through the rock. The iron-bearing carbonate also occurs in irregular grains but is often found in rhombohedrons, and may be distinguished from the calcite in that it is usually bordered by or contains a surface coating of limonite. Alteration of this carbonate to limonite is usually so advanced that the process has gone to completion and rhombohedral pseudomorphs of limonite after the carbonate may be seen. Figure 13 is a photomicrograph of one of the "spotted sandstones" described earlier (p. 19) in which each spot is a small area cemented by limonite (black) formed by oxidation of pre-existing ankerite (?) grains. Some of the finer grained sediments contain more than 40 percent limonite (table 1).

These rocks have a wide range in size of the smallest and largest fragments and hence may be said to be poorly sorted. In the carbonate-free and low-carbonate types there is no cementing material, and the grains and matrix have been welded together during compaction. In others, cementing is only local (e.g. the spotted sandstone in figure 13) while in the rocks with a higher limonite content cementing appears to be very extensive.

One thin section which was examined shows two bands of very fine-grained sericitic material cutting through the sandstone and making sharp boundaries with it (fig. 14). One of these is about 0.5 mm. wide, the other 0.2 mm., and they represent minor interruptions in the normal progress of sedimentation. The bands are folded on a microscopic scale and have a cleavage which makes a high angle with the margins. This feature resembles closely the "false cleavage" described by Harker (1932, page 157).

(v) Definition of sandstone types

There are many sandstone classifications in the literature and all are based on the various proportions of quartz, felspar, rock fragments, matrix and cement. The sandstones of the Lake Ambrose formation have the following characteristics:

(1) The quartz/felspar ratio is very high.

(2) Rock fragments are virtually absent.

(3) In contrast to the apparent mature aspect of the rocks as indicated by the quartz/felspar ratio, the high percentage of matrix is indicative of an immature sediment. Rather than being a reflection of immaturity, however, the high content of matrix is probably due to the poor sorting which is usually evident in fine-grained sediments.

(4) The content of iron-bearing carbonate and of limonite derived from its alteration is extremely high in some cases.

According to Pettijohn's classification (1957, p. 291, table 48), a rock in which the quartz content is generally lower than 75 percent, felspar exceeds rock fragments, the detrital matrix exceeds 15 percent and chemical cement is absent, is called a felspathic greywacke. The term "greywacke", however, conveys the misleading impression that there are high percentages of both felspar and rock fragments. The actual compositions of the Lake Ambrose sandstones are closer to, but not the same as, the rock called "subgreywacke" by Krumbein and Sloss (1956, p. 134, table 58).

The writer therefore prefers the more general term "impure sandstones" for those rocks which are carbonate-free, "calcareous impure sandstones" for those containing 10 percent or more of calcium carbonate and ankerite, and "ferruginous impure sandstones" for those in which the content of limonite is 20 percent or more.

(vi) Environment of deposition

As we have seen in the previous paragraph the sandstone member has characteristics both of a mature and an immature sediment, and in this way it resembles the conglomerate member. The contact between the two members was nowhere observed so it cannot be stated with certainty whether the one grades into the other, or if the conditions which prevailed at the time the conglomerate was deposited came to an abrupt halt before the sandstone was lain down.

By this time the highland which had provided the gravel for the conglomerate member had been reduced so that the sedimentary processes continued on a much milder note, but the source area still consisted predominantly of sedimentary rocks, and fine sand was the main constituent transported by the rivers which meandered across the ever-growing delta.

sedimentation proceeded rapidly enough, or conversely, the depositional area sank at such a pace, that there was no time for the finer-grained material to be winnowed out.

Burnt Pond formation

The most northerly formation in the thesis area is the Burnt Pond formation, which outcrops in Burnt Pond Brook in the extreme northeast corner of the map area. It consists of a tightly folded sequence of black slate and grey siltstone with thin bands of tuff, and is intruded by sills of dioritic composition. Burnt Pond Brook runs more or less parallel to the general strike of the formation, and as only a few outcrops were found in the wooded area north of the brook it is not possible to estimate its thickness. However, it is interesting to note that Howley (1888) was the first writer to mention these rocks. After his description of the limestone bands interbedded with the greenstones below the Main Dam, he states that the limestone

> . . . is succeeded at intervals by bluish-grey slate, but at the lower falls, about two miles from the junction with the main Exploits river, the slates are interstratified with beds of diorite and here assume a hard flint nature approaching feldsites . . . . These slates and associated limestones, sandstones, etc., are clearly of one geological horizon and correspond so closely in character with those of the Exploits Valley proper, that there is little doubt of their being identical.

This formation is probably the same one reported by Murray (1881) to outcrop along the Exploits River above Badger Brook, nearly all the way to the upper falls of the river. Outcrops were also recognized at several places between the upper falls and Red Indian Lake, and again near the entrance to Victoria Brook. The present writer observed an outcrop in a road-cut several miles north of Lake Ambrose, about 20 miles to the south-west of Burnt Pond Brook, and the black pyritiferous slates in that out-crop bear such a close resemblance to those in Burnt Pond Brook that there can be little doubt that they are part of the seme formation. David Catherall - a student from the Royal School of Mines, who was working under the direction of the writer in the summer of 1959 - mapped over 5000 feet of black shales along Harpoon Brook, and he found similar rocks outcropping far to the northeast, near Exploits River. There can be no doubt that this black shale formation is one of the most widespread in the interior of Newfoundland.

These slates have a high organic content and contain a great deal of pyrite in the form of thin beds, ranging in thickness from 0.2 to 0.5 inches; irregular veinlets also cut through the rock, and concretionary or nodular forms up to 0.5 inches in diameter are abundant in some areas.

In contrast to the other formations in the area, which have steep southerly dips, the rocks in Burnt Pond Brook dip to the north at angles ranging from 55 to 80 degrees. The whole formation is tightly folded and many small synclines and anticlines can be seen along the brook. The strike of the formation is more northerly than that of the formations to the south.

In the vicinity of the dikes the slates weather more rusty than elsewhere. It is not improbable, therefore, that the cross-cutting vein-lets of pyrite in the sediments were introduced during the intrusion of these dikes. However, no cases were observed where the bedded pyrite is intersected by the cross-cutting veinlets.

The black slates of the Burnt Pond formation are much more massive than those in the formations to the south. In spite of the high organic content, which can be seen by the way in which the rock soils the hands, no fossils were found in the slates.

The tuffs are found in bands about a foot wide. They are very tough rocks, greyish-green in color, and contain small fragments of black shale. A thin section from one of the bands shows that the rock has a very fine-grained matrix composed largely of white mica and volcanic ash. Imbedded in the matrix are small rounded fragments of black shale, angular quartz grains, calcite crystals, and disseminated pyrite in cubes and irregular grains (fig. 26). In contrast with the highly angular shape displayed by the quartz grains, the felspars exhibit some crystal faces. Fragments are also present which are composed of interlocking quartz grains, and could be either sedimentary or volcanic in origin.

a. Environment of deposition

It is a well established fact that black shales can form in a number of depositional environments. Dunbar and Rodgers (1958, p. 202) state that:

> Since the accumulation of organic matter in mud depends simply on the relative rates of supply and destruction rather than on the total amount supplied, black shales have surely accumulated under a wide range of conditions. The preservation of abundant carbonaceous material sets certain limits to the possible environments of deposition but we must depend on other features to narrow down the possibilities for each particular black shale.

Dunbar and Rodgers point out that a black shale band occurs in the Middle and Upper Ordovician deposits from New York to Alabama, and it does not require much effort to picture the black shales of the Burnt Pond formation as being the same type of deposit. It was Ulrich's belief (Dunbar and Rodgers, p. 206) that since the various species of graptolites range all the way from north to south, ocean currents must have streamed through the geosyncline and hence the bottom on which the black shale accumulated could not have been stagnant.

However, the black shales which are now the slates of the Burnt Pond formation may have accumulated in a part of the trough where water circulation was much restricted. This theory is supported by the fact that the thin beds and nodules of pyrite which are so commonly interbedded with the shale could have formed under extremely reducing conditions when no oxygen was available on the bottom of the trough. Dunbar and Rodgers (p. 206) postulate that subsidence was uneven along the floor of the geosyncline, and as a result:

> . . . the shallower places must have been thresholds preventing free circulation at the bottom in the deeper basins even though surface currents flowed through the trough.

Pettijohn (1957, p. 452) has noted that:

> . . . the association of pyrite with carbonates and with organic matter . . . is rather general. . . . The black shales or slates have the most pyrite. This suggests that the source of the sulfur is the nitrogenous component of the organic matter; it is possible also that the association is due primarily to the reducing environment needed for the preservation of organic matter and the bacterial reduction of the sulfates of sea water.

That some of the pyrite is much younger than the enclosing sediments is a possibility that must also be considered, for nodular bodies composed of one mineral or an aggregate of several minerals are often precipitated from meteoric waters which percolate along fractures and pore-openings in sedimentary and other rocks.

Loon Brook formation

a. Divisions and type area

The Loon Brook formation extends across the map area in a band which outcrops mainly south of Noel Paul's Brook, although it does extend north of the river in a thin band along approximately half its length. Its name is derived from its type area along the course of Loon Brook, in which continuous exposures and intermittent outcrops may be seen over a total distance of 4 miles. The formation can be separated into two divisions on the basis of lithology, but the only evidence of a break between the Northern and Southern divisions is a narrow conglomerate band which lies to the south of Veneer Brook. To the east where the formation is in contact with the Carter's Lake volcanics, the Southern Division is missing from the sequence.

b. Northern Division

(1) Outcrops and rock types observed

The Northern Division consists of about 4500 feet of sedimentary rocks which have undergone a moderate degree of regional metamorphism. The best exposures are found along the south shore of Haven Steady, in Veneer Brook, Loon Brook, and Carter Lake Brook, and in several places along Noel Paul's Brook.

Along the shore of Haven Steady are black phyllitic shales (fig. 15), greenish phyllitic shales and grits, and a minor amount of sericitic schist. The black shales are thinly laminated and contain thin, silty interbeds approximately 0.3 inches in thickness. Occasionally, thin pyrite bands are found in the shale and small quartz stringers cut across the beds. The green grits contain thin, shaley lenses which pinch out at each end over very short distances.

In Veneer Brook the Northern Division is represented by green grits, pink quartzites, pyritiferous black slates with thin siliceous bands, and a highly sheared quartz-felspar crystal tuff in which the original crystals are barely visible. About 4500 feet from the mouth of Veneer Brook the sheared crystal tuff is intruded by a metadolerite sill over 100 feet thick.

In Loon Brook an almost continuous section of the Northern Division is found outcropping for about 4500 feet. The section displays green, greenish-grey and pink phyllitic shales, siliceous shales, grits, and thick beds of pink quartzite similar to those in Veneer Brook.

In Carter Lake Brook at the eastern boundary of the area mapped to the south of Noel Paul's Brook, rocks of the Northern Division outcrop intermittently for about 7000 feet diagonally across the strike. Grey and greenish-grey quartzites, grits, silty shales and phyllitic shales are the predominating rock types, and considerable amounts of black shale are also present. Further upstream are found outcrops of crystal tuff belonging to the Carter Lake formation, but the contact between the Carter Lake volcanics and the Loon Brook formation is concealed.

In addition to the rocks already mentioned the Northern Division contains sericite phyllites, sericite schists, rusty quartzites (with excellent cleavage), altered quartzites and felspar crystal tuffs. The latter are highly sheared.

The quickly changing conditions of sedimentation which prevailed during the deposition of the Northern Division are aptly illustrated in a small outcrop north of Noel Paul's Brook. From top to bottom the rock types and their respective thicknesses are as follows:

Greyish-green quartzite	-	18 inches
Grey phyllite	-	1 inch
Greyish-green quartzite	-	8 inches
Grey phyllite	-	5 inches

The boundaries between these different rock types are sharp in each case, and no gradation is seen between the coarser and finer beds.

(iii) Structures

The rocks of the Northern Division display great contrasts in bedding from the paper-thin beds of some of the shales to massive bedding in certain of the quartzites. Apart from normal stratification not a single primary feature (e.g. mud cracks, ripple marks, cross bedding) was observed; either existing examples have been destroyed by recrystallization and shearing, or else none were formed during deposition.

(iv) Petrographic description

<u>Grits</u>. The grits of the Northern Division range from light-green to light-grey in color and display a slight foliation in the hand specimen. In thin section this foliation is much more pronounced and the clastic grains have assumed a preferred orientation with their longest dimensions parallel to the planes of foliation. The rocks are composed, on an average, of 28 percent quartz and 2 percent orthoclase, with some plagioclase and disseminated grains of leucoxene and limonite. The matrix, which

comprises 70 percent of the rock, consists of silty material and sericite, which undoubtedly has arisen through recrystallization of the finest-grained components.

Shearing has been fairly intense and the larger quartz crystals have become enveloped in a mantle of finely-crushed material (mortar structure, fig. 16). As a result of this shearing many of the quartz grains have developed undulatory extinction.

In the finer-grained grits the quartz grains are barely visible in hand specimen, and only when light is reflected off them, but they are much more evident in the coarser-grained rocks. On the Wentworth scale these rocks range from medium-to coarse-grained.

Arkoses. In hand specimen the arkoses are obviously coarser-grained than any of the other sediments in the Northern Division. These rocks, which are grey in color and more or less massive, consist approximately of 19 percent quartz, 6 percent orthoclase, 6 percent plagioclase and 39 percent matrix. The matrix consists of finer-grained quartz and felspar and fine-grained sericite. Leucoxene grains are scattered throughout the rock and there is a small amount of chlorite with anomalous blue birefringence. The maximum grain size does not exceed 1 mm. in diameter.

Apparently the grains in this rock were not transported very far. The grains are angular, the felspars have not undergone much alteration, and sorting is poor.

Shearing is evident: the smaller quartz grains have an interlocking texture which suggests that recrystallization has taken place, and mortar structure has been developed.

Quartzites. The quartzites of the Northern Division are usually light-green to greyish-green in color. There is every gradation in grain size from the small, recrystallized quartz grains in the matrix to those which are medium-grained according to the Wentworth scale, and hence it is difficult to set a size limit for the grains of the matrix. Point counts reveal that these rocks have an average composition of 78 percent quartz, 4 percent orthoclase, 1 percent plagioclase, 3 percent calcite and 14 percent "matrix". Calcite occurs in irregular grains and as veinlets cutting through the rock, and in outcrop is visible along some of the bedding planes.

One very rusty type with an excellent cleavage parallel to the bedding consists mainly of quartz grains with some orthoclase and plagioclase, and accessory zircon. Its color is due to a high limonite content.

Sericite phyllites. In hand specimen these rocks are highly schistose and in some cases are paper-thin. Microscopic examination reveals that they are composed almost entirely of sericite with very thin, silty bands (fig. 19). One section has numerous tiny specks of magnetite, while another contains tiny grains of leucoxene and limonite. Any clastic texture which these rocks may have possessed has been completely obliterated by recrystallization.

Sheared felspar crystal tuffs. In the hand specimen these rocks are very schistose, weather grey, and contain barely visible felspar crystals. Thin-section examination reveals that the rocks are composed of euhedral plagioclase and orthoclase crystals in a groundmass consisting of interlocking quartz grains and sericite, with possibly some orthoclase (fig. 18).

TABLE II

(a) Mineralogical composition of sandstones in Northern Division of Loon Brook formation.

	Arkose (a)M202	Grit (b)M178	Grit (c)M22	Quartzite (d)M260A	Quartzite (e)M12
Quartz	19.0	28.0	28.0	78.0	73.0
Orthoclase	35.0	2.0	5.0	4.0	7.0
Plagioclase	6.0	-	-	1.0	1.0
Matrix	39.0	70.0	68.0	14.0	14.0
Calcite	-	-	-	3.0	1.0
Leucoxene	-	-	-	-	3.0
Limonite	-	-	-	-	2.0
	99	100	101	100	101

Some of the felspar crystals show the effects of crushing and are fractured and rounded; shearing stress has revolved some of the felspars so that now they are at right angles to the schistosity. Tyrrell (1956, p. 286) points out that sheared quartz porphyry in which the quartz and felspar phenocrysts escape granulation, and persist as porphyroclasts in a very fine textured, sheared quartz-sericite matrix is called "porphyroid". Other minerals present are scattered grains of limonite, and ilmenite altering to leucoxene.

Sheared quartz-felspar crystal tuffs. These rocks consist of quartz and felspar phenocrysts in a matrix consisting of very fine-grained quartz and sericite. Like the felspar tuffs they are highly schistose and dark-grey in the hand specimen, and except for barely-visible quartz eyes they are scarcely distinguishable from a metamorphosed shale.

The quartz and felspar crystals have undergone granulation, and individual pieces of the quartz crystals have been pushed apart by subsequent movements. The plagioclase crystals are in an advanced state of alteration and the end-product appears to consist largely of a brown, strongly pleochroic biotite. As is usual for most of the rocks of this formation, limonite and leucoxene grains are scattered throughout them and they are often traversed by tiny intrusive veinlets of quartz.

c. Southern Division

(i) Outcrops and rock types observed

The Southern Division of the Loon Brook formation is best exposed in Loon Brook, where intermittent outcrops are found in the upper 12,000 feet of the stream course. Many good exposures are also found in the upper part of Veneer Brook to the west, but eastward in Carter Lake Brook the Southern Division does not appear to be present and the Northern Division is in contact with the Carter Lake volcanics.

South of the Carter Lake formation another band of sedimentary rocks, which is probably the time equivalent of the Southern Division to the west, has accumulated to thicknesses ranging from 500 to 5000 feet. Black and grey slates and phyllites predominate in this band, but quartzites occur frequently, and injection gneisses are found in increasing quantities southward toward the Boyd's Pond granite.

The Southern Division consists dominantly of massive quartzites which range in color from greyish-green in the west to light-grey and dark-grey in the east. Interbedded with the quartzites are numerous silty and schistose bands. In the part of the map area east of Loon Brook the quartzites are sometimes so massive in appearance that they bear a striking similarity to aplite, but associated with them are considerable amounts of slightly metamorphosed, light-green sediments and dark-grey to black phyllitic shales.

Alteration has taken place in the quartzites but it has been selective so that only thin bands have been affected. The alteration appears to be of two types: (1) the quartzite has become more or less porous and usually weathers to a distinctively rusty color; and, (2) the quartzite has been silicified and bleached, and pyrite and chalcopyrite have been introduced. Bands of this type of alteration up to five feet in width were noted in the vicinity of Veneer Brook.

Some pyrite is usually associated with the quartzites, and although it is not present in very great quantities the large amount of rust produced through weathering of the pyrite gives the impression that it is very plentiful. In some outcrops there are rusty patches having a diameter of 5 or 6 feet but no apparent mineralization is associated with them. Small stringers of chalcopyrite were observed in the quartzite immediately to the east of Veneer Brook.

In some areas the division is highly intruded by quartz stringers (fig. 63) which are often thrown into small folds - a phenomenon which suggests that the quartz had a certain degree of plasticity at the time the deformational effects were in progress. The amount of quartz intruding the rocks appears to increase as the contact with the Boyd's Pond granite is approached.

(ii) Petrographic description

Quartzites. The quartzites of the Southern Division are poorly sorted, medium-grained rocks in which the maximum grain size ranges between 0.3 and 0.5 mm. In most of these rocks it is practically impossible to distinguish individual grains with the naked eye but a thin-section study shows that they fall into several groups.

The purest quartzites in the area contain over 80 percent quartz (fig. 21). There is no "matrix" in the strict sense of the word; i.e., practically all of the quartz and felspar grains are greater than 0.01 mm. in diameter. Tiny flakes of sericite and chlorite are disseminated through the rocks, together with a few clastic quartz grains less than 0.01 mm. in diameter. Orthoclase makes up not more than 9 percent of the rock, and there is some plagioclase, an occasional grain of perthite, disseminated grains of leucoxene and magnetite, and a fair number of zircon grains in irregular shapes. Recrystallization has taken place and the quartz grains have been welded together, giving a crystalloblastic texture (fig. 21). In many cases the small grains encroach upon the larger ones and partially replace them.

The micaceous quartzites are not as well sorted as those described above, but they also have a crystalloblastic texture (fig. 22). The mica content exceeds 30 percent and is predominantly sericite, but there is also a considerable amount of light-green chlorite, both intergrown with sericite and disseminated in minute flakes throughout the rock. Intergrown with both the sericite and chlorite is a strongly pleochroic biotite. Much of the mica may be authigenic but some of the coarser crystals are probably detrital in origin.

There are also felspathic quartzites in which the felspar content, most of which is orthoclase, exceeds 10 percent and ferruginous quartzites in narrow, rusty-weathering bands, with more than 10 percent limonite.

Quartz-mica schist. This rock type is found in only one location - southwest of Loon Lake - where it occurs in an outcrop over 200 feet wide.

The grains in this rock are fairly well-sorted, have a maximum grain size of 4 mm. and consist, as in the quartzites, mainly of interlocking quartz grains with some plagioclase and orthoclase. In the field, however, this rock was readily classified as a schist because of the presence of prominent bands of dark mica. In thin section these bands, which have been thrown into tiny folds (fig. 23), are found to consist predominantly of muscovite with only subordinate amounts of chlorite and biotite.

Sericite phyllites. These rocks are usually found as thin bands in the quartzites. Although they do not have the silky appearance of many of the phyllites of the Northern Division some of them are very similar in thin section and consist almost entirely of sericite (compare figs. 19 and 24). Others, however, contain high percentages of clastic quartz grains in the silt range, and it would probably be more accurate to refer to them as phyllitic siltstones.

Siliceous bands. The quartzites contain numerous siliceous bands up to 5 feet wide, composed of milky quartz. These bands are especially prevalent in the vicinity of Veneer Brook where they contain considerable percentages of pyrite and chalcopyrite.

A thin-section examination shows that the rock consists mainly of anhedral quartz crystals. Portions of the rock are highly micaceous, however, and appear to be of sedimentary origin. As the bands show conformable relationships with the quartzites it is not unreasonable to suspect that they were formed by a process of replacement, and that the growth took place by transfer of material in the solid state. The presence of rock portions which still have a sedimentary aspect can be explained by assuming that the replacement process did not proceed to completion.

The pyrite occurs as cubes, anhedral crystals, and aggregates of crystals. Inclusions of quartz are found in some of the pyrite crystals, indicating that the pyrite formed later. The force exerted by the growing pyrite crystals has given rise to a peculiar texture in which the surrounding quartz grains have assumed elongate shapes, flaring out from

TABLE II

(b) Mineralogical composition of rocks in Southern Division of Loon Brook formation.

	(i) M(2)184	(ii) M192	(iii) M198A	(iv) M198B	(v) M273
Quartz	55.0	83.0	84.0	71.1	71.0
Orthoclase	2.0	5.7	9.0	-	14.0
Pla gioclase	-	1.9	-	-	1.0
Matrix	39.0	8.5	6.0	13.0	14.0
Leucoxene	-	0.9	1.0	1.9	-
Ilmenite	-	-	-	-	-
Magnetite	4.0	-	-	-	-
Zircon	-	-	-	-	-
Muscovite	-	-	-	1.0	-
Limonite	-	-	-	13.0	-
	100	100	100	100	100

(i) Micaceous quartzite
(ii) Quartzite
(iii) Quartzite
(iv) Ferruginous quartzite
(v) Felspathic quartzite

the boundaries of the pyrite (fig. 25).

Some of the quartz grains are traversed by small veinlets of sericitic material, and their turbid appearance sets them off markedly from the others. Such a texture is quite uncommon and may be attributed to a type of selective alteration by the mineral-bearing solutions which introduced the pyrite.

(iii) Origin and environment of deposition

A fair amount of contrast exists between the Northern and Southern Divisions of the Loon Brook formation; hence they must have been deposited under contrasting environmental conditions. The Southern Division, while it contains numerous thin bands of phyllite and schist, is characterized by a persistent, monotonous quartzite sequence, which indicates that the conditions under which it accumulated remained fairly constant throughout extended periods of geologic time.

What was the origin of these relatively clean quartzites of the Southern Division? On the one hand, both the source area and the site of deposition may have been tectonically very stable so that there was ample time for reworking and winnowing prior to final burial. On the other hand, the wide range in grain size which is found in many of the quartzites shows that there was insufficient time to attain a high level of sorting. In this connection, according to Dunbar and Rodgers (1957, p. 522), Folk has found that:

> . . . . the passage from an initial clayey, poorly sorted, angular sediment to a completely matured, rounded and sorted sand is marked by three stages. . . . These are (1) removal of clay, (2) attainment of good sorting of the nonclay fraction, and (3) rounding of the quartz grains. The first two steps are quickly achieved, even by the brief transport of ephemeral streams. The last stage is attained only after prolonged transport and

> characterizes only the mineralogically mature multicycle sands or the sands of certain beaches.

There has been some recrystallization of the grains in the quartzites, but it is still evident that they had never been well-rounded. All the evidence taken together - thickness of the division, poor rounding and relatively poor sorting of the grains - precludes the possibility that we are dealing with a beach deposit and favors the assumption outlined above, i.e., stream erosion of a tectonically stable source area and deposition in a stable-basin environment. Periodic fluctuations in the competency of the streams could account for quiescence in the basin and the settling of clay-size particles to produce thin shale bands.

There is a greater preponderance of shales - black, greenish and grey- in the Northern Division, grits are widely distributed especially in the western part, and the overall impression imparted to the observer is that of instability in the depositional basin. The high content of matrix and the angularity of grains in the grits, and the presence of arkosic bands indicate that rapid burial took place during some periods. Opposed to these conditions were more quiescent times which allowed the accumulation of mud, sometimes in stagnant basins so that pyritiferous shales were produced.

Black slates, phyllites and siltstones

Three widely separated occurrences of black slates, phyllites and siltstones are found in the area north of the river. One of these units, which has already been mentioned in connection with the occurrence and chief rock types of the sandstone member of the Lake Ambrose formation, was observed in two exposures: one near the extreme southern shore of Tally Pond, the other close to the southeast shore of West Tally Pond.

The former exposure has been warped into small folds with an amplitude of about 1 foot, while the axial planes strike about 15 degrees north of west and are vertically dipping. The other outcrop has been highly weathered and crumbles into small fragments when any attempt is made to procure a specimen, but close examination of the bedding planes reveals that it, also, is tightly folded.

The second occurrence is found immediately to the east of Five Mile Camp, and consists of 3 exposures, each about 1000 feet from the other, which outcrop between the Pine Falls formation and the sandstone member of the Lake Ambrose formation.

The third unit, also, is found between the Pine Falls and Lake Ambrose formations and consists of widely separated outcrops of black phyllite, and black and grey shales which are often pyritiferous. The westernmost exposure was found just to the west of the junction between the Tally Pond and Noel Paul roads, while the easternmost outcrop was observed just to the northeast of the camp at Pine Falls, the two outcrops being thus separated by a distance of nearly 3 miles.

The writer sees the main problem presented by these black sediments as follows: were they deposited in their present positions? or are they erosional remnants of larger blocks which were thrust over from the south? Lack of fossils in the black shales and siltstones, as well as in the formations which enclose them, only serves to intensify the problem, and its solution is hampered also by the absence of outcrops at the contacts. Until it can be proven otherwise, it must be assumed that these isolated bodies of sediments are resting in their original sites of deposition.

CHAPTER IV

VOLCANIC ROCKS

General Statement

The volcanic rocks in the Noel Paul's Brook area are approximately equivalent to the sedimentary rocks in variety and thickness if not in extent. In addition to narrow bands of tuff in the Northern Division of the Loon Brook formation, 5 formations of volcanic rocks were mapped. These are: the Pine Falls formation, the Tally Pond volcanics, the West Tally volcanics, the Chickadee lava formation and the Carter Lake volcanics. Although separated by a distance of over 3 miles, the Carter Lake and West Tally volcanics show a marked similarity both in the field and in thin section, but the Tally Pond and Pine Falls formations are decidedly different, both from each other and from the other two formations.

None of these formations have a precise type locality; all of them received their names from a pond or lake close to, or within the boundaries of, the formation. Their relative ages could not be determined and the formations are not dealt with in any specific order in the discussion which follows. As no chemical analyses of these volcanic rocks were made, they have been named strictly on the basis of their mineralogical compositions as determined with the aid of the petrographic microscope.

Pine Falls formation

The main body of the Pine Falls formation is found to the east of West Tally Brook, but a thin band extends as far west as Haven Steady and is cut off from the main body by a narrow band of sedimentary rocks belonging to the Northern Division of the Loon Brook formation. The Pine Falls formation has a thickness of over 5500 feet in the area south of the Tally Pond Road, thins to 3200 feet in the vicinity of Pine Falls, and thickens gradually eastward to more than 2 miles. It is composed dominantly of highly altered and sheared green flows and tuffs with interbedded limestones, silicified limestone breccias, limy shales, and green schists.

The greenstones show much variation in competence, color, grain size and weathering characteristics from one outcrop to another and even between points in the same outcrop. Locally, shearing has converted these rocks to schists. The color varies from light greenish-grey, through yellowish-green to dark green. The heterogeneity observed suggests that the formation consists of a considerable number of thin flows and tuff beds. The boundaries have been more or less obscured, and mineralogical assemblages altered, by metamorphic effects; it is evident, however, that the greenstone volcanics of the Pine Falls formation were originally intermediate to basic lavas.

In the greenstones epidotization has been the most common type of alteration, the epidote being found as small pods, stringers, veinlets averaging 0.3 inches in width, and nodules a foot or more in diameter. Serpentinization has also been fairly intense, and asbestos veinlets, which average 0.1 inches in width and usually pinch out within less than a foot (fig. 28), occur in many outcrops. Pegmatite is present in veins varying in width from a fraction of an inch to 2 inches, and in lenses of larger dimensions (fig. 29). These bodies are composed of quartz and felspar and often contain small fragments of wall rock. The writer believes that they probably are of the replacement type.

<u>Limestones</u> are found at several locations within the formation and were first noticed by Howley in 1888 on a trip from the south coast of the island by way of Bay d'est River and Noel Paul's Brook. In his report for that year he stated that: " . . . on the course of the river downwards at about a mile and an half below the steady, strong bands of bluish-grey limestone strike across the river." The writer investigated the river below Noel Paul's Steady, the waters of which are now kept back by a large dam. For the first third of a mile below the dam the only rock type observed is greenstone, but about 1600 feet downstream there is a bed of limestone over 100 feet thick. The top and bottom parts of the bed are dense, black, strongly banded rock, but the main part of the outcrop consists of light-grey, silicified limestone-breccia. Similar outcrops are found further downstream and one of them contains interbedded quartzite bands. Limestones were also found in two outcrops south of the Tally Pond Road. In one of them a vertically dipping bed of light-grey limestone about two feet thick is interbedded with massive greenstone (fig. 30), and large inclusions and small stringers of calcium carbonate are found in the surrounding rock. In the other outcrop, half a mile to the east of the first the writer found a bed of dark-grey to black limestone about 150 feet thick.

Striking obliquely across Noel Paul's Brook just above Pine Falls are several beds of grey to purple limestone interbedded with grey, greyish-green and pink limy shales. One of these limestone beds is about 30 feet thick and is highly contorted, a feature which has been emphasized by the eroding effect of the river water (fig. 31). As the beds above and below are not even mildly folded, it is possible that the contortions are a primary features imposed upon the limestone before consolidation.

Of all the rocks in the Noel Paul's Brook area the limestones of the Pine Falls formation evoked the greatest hopes for finding fossils, but many hours of painstaking examination unfortunately yielded no trace of any.

Petrographic description

a. Metamorphosed lavas

Except for a single occurrence of agglomerate, a microscopic study of the greenstones of the Pine Falls formation revealed that they consist of metamorphosed lavas, tuffs and impure sandstones. As the intensity of metamorphism was not everywhere the same, and as the greenstones consist of many separate flows which undoubtedly had variations in composition, the rocks show great differences of texture and composition.

Where the greenstones have undergone only mild metamorphism and still present a massive appearance, they consist of anhedral pyroxene grains, plagioclase laths and minor amounts of epidote and leucoxene. The original texture of these rocks is still preserved (fig. 32) and the pyroxene grains enclose small plagioclase felspar laths, giving an ophitic texture. In other areas the alteration has advanced to a stage where the rocks consist mainly of a fine-grained aggregate of cloudy epidote grains and fibrous crystals of uralite, with occasional quartz grains and patches of chlorite. Intermediate between those two types is a schistose rock composed of large, clear, euhedral felspars and large, irregular, shredded grains of uralite, some of which are almost entirely altered to chlorite (fig. 33).

That the original flows must have varied in composition is demonstrated by the fact that one rock type which is easily distinguished from the others in the field by its light greenish-grey color and its softness, consists almost entirely of a non-pleochroic uralite, which occurs mainly in tiny shreds (fig. 34). A few anhedral grains of this mineral, however, still show the two cleavages, almost at right angles, of the pyroxene from which they were derived. Disseminated throughout this rock are minute grains of epidote, and a few small crystals of quartz may be observed in the groundmass.

Although some of the rocks have undergone a fairly high grade of alteration, shearing stress must have been generally low as the original textures are often beautifully preserved: e.g., the greenstone shown in figure 35 has a texture in which the felspar laths are associated in radiating, sheaflike aggregates called "keraunoids" by Washington (quoted by Johnsen, 1952, vol. 3, p. 253). The large number of calcite grains, both singly and in aggregates, which are found in this rock suggest that it may have been carbonatized.

b. Impure sandstones

Interbedded with the metamorphosed volcanics and well exposed in the bed of Noel Paul's Brook at Pine Falls, are schistose greenstones which are quite similar to the others in hand specimens, but can be recognized as being of sedimentary origin by microscopic study. These schists are also fine grained, but differ from the rocks of volcanic origin in that they have a stronger banding and consist dominantly of interlocking grains of quartz and flakes of chlorite. Some of the latter are almost isotropic, with the majority displaying peculiar reddish-brown anomalous birefringence. Felspar crystals are also present and they range in size up to 0.4 mm., while minute grains of epidote are disseminated throughout the rock. In one of the sections examined calcite grains make up about 5 percent of the rock, while in another only a trace of calcite is present and instead there are about 5 percent of fresh euhedral ilmenite crystals showing cubic, triangular, and 6-sided cross-sections (fig. 38). That the ilmenite is authigenic is shown by the fact that the quartz surrounding some of the crystals has been recrystallized and shows a texture similar to that in figure 27. It is not unlikely that the calcite is also authigenic, being formed in situ from percolating solutions saturated with calcium carbonate.

c. Tuffs and agglomerate

The tuffs are very fine grained and similar to the altered lavas in appearance, but they show a primary banding and have a streaked and spotted appearance arising from the presence of bands and clots darker than the main body of the rock. These rocks consist of angular grains of quartz and felspar, a high percentage of turbid epidote grains and aggregates, and a considerable amount of an unidentified isotropic material (fig. 36) which is white when viewed in reflected light and is possibly the mineral forming the dark streaks and spots in the hand specimens.

The agglomerate has a greyish-brown color on the weathered surface, has a peculiar pitted appearance (fig. 37), and contains fragments of basic lava up to 3 inches in length, composed of tiny felspar laths and large euhedral felspar phenocrysts. The matrix contains smaller rock fragments, euhedral felspars and angular grains of quartz, epidote and calcite grains, and patches of chlorite. Locally the matrix is not clastic but is made up of basic or intermediate lava showing a well-defined flow texture. An unusual fragment embedded in the matrix consisted of a granophyric intergrowth of quartz and orthoclase.

Tally Pond volcanics

The Tally Pond formation lies immediately to the east of Tally Pond and extends northeastward to within a mile of Noel Paul's Brook, a distance of some 12 miles. The formation is composed of numerous rhyolite flows and others of less acid composition, with interbedded thin bands of tuff and some mudstone.

Individual flows range from 1 inch to several feet in thickness, while tuff beds are usually less than a foot thick.

An exposure observed approximately one mile east of Tally Pond is shown in figure 39. At this location the individual flows and tuff beds have straight and well-defined boundaries, whereas elsewhere in the Tally Pond formation the rocks are massive. From bottom to top this outcrop contains:

(1) Very fine-grained, greyish-green quartz latite - 2 feet

(2) Very fine-grained, greenish quartz latite - 5 inches

(3) Very fine-grained, greenish quartz latite - 8 inches

(4) Acid tuff - 4 feet

(5) Very fine-grained quartz latite - 2 feet

The rocks of the Tally Pond formation gave much trouble in the field because of their extremely fine grain and absence of primary features, and some of them which were mapped as siltstones were eventually proven to be volcanics on the basis of examination in thin section.

Petrographic description

a. Flows

The flows range in color from light greyish-green to dark-grey and brownish, but practically all outcrops are white on the weathered surface. Some of the rocks are extremely fine grained and display a conchoidal fracture; other varieties are slightly coarser grained and break with a subconchoidal fracture.

The majority of the flow rocks cannot be scratched with a knife blade and it may be safely assumed that they have a highly acid composition. Their cryptocrystalline nature, however, makes it impossible to determine their mineral composition under the microscope. The finest grained varieties contain much material which is practically isotropic but occasionally shows aggregate polarization, so that the rocks can be considered as probably consisting of a partially devitrified glass. The lamination or flow banding which is fairly well expressed in one of the hand specimens studied cannot be seen in the corresponding thin section. All of the thin sections examined show tiny fractures that have subsequently been filled with quartz.

All flow rocks of the Tally Pond formation contain microlites, and it is only on the basis of the composition of these microlites that it is possible to distinguish different rock types. Two such types occur in the finer grained flow rocks and a third in the rocks of coarser grain. In the first group the microlites are muscovite. In the second group they are hornblende of an almost needle-like appearance, but large enough to allow optical identification (fig. 40).

In the third group of rocks the microlites are a mineral showing pleochroism from yellowish-brown to almost black, which is either biotite or cossyrite. These microlites are stubby in contrast to the elongated shapes assumed by the muscovite and hornblende microlites. They form sheaf-like crystals, broader on the ends than in the middle, which are often associated in aggregates of stellate patterns (fig. 41). The third group are much fresher in appearance than those of the two others and contain no isotropic material; their microlites constitute a much higher percentage, and with their larger size may be readily seen in the hand specimens to which they impart a brownish hue.

b. Tuffs

The tuff beds are tough, have a greenish-grey color, and contain subrounded greenish to black rock fragments and grains of quartz and felspar visible with the unaided eye.

In thin section the tuffs are found to consist of fragments of very fine-grained volcanic rocks containing hornblende microlites, and others which are apparently more acid in composition. In addition there are very turbid crystals of plagioclase and orthoclase, angular grains of quartz, and a few irregular grains of ferruginous carbonate. There is a fair percentage of pyroxene grains scattered throughout the rock, and a few patches of an unidentified mineral with low birefringence. The matrix is composed mainly of isotropic material, probably glass, and a chlorite with anomalous blue interference colors.

c. Nomenclature of rock types

Because the rocks of the Tally Pond formation are so fine grained that it is impossible to estimate the relative percentages of the minerals constituting them, and because no chemical analyses were made, they have to be named as best as possible with the evidence available.

All types are definitely acid. The fine-grained rocks with muscovite or hornblende microlites are almost certainly equivalent to either quartz latite, rhyodacite or rhyolite. It is, however, impossible to choose one of these names in preference to the other two as neither orthoclase nor plagioclase are developed, on whose relative percentages alone the choice can be made.

The rocks with biotite (or cossyrite) microlites present are the least acid types, but even they are by no means close to andesite in composition, and can rather be compared with quartz latites.

West Tally volcanics

The West Tally volcanic formation is found to the west of Tally and West Tally Ponds, on two islands in Tally Pond, and in one outcrop northeast of this pond to the north of the Tally Pond volcanics. The formation consists dominantly of rocks looking like quartz porphyry, but it also includes felspar porphyry, flow breccia and very fine-grained, sheared rhyolites (which were not studied in thin section). The paucity of outcrop within the boundaries of this formation renders it impossible to determine the relationships between the different rock types.

a. Petrographic description

(i) Felspar Porphyry

The felspar porphyry is grey on the fresh surface and weathers grey. Phenocrysts of buff to pink felspar are visible with the unaided eye. Under the microscope the rock is holocrystalline and consists of orthoclase and plagioclase in a fine-grained matrix of quartz, plagioclase, orthoclase and a few grains of perthite (fig. 42). The plagioclase crystals were found to have a composition of Ab90 An10, but the plagioclase in the matrix is twinned so poorly that it is impossible to determine its composition. Quartz not only occurs in the matrix, but also in segregations of anhedral grains. Leucoxene is disseminated throughout the rock, and there are many pseudomorphs of limonite after pyrite. Rutile is also present in the form of small acicular crystals, sometimes associated in clusters. On the basis of this microscopic study the rock may be called latite porphyry.

(ii) "Quartz porphyry"

The rocks that look like quartz porphyry range from light grey to almost black in color and contain small, glassy quartz eyes in an aphanitic groundmass. In some cases small, brownish crystals can also be seen especially where intense weathering has given them a very rusty aspect. In thin section these rusty patches were found to consist of an aggregate of iron-bearing carbonate, quartz, and sericite, and are probably the remnants of original felspar crystals. The quartz grains are usually rounded, but as a result of the moderate metamorphism which the rocks have undergone some of them are shattered into smaller fragments. The spaces between the fragments are filled with quartz "powder".

The groundmass is holocrystalline and consists of fine-grained quartz and orthoclase with disseminated sericite (fig. 43). Other minerals occurring in minor amounts are magnetite, leucoxene, small acicular crystals of rutile, and long prismatic crystals of zoisite.

Judging from composition and texture as seen under the microscope these rocks could be called rhyolite porphyries, but a recent study made of similar rocks in the vicinity of Buchans casts considerable doubt on their flow nature. The members of the geological staff had this to say about their results:

> A rock exposed at Lucky Strike and westerly from there in considerable quantity, has been described in the past as quartz porphyry and stated to be intrusive. This is in error. This formation is dominantly a coarse acid tuff with some agglomerate areas and lava sheets. The most noticeable feature of the tuff is the presence in abundance of quartz grains up to 1/3" and felspar grains up to 1/10" in size. The matrix is fine-grained ash.

The presence of a flow horizon such as was discussed above tends to suggest that the West Tally formation is also, at least partly, of tuffaceous origin.

In view of this recent result and the presence of flow breccia such as described below, the writer concludes that the "quartz porphyries" of the West Tally formation might also be of pyroclastic origin and could be called rhyolite tuffs.

(iii) Flow breccia

The flow breccia found in one only outcrop, not far from the shore of West Tally Pond, has a massive appearance and contains fragments up to a foot in length. Some of them seem to be acid volcanic rocks; they are almost white and contain tiny quartz eyes. Other fragments of dark green color are apparently less acid in composition. The fragments are set in a matrix of acid appearance which includes small quartz eyes and tiny white felspar phenocrysts.

Examination of a thin section from this outcrop reveals that the matrix contains crystals of quartz, orthoclase and plagioclase of both euhedral and broken outlines (fig. 45). The felspars are very turbid as their surfaces are covered by a black opaque mineral. They are also in part altered to sericite and chlorite.

The presence of banding which is observed in thin section, the varied nature of the larger fragments, and the contrast between angular fragments and euhedral crystals in the matrix suggest that this rock is an acid flow breccia containing foreign fragments.

Chickadee lava formation

The Chickadee lava formation extends westward for about 6 miles from the shore of West Tally Pond, and has an average thickness of about 4000 feet. The mass is somewhat heterogeneous: the grain size varies from aphanitic to phaneritic and the color from light green, to dark green to almost black.

No primary flow banding was seen in the lava, but locally there is poorly developed pillow structure. The pillows range from a foot to three or four feet in diameter, but they are usually irregular in shape. In at least one outcrop their arrangement nevertheless suggested that the top of the lava formation is toward the north. If this interpretation is correct then there may be overturning, at least locally, within the formation. In one exposure a small patch of red chert was seen in the interspaces between two pillows, indicating that some sediment was mixed with the lava at the time of its eruption.

Epidotization is not prevalent in the Chickadee lava formation, but a few outcrops show many epidote blebs and stringers. Near one of these epidotized outcrops a flow-breccia zone about 3 or 4 feet thick was observed. Most of the fragments in the breccia are angular though some are rounded, probably through reaction with the enclosing lava.

The lava is amygdaloidal in some outcrops and whilst one exposure contains only reddish siderite amygdules, another was seen whose numerous vesicles have been filled with calcite and ankerite. The amygdules do not often exceed 0.1 inches in diameter and are usually smaller.

A few outcrops of very fine grained, light-green, rusty-weathering lava were found to contain a small percentage of pyrite. It is possible that the pyrite was introduced by mineralizing solutions which bleached the rock to its present light color. The pyrite may, however, be primary and hence the bleaching could have been caused by H_2SO_4 resulting from intensive weathering of the mineral.

<u>Petrographic study</u>

Although the Chickadee lava formation has not been subjected to any apparent shearing, it has been moderately metamorphosed so that all of the original ferromagnesian minerals have been destroyed. It now consists dominantly of plagioclase felspar and prochlorite, but carbonate minerals sometimes constitute a high percentage of the rock. A microscopic study showed that no one texture is dominant, the rock changing greatly in its characteristics from place to place. Like greenstones of the Pine Falls formation (p. 34) the Chickadee lava formation probably consists of a large number of flows, and one example of flow banding was seen in thin section (fig. 46) although it is not readily apparent in the corresponding hand specimen.

The plagioclase occurs as elongated microlites and laths, less commonly as more or less equidimensional larger crystals. In some specimens only microlites are found; in others microlites occur in addition to laths; while in still others microlites, laths and the larger crystals are found together. The laths and microlites usually have a random criss-cross arrangement, giving rise to the familiar felty or dolerite texture (fig. 47).

The composition of the plagioclase felspar was determined by 3 methods:

(1) Measurement of maximum extinction angles from the direction of elongation in microlites.

(2) Determination of maximum extinction angles of albite twins in sections normal to (010).

(3) Estimation of refractive index.

The result was: An_{35} Ab_{65} (andesine).

The interstices between the felspar laths are occupied by a fine-grained aggregate of nearly isotropic prochlorite. Coarse, tabular crystals of this mineral occurring here and there made its optical identification possible. In some specimens the matrix contains a finely divided aggregate of sericite and felspar in addition to the chlorite.

The Chickadee lava is fairly highly carbonatized and calcite, ankerite and siderite have developed. Calcite is found in irregular grains; ankerite usually displays good crystal outlines and is surrounded by a rim of limonite; siderite occurs as vesicular fillings and is characterized by a heavy coating of iron oxide.

The rock also contains a small amount of secondary quartz which occurs as subround crystals and aggregates of interlocking grains. Calcite often occurs as replacement of quartz but much more commonly it replaces plagioclase. There appears to be a very close relationship between the calcite, quartz and prochlorite, and in one instance a grain of calcite is surrounded by a corona composed partially of prochlorite and partially of quartz. Chlorite also fills cracks in, and replaces, plagioclase.

The samples which are darkest in color contain a high percentage of iron oxide. The ankerite-bearing types are characterized by small, elongated magnetite grains, which assume a more or less dendritic pattern (fig. 48). Some ilmenite is also found and most of the specimens contain disseminated small grains of leucoxene. As a rule, minor accessory minerals are lacking but in two of the thin sections which were examined, tiny acicular crystals of rutile are found in great profusion. They occur in clusters of crystals, less commonly in irregular grains, and also as knee-shaped twins.

Many writers would call the Chickadee lava an andesite because the plagioclase has a composition less calcic than An_{50}, but because of the absence of porphyritic and flow textures usually associated with andesites, the writer prefers the name "basaltic andesite".

Carter Lake volcanics

The Carter Lake volcanic formation coutcrops in a band which extends westward from the eastern margin of the map area for a distance of some six miles and has an average thickness of about 8500 feet. The formation consists of a group of grey-weathering volcanic rocks in which the dominant type is "quartz-felspar porphyry". Also present are black rhyolite, buff rhyolite with associated coarse tuff, very fine-grained black volcanic ash, and coarser volcanic tuffs with quartz eyes.

The "porphyry" is locally sheared, bleached and silicified, and the bleached outcrops usually display a rusty color due to the weathering out of pyrite.

A detailed description of the petrography of the Carter Lake formation is unnecessary because most of them (the "porphyries") closely resemble the tuffs of the West Tally formation described above (p. 61). Others are identical to the tuffs which are found in the extreme southern part of the Northern Division of the Loon Brook formation, in the vicinity of Veneer Brook, which were also described above (p.40).

CHAPTER V

INTRUSIVE ROCKS

General statement

A variety of intrusive rocks are found within the thesis area. They consist of bodies ranging in size from a batholith measuring at least 36 miles across, to sills and dikes no more than 100 feet thick. The following intrusive rock types were mapped in the field and are discussed in this chapter: a. granite, b. crushed granodiorite-greisen, c. sericitized quartz monzonite-granodiorite, d. diorite, e. micropegmatite, f. syenodiorite, g. metadolerite.

Some of the larger intrusions, or intrusions of medium size - especially the large micropegmatite dike and the quartz monzonite-granodiorite stock - are quite probably linked to a granite at depth, and it is not unlikely that the smaller dikes are differentiates of the same granite mass.

Dikes and sills

a. Micropegmatite dike

A large dike, intrusive into the Loon Lake formation, strikes parallel to the shore of Haven Steady in the southwest corner of the thesis area (fig. 49). The dike, which rises 400 feet above the waters of the steady, is about 2 miles long and ranges in thickness from 800 to 2300 feet. To the west it terminates at the shore of Lake Douglas and apparently plunges beneath the lake, as it does not appear on the opposite side.

The rock has been highly sheared and displays a foliation parallel to its margins. At its northeastern extremity it is also highly brecciated. An outcrop near the mouth of Rosie Brook contains angular to rounded fragments ranging from 0.1 to 5 inches in length (fig. 65), and nearby, on the shore of Haven Steady, crushing has reduced the fragments to an average diameter of 0.1 inches.

Most of the rock consists of intergrowths of quartz and orthoclase giving it a micrographic or micropegmatitic texture (fig. 50). Quartz is usually the dominant mineral and occurs as blebs, drops, angular rods and linear forms within the orthoclase. Tabular crystals and extraordinarily elongated laths of plagioclase are found which appear to have crystallized prior to the micropegmatitic constituents. Occasional intergrowths of quartz and plagioclase are also present.

The ferromagnesian minerals in the rock are intergrowths of deeply pleochroic biotite and chlorite (var. penninite). A few grains of calcite may be seen and on a smaller scale the mineral is found to replace plagioclase. Scattered grains of leucoxene, hematite and limonite are also present. Much twisting and fracturing of the individual components is evident, especially in the case of the long felspar laths, and are a reflection of the shearing stress which the rock has undergone.

Mineralogically, the brecciated rock differs from the sheared micropegmatite only in that it contains broad muscovite flakes in addition to sericite. In the section examined (fig. 51) the crushing effects have actually progressed beyond the stage of brecciation, and the rock is composed of rounded relics of the original fragments embedded in a groundmass of smaller elements - dominantly sericite.

b. Syendiorite sills

Three sills, having an average thickness of about 100 feet, intrude the sedimentary rocks of the Burnt Pond formation in Burnt Pond Brook. They have a porphyritic texture and are composed of white, anhedral felspar crystals in a greyish-green matrix.

A microscopic study reveals that the rock consists mainly of felspars and pyroxene (fig. 52). About 28 percent of the felspars are oligoclase, the remainder is orthoclase. Most of the plagioclase and orthoclase are turbid as a result of alteration to sericite. Pyroxene (var. pigeonite) makes up about a third of the rock. In addition to penninite, which comprises about 15 percent of the rock, grains of zoisite and calcite occur in the interstices between the felspars and pyroxene. A few grains of accessory quartz are also found, while ilmenite, altering to sphene, is the most common accessory mineral.

According to Johannsen's classification a rock with the above composition is called a syendiorite.

c. Metadolerite sill

A metadolerite sill intrudes rocks of the Loon Brook formation in Veneer Brook, but is nowhere else exposed. The sill has a thickness of over 100 feet and is composed of a fine to medium-grained rock, light green in color, with clearly visible amphibole crystals. Contact effects in the vicinity of the dike are slight and there is noticeable change in grain size at the borders.

The sill has been subjected to moderate metamorphism and the present mineral assemblage is only a reflection of the original composition.

The rock consists mainly of tremolite phenocrysts with minor amounts of anthophyllite and plagioclase in a matrix composed of zoisite, chlorite, and small needles and sheaf-like aggregates of tremolite (fig. 53). Ilmenite and epidote are accessories.

The tremolite is probably a uralitic pseudomorph of pyroxene, although no original pyroxene remains to support this assumption, and the tremolite in turn shows alteration to chlorite. Zoisite occurs as euhedral crystals, aggregates of anhedral crystals and irregular grains. Some of the grains are enclosed by larger crystals of tremolite. Its frequent euhedral development and its relationship to the tremolite suggest that zoisite crystallized at an early stage. Skeletal crystals and irregular grains of ilmenite are disseminated throughout the rock, and in contrast with its usual tendency to alter to leucoxene it has given way to sphene in this case.

Plutonic rocks

a. Boyd's Pond granite

The Boyd's Pond granite was first named by N. L. Brown in 1952 (unpublished M.Sc. thesis, McGill) and is part of a large batholith which extends far into the southern part of Newfoundland. This granite outcrops adjacent to the Southern Division of the Loon Brook formation. The contact between the two is nowhere exposed in the thesis area but can be assumed to be intrusive.

The granite is medium grained and usually grey in color, but some outcrops show a tinge of pink, and many boulders of dark, hybrid granite are found in the vicinity of the contact. In many outcrops small, quartz eyes can be seen in the rock.

Two thin sections were cut from samples of the Boyd's Pond granite. One of them consists almost entirely of euhedral microperthite and anhedral quartz grains, with only an occasional small flake of muscovite (fig. 54). A few grains of perthite have reached an advanced stage of alteration to sericite, while the odd grain of plagioclase does not appear to have any orthoclase intergrown with it.

In the other thin section the quartz and perthite are intergrown to give a granophyric texture (fig. 55). A few crystals of quartz and orthoclase have not taken part in any intergrowths, but the most peculiar feature in this rock is the presence of spherical grains of quartz and perthite with absolutely sharp boundaries (fig. 54).

b. Crushed granodiorite-greisen

A small intrusive body is found slightly north of the Chickadee lava formation in the area just to the west of the West Tally formation. Its size could not be determined exactly because of the scarcity of outcrop in this area.

The rock consists of about 45 percent quartz and a similar amount of felspars which are represented by about equal amounts of orthoclase and a plagioclase of composition Ab90 An10. The only mafic mineral is prochlorite which is found in several small patches. Under crossed nicols it shows purple halos formed by radioactive particles emitted by tiny inclusions of zircon (fig. 56). Some of it is found as inclusions in the felspar but much of it is concentrated in veinlets filling cracks in, and at the boundaries between, the felspar and quartz. Irregular grains of pyrite altering to limonite are scattered throughout the rock, and there are a few grains of leucoxene and calcite as well as accessory apatite and zircon. About 6 percent of the rock is fine-grained muscovite and sericite.

A rock with this composition, if named in the manner prescribed by Johannsen, is a granodiorite-greisen. Johannsen, himself, prefers the name quartz-granodiorite, as he objects to the qualifying term "greisen" for unaltered rocks.

The order of crystallization in this intrusive seems to have departed somewhat from the normal because large blebs of quartz are sometimes found in the orthoclase, indicating that at some stage in the cooling of the rock the two minerals crystallized side by side. One example was seen where small offshoots from a quartz grain are invading, and apparently replacing, a plagioclase crystal.

The rock has been subjected to fairly strong dynamic metamorphism, and crushing effects have drastically altered the original igneous texture. Some of the quartz grains were broken into many small pieces which became welded together again, giving an interlocking texture similar to that found in sedimentary rocks.

c. Sericitized quartz monzonite - granodiorite stock

A small intrusive stock, just over 2 miles long and a little more than a mile wide at its widest part, is found at the extreme eastern margin of the map area. The stock is in contact with the Tally Pond formation on its western boundary and the Lake Ambrose formation on the south, but because of the extreme scarcity of outcrop in the area no contacts can be seen. However, it is possible that the stock has intruded both these formations.

In the field two main rock types may be found within the stock. One is characterized by rusty patches in a fine-grained groundmass which is light greenish-grey in color with black streaks. A microscopic study shows that the groundmass, which comprises about 35 percent of the rock, consists of an aggregate of finely divided sericite (fig. 57). Approximately 20 percent of the rock is quartz which shows undulatory extinction and has been fractured by dynamic metamorphism, while orthoclase, with 42 percent, is the predominant mineral. The remaining 3 percent are plagioclase, and there are a few grains of leucoxene.

The surfaces of the orthoclase crystals are covered with tiny irregular grains and euhedral rhombs of ferruginous carbonate, and this explains why the rock weathers with rusty patches. The groundmass has obviously been formed through the alteration of plagioclase, because some remnants of the crystals may be seen under strong magnification. It is strange, therefore, that some plagioclase escaped the alteration suffered by the majority of the crystals.

If it is assumed that the groundmass was indeed made up originally of plagioclase then the original rock must have been a quartz monzonite.

The other rock type found in this stock is similar to the quartz monzonite described above, but in the field it shows anhedral phenocrysts of pink felspar instead of rusty patches. It also differs in that quartz is readily visible in the hand specimen, and the groundmass contains more dark material than that of the rusty rock.

Thin-section examination reveals that the groundmass is similar to that in the quartz monzonite and comprises about 45 percent of the rock. It appears that the rock originally contained a high percentage of zoned felspar and that the cores of the crystals, which originally were potash felspar, were highly sericitized; the rims, comprised of albite, are still fresh (fig. 58). Examples may be seen, however, of fresh potash-felspar crystals surrounded by a rim of albite. Unaltered potash felspar crystals and potash felspar forming coarse perthitic intergrowths with albite comprise about 17 percent of the rock, and there are about 20 percent quartz, 8 percent chlorite, 5 percent calcite, accessory sphene and apatite.

The quartz often presents sharp crystal boundaries in contrast with its usual poor development, and it is not unreasonable to assume that it crystallized with the felspars at an early stage in the cooling of the magma. Calcite occurs in scattered irregular grains and is often associated with the chlorite which, locally, shows purple anomalous interference colors. Sphene occurs in euhedral crystals showing the characteristic diamond-shaped cross section, while apatite is found in both hexagonal and prismatic sections.

Assuming that the altered felspars constituting the groundmass consisted originally of equal amounts of plagioclase and potash felspar, then this rock, in contrast with the rusty rock, is a granodiorite.

d. Diorite plug

A small diorite plug intrudes the greenstone of the Pine Falls formation close to its contact with the Lake Ambrose formation. The rock is dark grey and coarse grained, and contains large laths of white felspar. This particular rock type was found in only one location, where it forms a small knob about 50 yards across, but a short distance to the west, in the bed of the brook which runs approximately along the contact between the Lake Ambrose formation and the Pine Falls formation, an outcrop of similar composition, but much finer in grain, was seen.

A microscopic study showed that the rock contains 57 percent plagioclase, 14 percent pigronite, 11 percent antigorite, 5 percent calcite and 12 percent of ilmenite plus sphene. In addition there are small crystals of apatite.

The plagioclase has a composition of approximately Ab90 An10 and occurs in euhedral to subhedral crystals, some of which are twinned only on the Carlsbad law while others show albite twinning, and still others are untwinned.

Some of these plagioclase crystals contain many small inclusions, some of which appear to be an earlier generation of plagioclase while others are quartz. In spite of the large number of inclusions, most of the felspars have a very clear and limpid appearance (fig. 59); some crystals, however, have been highly altered to calcite, and a few others to chlorite.

Antigorite is found in fine-grained aggregates but a few fibrous crystals are also present. It fills spaces between the other minerals and fractures in the felspars. The percentage of ilmenite is unusually large. It occurs in skeletal crystals and irregularly shaped grains, and is intimately associated with a considerable amount of sphene which has probably arisen through the alteration of the ilmenite.

CHAPTER VI

HISTORICAL GEOLOGY

Problems encountered

In attempting to work out the historical geology of the thesis area, the writer was confronted by two major problems:

1. No fossil remains were found in the sedimentary formations.
2. No exposures exist at the contacts between the different formations, with one only exception.

Consequently, the age relationships between some of the formations remain in doubt.

Relative ages inferred from observations in thesis area

It has been mentioned above (pp. 62 and 67) that the West Tally and Carter Lake volcanic formations are composed partially, if not predominantly, of massive tuffs with discontinuous flow horizons. No contacts were found between these volcanic rocks and adjacent formations, but mapping revealed that in the western section of the Loon Brook formation thin bands of sheared tuff (p.40) are conformably interbedded with the sediments above and below. As these tuffs are very similar to some of the rocks in the Carter Lake formation, the writer believes that the latter, in spite of their dominantly massive aspect, may also be conformable with the Loon Brook rocks. Depending upon the interpretation of the large-scale structure in this zone (see p. 84), the Carter Lake volcanics are either intercalated between the Southern and the Northern Divisions of the Loon Brook formation or perhaps younger than the whole unit.

All intrusive rocks are, of course, younger than the formations into which they are intruded. Most of them have suffered moderate metamorphism after their emplacement, except the Boyd's Pond granite and the small diorite plug near the boundary between the Lake Ambrose and the Pine Falls formations. The granite and diorite can therefore be assumed to be the youngest of the intrusive rocks.

Field evidence suggests that the sediments of the Lake Ambrose formation are the youngest rocks of the area. As was stated above (p. 21), an outcrop was discovered in which small pods of conglomerate of the Lake Ambrose formation have been deposited upon an erosional surface cutting rocks of the Tally Pond formation. The presence in the conglomerate member of the Lake Ambrose formation of pebbles resembling rock types in the Chickadee lava, West Tally and Pine Falls formations, and of fragments with granophyric texture that may have come from the micropegmatite dike, shows that the conglomerate is also younger than all these formations. The fact that, in contrast with the other formations in the area those of the Lake Ambrose formation have hardly been subjected to metamorphism, and that no stretched pebbles occur in the conglomerate member except in areas of local shearing, likewise demonstrates the younger age of this formation.

As no pebbles derived from the Boyd's Pond granite were found in the Lake Ambrose conglomerates it can, perhaps, be assumed that the intrusion of this granite (as well as that of the diorite plug mentioned above) is the youngest major event in the development of the bedrock geology of the area.

<u>Relative ages inferred from comparison with other areas</u>

Some similarity exists between the assemblage of rocks in the Noel Paul's Brook area and those of the Buchans area to the northwest; the main difference is that the rocks in the vicinity of Buchans are dominantly of volcanic origin, whereas the thick Loon Brook and Lake Ambrose formations and the Burnt Pond formation of the thesis area are composed of sedimentary rocks. No fossils have been found in the Buchans series, but the members of the geological staff of the American Smelting and Refining Company have stated (unpublished paper) that "the Buchans series is believed to be of Ordovician age on the basis of petrographic similarity to the Exploits series of Heyl" (1936).

As mentioned earlier (p. 33), the Burnt Pond formation of black slate and siltstone with minor tuffaceous bands is probably the most extensive formation in Central Newfoundland. It is not unlikely that similar strata in Black Duck Brook, which has its source about 4 miles to the northeast on the east side of Noel Paul's Brook, are an extension of, and hence equivalent in age to, the Burnt Pond formation. Heyl (1936, pp. 11-12) has pointed out that Howley reported the presence, at Little Red Indian Falls, of the common Normanskill graptolite <u>Dicranograptus ramosus</u> in black slates. In the black graphitic slate and argillite at Black Duck Brook, Snelgrove (personal communication with Heyl, 1936) collected the following forms: <u>Climacograptus caudatus</u> and <u>Orthograptus calcaratus</u>. Ruedemann (1947, p. 66) lists a collection of fossils from Exploits Bay which he considers to be "clearly a lower Normanskill fauna", but he also states that:

> Other faunules were found in the interior of Newfoundland in the Exploits River section. These were Dicranograptus ramosus in the lower beds and Orthograptus calcaratus Lapworth and Climacograptus caudatus Lapworth; these probably indicate a horizon above the Normanskill Magog beds of Mohawkian age.

Ruedemann's reason for placing these beds above the Normanskill is that he had found Climacograptus caudatus in the Snake Hill shale (New York) of early Trenton age. The Burnt Pond formation is therefore assumed to be of an age similar to that of the Snake Hill beds, that is, upper Middle Ordovician.

Only one other formation anywhere near the thesis area has been accurately dated. It was first described by Newhouse (1931), and the members of the geological staff of the American Smelting and Refining Company (unpublished paper) have stated that:

> On the west shore of the lower part of Red Indian Lake and along the south shore for a distance of 25 miles are red sandstone beds . . . Fossil plants in these beds prove them to be of Carboniferous age.

Reasons were given above (p. 78) for believing that the youngest rocks in the thesis area are those of the Lake Ambrose formation. Moreover, the reddish color of the conglomerate member is unlike that of any of the Ordovician strata in Newfoundland, and it is much less metamorphosed than, for example, the Burnt Pond formation of upper Middle Ordovician age. To the best of the writer's knowledge only one other conglomerate in Newfoundland attains a comparable thickness: i.e., the Devonian Great Bay de l'Eau conglomerate in the Fortune Bay area, which is 3000 feet thick. Red conglomerate is also known in the Devonian Clam Bank series of the west coast, and in the Springdale group of Exploits

Bay. The Springdale group was originally (1939) assigned to the Silurian by Twenhofel and Shrock, but in a more recent paper Twenhofel (1947, p.114) expresses his belief that the original conclusions were incorrect. He states the reasons for his change of opinion:

> The strata of the Springdale-Botwood formation have been folded and the composing rocks somewhat metamorphosed, but the metamorphism has not been severe and is far less than of all Silurian in Notre Dame Bay . . . The orogeny which first deformed the Silurian may be the Caledonian in which case the Springdale formation is Devonian or younger. The red sandstones in Central Newfoundland on Red Indian Lake contain fossil plants of Mississippian age . . . and contain pebbles, cobbles, and boulders derived from the Springdale formation which is thus older in some parts of the Mississippian. A period of orogeny must have intervened between the deposition of the Springdale formation and the red sandstone and conglomerates of Red Indian Lake as the rocks of the former are metamorphosed and the latter are not. This probably was the Acadian orogeny toward the end of the Devonian in which case the deformation responsible for the metamorphism of the Silurian strata must have been the Caledonian and the Springdale formation must be Devonian or perhaps very early Mississippian.

The foregoing remarks could be applied with equal weight to the Lake Ambrose formation. It is obviously less deformed than the basal Silurian conglomerate on the north shore of Sir Charles Hamilton Sound in Notre Dame Bay, which "is really a schist and except for the stretched and fractured pebbles, cobbles, and boulders, there is little resemblance to a conglomerate". (Twenhofel, 1947, p. 75). The Lake Ambrose formation thus appears to be approximately equivalent in age to the Springdale formation, and like the thick Devonian conglomerate in the Fortune Bay area and that of the Western Clam Bank series it reflects sharp uplift immediately preceding, and probably continuing through, the period of deposition. The uplift could have been provided in all areas named by the terminal Devonian orogeny. On the strength of the arguments outlined above the writer proposes that the Lake Ambrose formation be assigned to the Devonian.

The relative ages of the Loon Brook formation and the Chickadee lava-Pine Falls greenstone formations are somewhat obscure, but the Betts Cove-Tilt Cove area offers a basis for correlation. Snelgrove (1931), quoted by Schuchert and Dunbar (1934, p. 101), found that:

> . . . the shallow-water marine conditions of late Lower Ordovician time were attended and succeeded (and possibly preceded) by the ejection of andesitics from volcanoes of the central type, and also by the extrusion along fissures of lavas which solidified largely into ellipsoidal forms on the sea bottom.

The presence of rhyolitic flows and tuffs interbedded with the sedimentary rocks of the Loon Brook formation suggests that the greenstones of the thesis area are older, for the acid volcanics of both the Notre Dame Bay area (Snelgrove, 1931) and the Buchans area (geological staff, American Smelting and Refining Company, unpublished paper) succeed the major intermediate and basic flows.

Sequence of geological events in the thesis area

As no rocks older than the Ordovician are found in the Noel Paul's Brook area, its known geologic history begins with that period. It appears likely that prior to the early Middle Ordovician most of Central Newfoundland was a highland area which provided much of the clastic material for the Cambrian and Lower Ordovician formations preserved along the west and southeast coasts. Late in the Lower Ordovician, however, the present interior began to subside, and Central Newfoundland became the site of broad geosyncline which throughout its existence was repeatedly racked by orogenic movements.

Early Middle Ordovician time was a period of volcanic activity which resulted in great outpourings of intermediate lava. The presence locally of pillow structure in, and the association of red chert with, the Chickadee lava suggests relatively quiet intrusion under water, but the Pine Falls formation contains considerable quantities of tuff and agglomerate which are indicative of more violent volcanic activity, probably from a number of centres along a zone of weakness. While the latter formation was collecting, thin limestone and limy shale deposits formed locally during periods of volcanic rest, and on occasion impure sandstones were derived from the islands which protruded above the surface of the sea. With the waning of volcanic activity subsidence began along a different zone which became the site of accumulation of the Loon Brook formation. Settling of the basin floor proceeded at a slow rate, while rivers eroding a sedimentary terrain, situated probably to the southeast, caused a thick succession of cleanly washed sands, now reflected in the quartzites of the Southern Division, to accumulate. The quickly changing nature of the sediments in the Northern Division of the Burnt Pond formation is indicative of rapid clastic sedimentation, but the frequent occurrences of black shale indicates that the basin of sedimentation became landlocked and stagnant during some intervals.

At this time conditions may have become favorable for the deposition of the Burnt Pond formation. Pettijohn (1957, p. 363) quotes James (1954) as saying that:

> . . . black shales and related products of strongly reducing environment seem to appear in the geosynclinal cycle just after the sediments formed on the aerated shelf and those derived from the rising geanticlinal island arc. The rise of the latter, prior to emergence

> within the geosyncline, produces the semi-isolation required for black shale deposition.

Sedimentation over the trough in which the Loon Brook formation was being deposited may have been interrupted for an interlude at one stage, and explosive volcanoes spewed forth a great volume of acid tuff in the east, producing the Carter Lake volcanics. The volcanic activity was much more subdued toward the west and produced only thin tuff bands, while sedimentary processes continued over the center of the trough. The West Tally volcanics may have been extruded contemporaneously with those of the Carter Lake formation, while the finer grained volcanics of the Tally Pond formation probably were ejected during the waning phases of this period of vulcanism.

Alternatively, it is possible that extrusion of the acid volcanics followed the deposition of the Loon Brook and Burnt Pond formations. The apparent interbedding of the Carter Lake volcanics with the Loon Brook formation could be attributed to pointed, and perhaps thrusted, synclines, thus accounting for the appearance of the volcanic rocks in both the eastern and western parts of the formation and their absence in the central portion.

As we have seen above (p. 80), the Burnt Pond formation was deposited late in the Middle Ordovician period. Afterwards followed a period of folding and uplift which constituted the chief phase of orogenesis in the thesis area. It cannot be stated exactly when this movement took place, but it probably began in the early stages of the Taconic orogeny, late in the Ordovician period. Little can be said of events during the Silurian, as no strata belonging to that period are known in Central

Newfoundland. It is possible, however, that the Silurian sedimentary rocks of Eastern and Northeastern Newfoundland were derived partially from an interior highland area which existed during at least part of the Silurian. The folding of these Silurian strata may have taken place just prior to the Devonian period, and the movement which caused the folding may have contributed to the formation of the trough which, in the Devonian, received the sediments of the Lake Ambrose formation.

Toward the end of the Devonian the whole of the Northern Appalachians were intensely disturbed by the Acadian orogeny. During the latter stages of this upheaval many of the granite plutons of the Maritime Provinces and Newfoundland, including the Boyd's Pond batholith, were intruded.

Since the Devonian period most of Newfoundland has existed as a positive area, subject to processes of erosion. Toward the latter part of this time (Mesozoic ?) the land was reduced to a level plain whose remnants may be seen today in the High Valley Peneplain. After a period of uplift and valley incision, the countryside was once more peneplained, except for some higher hills which were incidentally spared. Since that time Newfoundland has, on the whole, been rising further out of the ocean.

At the beginning of the Pleistocene, for reasons which are still dark, the climate became cold and ice caps, one of which was located in Labrador, began to spread out from several centers on the North American continent. Some writers, including Coleman (1926), believe that the Labrador ice sheet spread southward and covered Newfoundland, but in recent years accumulation of new evidence has led more and more geologists to reject this idea, and the theory that Newfoundland supported its own ice cap is gaining ground.

The ice sheet eroded a large amount of bedrock and left a thick blanket of drift which disrupted the drainage and left, at the time of its withdrawal, many small lakes which have subsequently filled in to form bogs.

No other post-glacial events of significance have otherwise taken place.

CHAPTER VII

STRUCTURAL GEOLOGY

Introduction

Summarizing statements made in earlier chapters, the general features of the Noel Paul's Brook area may be described as follows:

The area is underlain by sedimentary and volcanic formations striking in a general northeasterly direction and dipping steeply to vertical. A major unconformity separates the older (Ordovician ?) formations from a younger (Devonian ?) one. Older, more or less metamorphosed intrusives can be distinguished from younger, unaltered ones of probable late Devonian age.

The more detailed structural analysis of the area was as handicapped as the stratigraphical and petrographic studies by the scarcity of outcrop. While small-scale structural features can be observed at many places, and some larger structural elements can also be defined, it was difficult or even impossible to gain full understanding of the relationships existing between these elements, of their position within the geologic time scale, and of the major orogenic happenings.

Minor structural features

Tiny asymmetric folds, measuring only an inch or two from crest to crest, are found at several locations in the Loon Brook formation, but are most evident in the area south of Pine Falls. Usually the axes of these folds have vertical plunges, but in one instance the plunge was found to be 45 degrees to the southwest.

Other minor folds were observed in the Burnt Pond, Tally Pond and Loon Brook formations. The amplitude of these folds ranges from a few inches (fig. 60) to several feet (fig. 61), and their plunge varies from one formation to another, as well as from place to place within the same formation. Minor folds are especially prevalent in the Loon Brook formation around the shore of Loon Lake (fig. 62), close to the contact with the Boyd's Pond granite. They do not appear to form any particular pattern, and probably resulted from deformational effects exerted during the intrusion of the granite. Pytgmatically folded quartz veins (fig. 63) are another common structural feature in the Loon Brook formation.

As was stated above (p. 68), the micropegmatite dike south of Haven Steady displays a foliation which trends parallel to its borders. Considering the deformational effects which were observed in thin section, it is likely that the foliation, rather than having formed during the crystallization of the magma, is of secondary origin.

In several outcrops within the Loon Brook formation cleavage was observed to intersect the bedding planes at varying angles, but everywhere else in the formation either no cleavage has formed or it is parallel to the original bedding planes. In at least one instance, the cleavage is parallel to the axial plane of a minor fold (fig. 64), but elsewhere it is apparently unrelated to minor folding.

Although many of the volcanic rocks of the Carter Lake formation are massive, a rude cleavage exists locally. This cleavage is probably the result of shearing, and although the attitudes are approximately parallel to the other linear features in the area, they locally depart from the general trend.

The Pine Falls greenstone formation possesses a schistosity which has a general trend of approximately N50E. In some outcrops this schistosity is well developed, in others it is less distinct, and in an area south of the Tally Pond Road, close to the diorite plug intruded into the Pine Falls formation, the rocks are still massive.

It is probable that faults are numerous in the thesis area, but they are difficult to detect because north of Noel Paul's Brook outcrops are rare, and because the major faults are parallel to the bedding planes.

One fault is suspected to exist immediately to the east of Louis Lake on the western border of the map area. Movement is indicated by the highly sheared nature of several outcrops along a north-south line parallel to the shore of Louis Lake, and also by erratic strikes observed near the zone of shearing. Another north-south fault is indicated in the lower part of Rosie Brook by the highly crushed nature of the granophyre near the brook (fig. 65). The amount of displacement on these faults could not be measured because of insufficient exposures near the fault zones, but it is not believed to be very great. Small strike faults, some of which may have involved slight thrust movements, are common in the Loon Brook formation south of Noel Paul's Brook, their presence being suggested by locally intensive shearing.

Joints are not common in the rocks of the thesis area. In the Tally Pond formation about a dozen examples, trending approximately at right angles to the synclinal axis mentioned below (p. 90) were recorded. Only a few sets of joints were observed in the Lake Ambrose formation, including small tension joints in several outcrops of the sandstone member, and none were found in the other formations.

Structural features of larger dimensions

a. Partition of thesis area into structural units

It can be seen by reference to the geological map (plate I) that it is possible to subdivide the thesis area into 3 major belts or units, as follows:

1. A central unit consisting of the Devonian? Lake Ambrose formation.

2 and 3. Northern and southern units consisting of Ordovician? rocks and separated from one another by the Lake Ambrose formation. To these a fourth major unit might be added; namely, the Boyd's Pond granite. Although it does not constitute a structural division in the same sense as the first 3 units, it is nevertheless distinct from the others, and its importance lies in the fact that it has contributed to the metamorphism of the adjoining Ordovician rocks.

The first, or youngest, unit is the clearest of the three; it has a generally synclinal nature. There is evidence that the major fold structure has been modified by at least 2 synclines: one in the vicinity of Chickadee Pond, the other in a small area lying on both sides of the Tally Pond Road.

The northern and southern units are similar in that both of them contain intermediate and acid volcanic formations. The intermediate volcanics - the Chickadee lava and Pine Falls formations - seem to form anticlinal areas with lateral plunges. A synclinal axis can be inferred from the dips in the Tally Pond volcanic formation in the northern unit; this syncline seems to plunge eastwards. A similar east-plunging syncline may be present in the Carter Lake volcanics, which occur within the sediments of the Loon Brook formation in the southern unit.

b. Tentative structural analysis

In reconstructing the structural events which have taken place in the thesis area, it is convenient to begin with the younger (Devonian?) events and proceed backwards in time.

It is obvious that the synclines in the younger rocks of the central unit originated with the Acadian orogeny in late Devonian time. The larger, plunging synclines and anticlines of the two Ordovician belts, however, probably all originated during one period of structural deformation prior to the Devonian period.

It is difficult to separate the pre-Devonian movements from the above-mentioned late-Devonian ones. That such movements have occurred is clear, however, because:

a. Higher metamorphism exists in the Ordovician rocks.

b. There is a pre-Lake Ambrose angular unconformity.

The writer suspects that some of the earlier movements took place shortly before the Devonian sedimentation. These movements contributed to the formation of the basin in which the Devonian sediments were deposited, and initiated the erosional-depositional cycle which produced the sediments. It is possible that still earlier movements occurred, as we have mentioned above, toward the end of the Ordovician period.

The stronger metamorphism in the Southern Division of the Loon Brook formation can obviously be attributed to its position adjacent to the late-Devonian Boyd's Pond granite.

c. Thrust faults

As Newfoundland belongs to the Appalachian orogenic belt in which overthrusting is common, the thesis area was scanned for thrust faults. No clear evidence was found, however, so any thrust faults present must be high angle faults parallel to the general strike, with movement along the direction of the dip. The small-scale strike faults mentioned above are perhaps an indication that large-scale faults of similar attitude could exist.

Brown (unpublished M.Sc. thesis, McGill, 1952) has postulated a thrust fault, along Noel Paul's Brook, below Haven Steady, between the Pine Falls formation and the Loon Brook formation. However, such a fault certainly does not persist throughout the whole area, as further downstream the Loon Brook formation can be seen striking across the brook (fig. 66), without any sign of faulting.

CHAPTER VIII

ECONOMIC GEOLOGY

The decision of the geological staff of the American Smelting and Refining Company to proceed with a detailed mineral exploration program in the Noel Paul's Brook area was made because a prospecting party had discovered mineralized boulders near Loon Lake in 1952 and had, moreover, reported traces of mineralization in the country rock. The alternating sedimentary and volcanic rocks provided conditions somewhat similar to those at the producing lead-zinc-copper mines of Buchans and, usually, where mineralization occurs in intermediate lavas, they have undergone alteration similar to that which has affected the intermediate rocks of the Noel Paul's Brook area. However, it was evident that while the time-honoured and proven method of prospecting by painstaking searching-out and methodical examination of outcrops could be retained to a limited degree, the serious lack of exposures called for a different approach. It was therefore decided that geochemical prospecting methods would be used, and B-horizon soils were collected and analysed.

During the summers of 1959 and 1960 more than 15,000 samples of B-horizon soils and some stream sediments were collected. Many of these were analysed for their zinc and copper content in a field laboratory, but because of the inability of the laboratory staff to keep pace with the large number of samples being brought in, the testing of samples and evaluation of results is still going on at the time of writing.

Previously, in the fall of 1958, a number of preliminary traverses were run in an area bounded by Noel Paul's Brook on the north and Loon

Lake on the south. Analyses of the soils revealed that high background values prevailed, and when the results were compiled it was found that anomalous areas were resampled early in the summer of 1959, and when high values persisted in one of them, detailed prospecting was begun and a ground electromagnetic survey was conducted. Again the results were encouraging, and it was decided to expose the bedrock, in a number of places, by trenching. Although only small stringers of pyrite and chalcopyrite were revealed by trenching operations, two drill holes were put down but no mineralization of any consequence was encountered.

The discovery of two mineralized boulders near Haven Steady in 1959 gave added impetus and encouragement to the prospecting program, but throughout that summer and the next all efforts to track down their source met with failure. Interest was revived in 1960 when one of the prospectors found a mineralized river pebble among the ballast in a bridge at Pine Falls, but the summer ended without any clue as to its origin.

A microscopic study was made of two polished sections from the siliceous, mineralized bands which are found in the Southern Division of the Loon Brook formation. The pyrite sometimes exhibits good crystal boundaries and is evidently younger than the surrounding chalcopyrite, which in turn is younger than the quartz. Tiny inclusions of chalcopyrite are found in the pyrite and appear to replace the latter mineral. It is unlikely that any considerable amount of mineralization will be found in the country rock which contains the siliceous bands, as quartzites are very unfavorable host rocks. No trace of mineralization was found in the quartz-felspar crystal tuffs which occur to the north of the Southern Division of the

Loon Brook formation and which are too localized in extent to be shown on the geological map, but their porous character would be ideally suited to the circulation of mineral-bearing solutions.

The volcanic rocks of the Carter Lake formation also show evidence of a period of mild pyrite mineralization, and geophysical work within the formation would likely give more gratifying results than were obtained elsewhere in the thesis area. Any anomalous values encountered in the soil samples collected within the boundaries of the Carter Lake formation should be checked carefully by ground geophysics.

Strangely enough, the two greenstone formations produced little evidence of pyrite or other sulfide mineralization but again, all high values appearing in the geochemical work warrant a careful check.

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Figure 5. Noel Paul's Brook. View from the west, looking downstream.

Figure 6. Typical glacial-drift exposure in gravel pit, 6½ miles east of Five Mile Camp.

Figure 7. Thick deposit of glacial drift exposed in bank of West Tally Brook.

Figure 8. Large tuff erratics in open country underlain by Carter's Lake formation. The heavily forested terrain in the background is, in contrast, underlain by sedimentary rocks.

Figure 9. Conglomerate outcrop in Lake Ambrose formation. Note thin sandstone band towards the top.

Figure 10. Typical exposure of grey-weathering sandstone in Lake Ambrose formation.

Figure 11. Cleaved mudstone band interbedded with sandstone in Lake Ambrose formation.

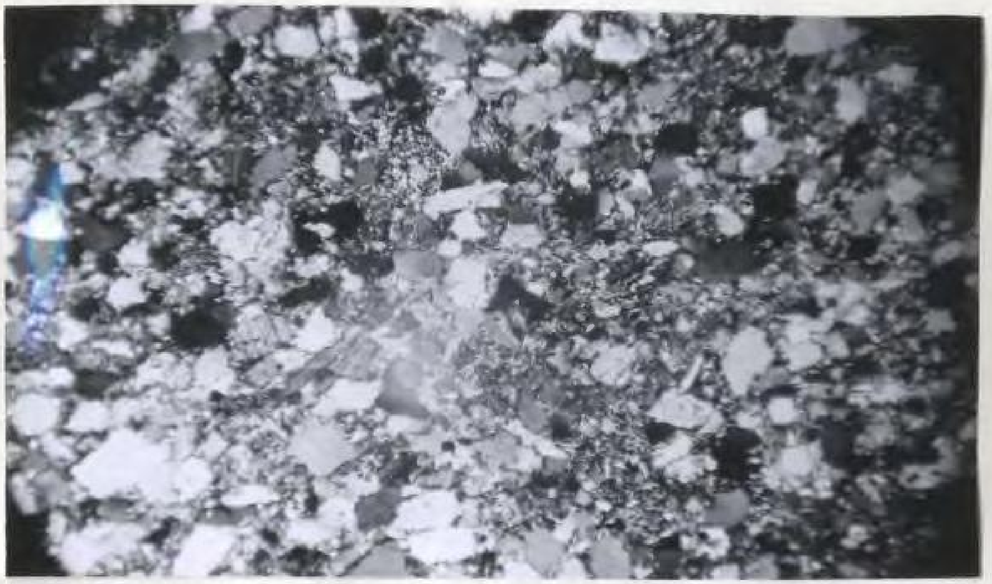


Figure 12. Photomicrograph. Impure sandstone in Lake Ambrose formation. Angular to subrounded band grains of quartz, with some plagioclase and orthoclase in a silty matrix. Crossed nicols. X 38.

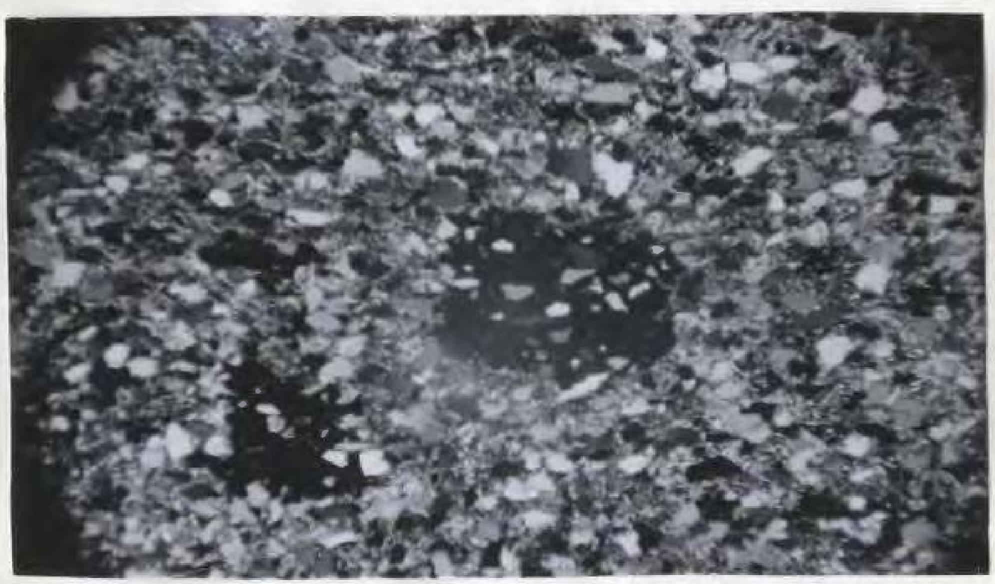


Figure 13, Photomicrograph. Sandstone from Lake Ambrose formation, showing spots where grains are cemented together by limonite derived from weathering of ferruginous carbonate. Crossed nicols. X 38.

Figure 14. Photomicrograph. Siltstone in Lake Ambrose formation with interbedded clay band displaying false cleavage. Crossed nicols. X 38.

Figure 15. Phyllitic to schistose shale in Northern Division of Loon Brook formation, outcropping on shore of Haven Steady.

Figure 16. Photomicrograph. Schistose grit, Northern Division of Loon Brook formation showing development of mortar structure around large quartz grain in centre, Crossed nicols. X 38.

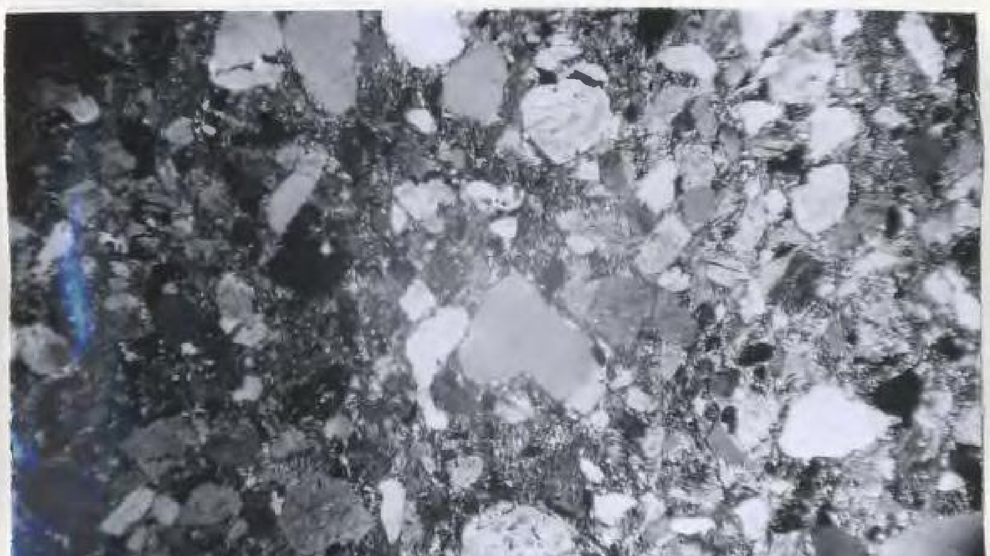


Figure 17. Photomicrograph. Arkose in Northern Division of Loon Brook formation consisting mainly of angular quartz grains (clear) and felspar (turbid). Crossed nicols. X 12.

Figure 18. Photomicrograph. Sheared felspar crystal tuff, lying to the south of, or interbedded with, the Northern Division of Loon Brook formation. Crossed nicols. X 38.

Figure 19. Photomicrograph. Sericite schist with silty bands in Northern Division of Loon Brook formation. Crossed nicols. X 38.

Figure 20. Photomicrograph. Poorly sorted, slightly metamorphosed impure quartzite in Northern Division of Loon Brook formation, consisting dominantly of quartz grains in a silty and sericitic matrix. A twinned plagioclase grain may be seen toward the centre of the picture. Crossed nicols. X 38.

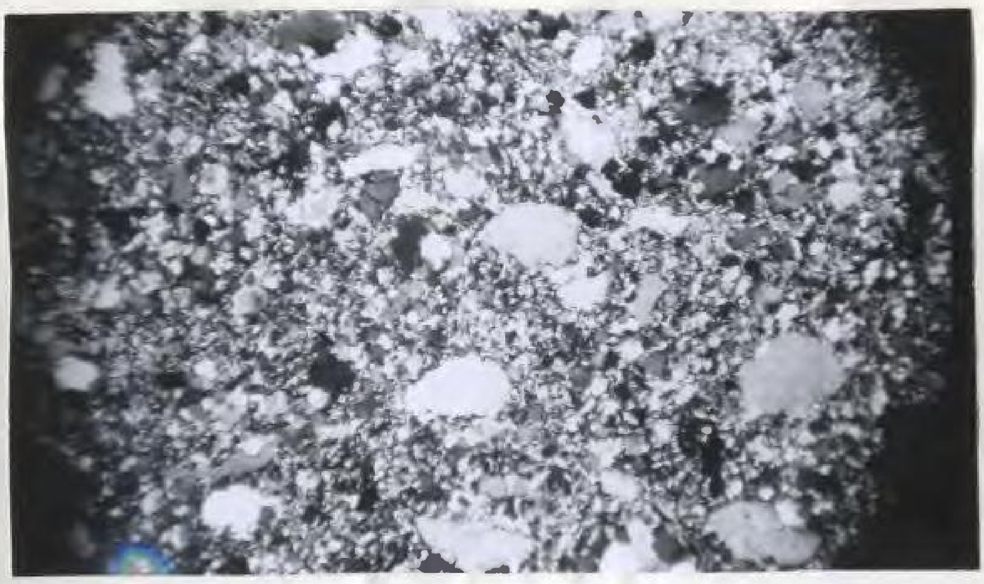


Figure 21. Photomicrograph. Poorly sorted quartzite in Southern Division of Loon Brook formation composed predominantly of quartz grains. Interlocking nature of smaller grains is suggestive of crystalloblastic texture. Crossed nicols. X 38.

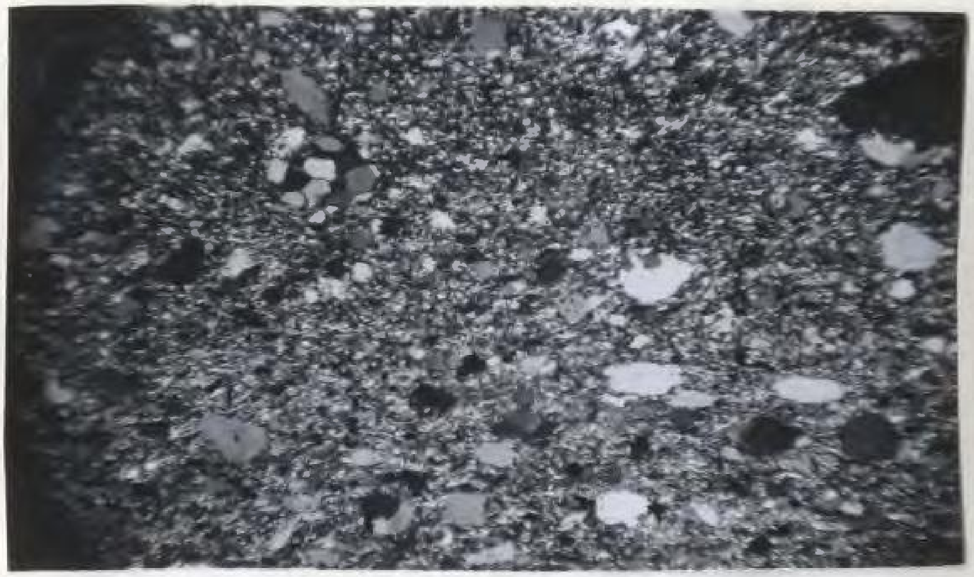


Figure 22. Photomicrograph. Micaceous quartzite in Southern Division of Loon Brook formation. Crossed nicols. X 38.

Figure 23. Photomicrograph. Quartz-mica schist in Southern Division of Loon Brook formation. Note the contorted nature of the micaceous bands. Crossed nicols. X 38.

Figure 24. Photomicrograph. Sericite schist in Southern Division of Loon Brook formation. Crossed nicols. X 38.

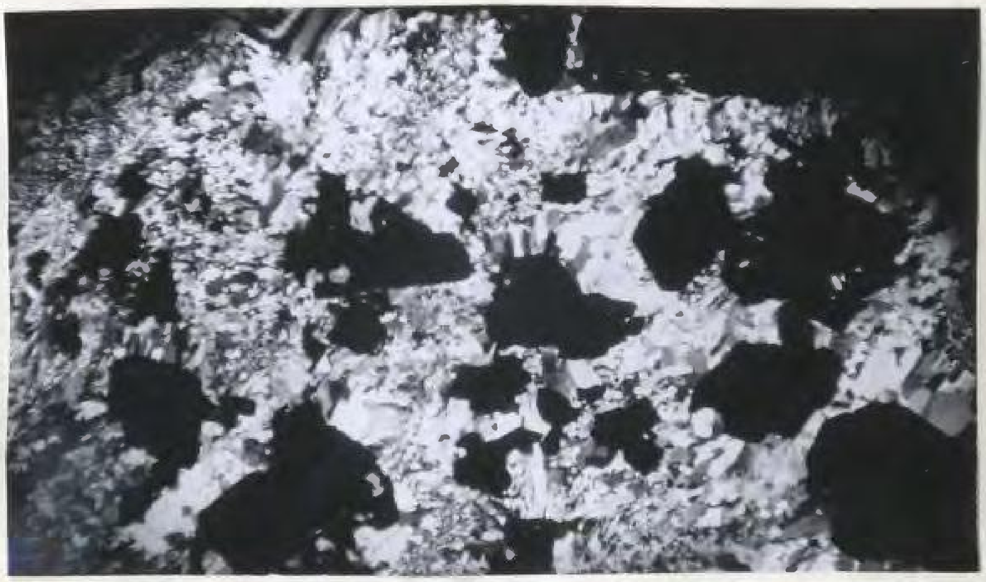


Figure 25. Photomicrograph. Anhedral pyrite crystals bordered by flaring quartz grains. Thin section from siliceous band in Southern Division of Loon Brook formation. Crossed nicols. X. 12.

Figure 26. Photomicrograph. Tuff from Burnt Pond formation, consisting mainly of rock fragments and angular quartz grains in a sericitic matrix. Crossed nicols. X 12.

Figure 27. Typical greenstone outcrop in Pine Falls formation.

Figure 28. Asbestos veinlets in greenstone of Pine Falls formation.

Figure 29. Pegmatite veinlets and lenses in greenstone of Pine Falls formation.

Figure 30. Narrow, slightly metamorphosed limestone band (centre) interbedded with greenstone in Pine Falls formation.

Figure 31. Crumpled, slightly metamorphosed limestone band in Pine Falls formation. Note erosional effects of river water.

Figure 32. Photomicrograph. Massive greenstone in Pine Falls formation consisting of anhedral pyroxene grains (white), plagioclase laths, minor epidote and leucoxene. Crossed nicols. X 12.

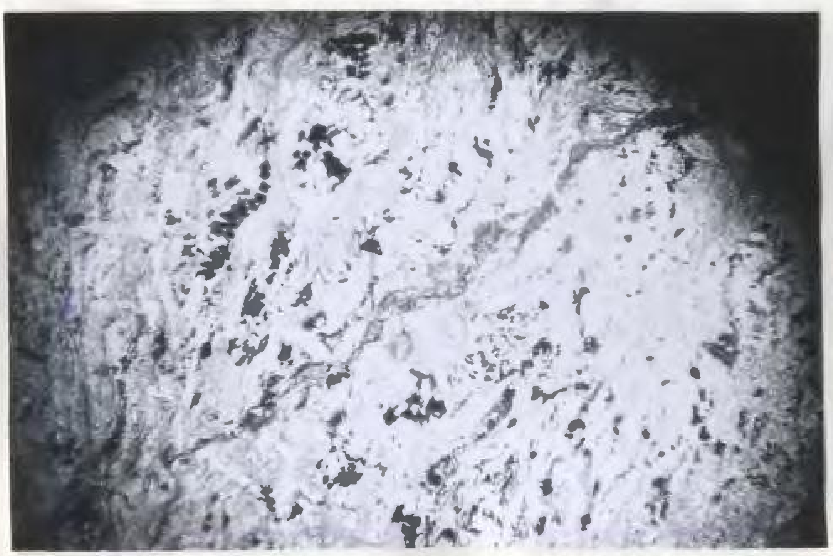


Figure 33. Photomicrograph. Coarse-grained uralite schist in Pine Falls formation, consisting of large, clear, anhedral plagioclase laths and shredded grains of uralite. Black grains are ilmenite. Plane polarized light. X 12.

Figure 34. Photomicrograph. Fine-grained uralite schist in Pine Falls formation. Consists mainly of tiny shreds of non-pleochroic uralite with tiny disseminated grains of epidote and a few small crystals of quartz. Crossed nicols. X 38.

Figure 35. Photomicrograph. Greenstone from Pine Falls formation exhibiting keraunoid-texture in which the felspars are associated in radiating, sheaf-like aggregates. Crossed nicols. X 38.

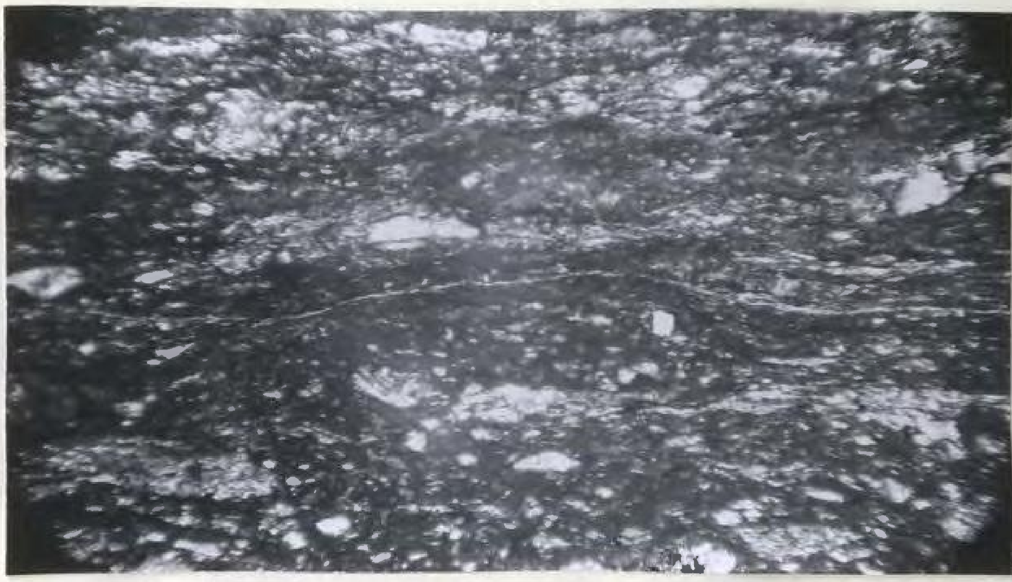


Figure 36. Photomicrograph. Tuff from Pine Falls formation consisting of angular quartz and felspar grains (white), epidote (turbid), and a high percentage of devitrified glass (black). Crossed nicols. X 38.

Figure 37. Agglomerate outcrop in Pine Falls formation.

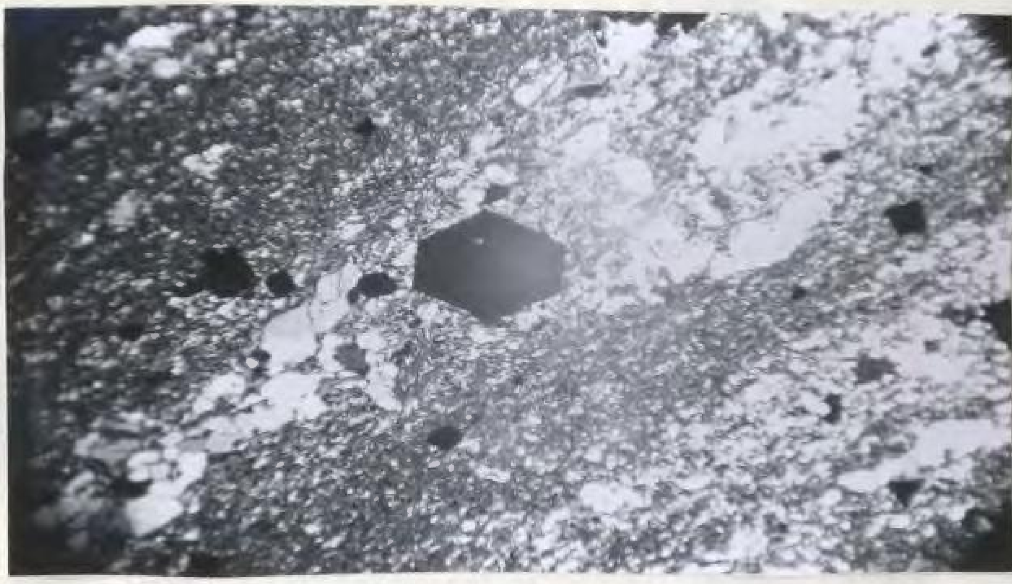


Figure 38. Photomicrograph. Greenstone of sedimentary origin in Pine Falls formation consisting of interlocking quartz grains, some felspar, tiny flakes of chlorite, and anhedral ilmenite crystals. Crossed nicols. X 38.

Figure 39. Flow-banded outcrop in Tally Pond formation.

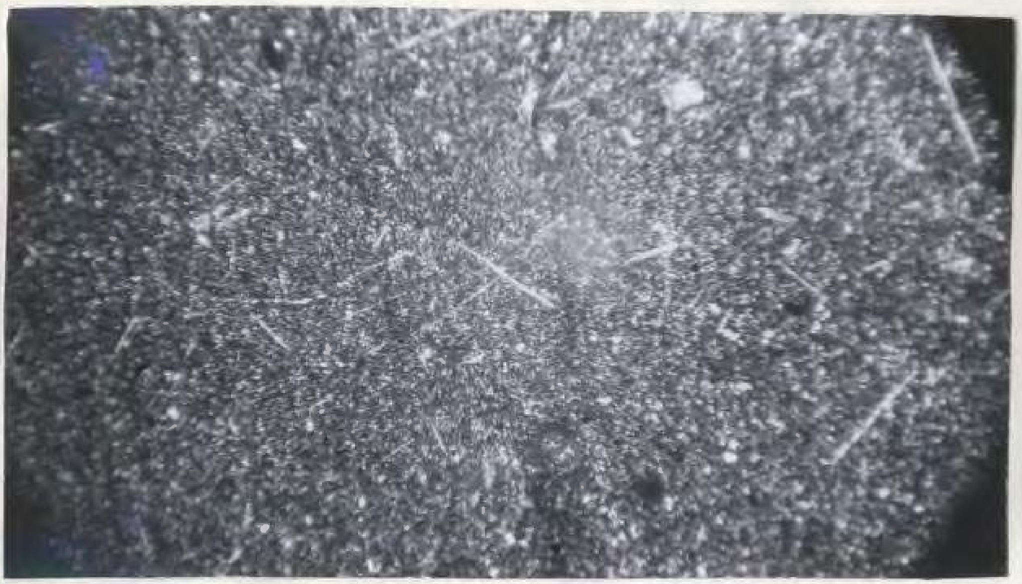


Figure 40. Photomicrograph. Very fine-grained quartz latite in Tally Pond formation, showing tiny hornblende microlites. Crossed nicols. X 38.

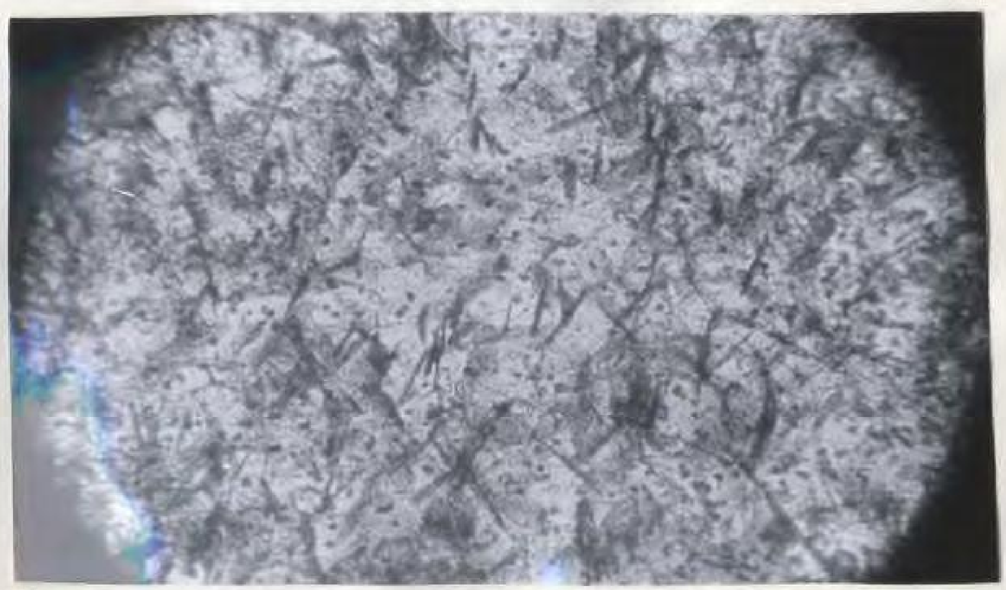


Figure 41. Photomicrograph. Fine-grained quartz latite in Tally Pond formation with biotite (cossyrite ?) microlites forming stellate-like patterns. Plane polarized light. X 171.

Figure 42. Photomicrograph. Felspar porphyry in West Tally formation, showing phenocrysts of plagioclase in a finer grained matrix. Crossed nicols. X 12.

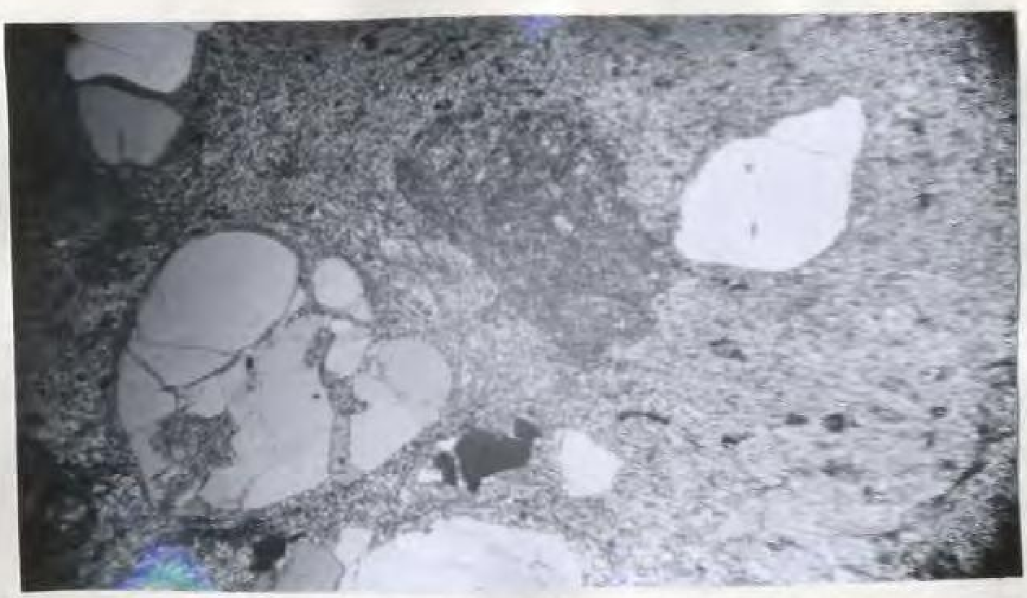


Figure 43. Photomicrograph. Rhyolite tuff in West Tally formation, showing shattered quartz grain (left of centre) and altered felspar crystal (dark) in fine-grained matrix. Crossed nicols. X 12.

Figure 44. Acid agglomerate or flow breccia outcrop in West Tally formation.

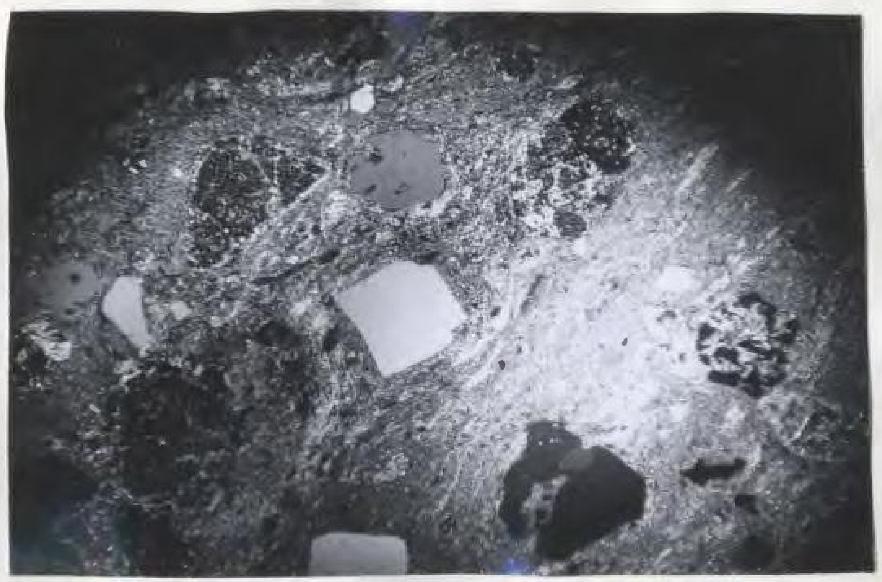


Figure 45. Photomicrograph, of agglomerate in Figure 44 exhibiting angular to rounded quartz crystals and altered felspar crystals embedded in flow-banded matrix. Crossed nicols. X 12.

Figure 46. Photomicrograph showing flow-banding in Chickadee lava formation. Crossed nicols. X 12.

Figure 47. Photomicrograph. Doleritic texture, typical of many rocks in Chickadee lava formation. Crossed nicols. X 38.

Figure 48. Photomicrograph. Ankerite-bearing rock in Chickadee lava formation showing large felspar laths and tiny elongated magnetite grains forming a dendritic pattern. Plane polarized light. X 38.

Figure 49. Micropegmatite dike on the south shore of Haven Steady, as viewed from the northwest.

Figure 50. Photomicrograph of thin section from dike shown in figure 49, exhibiting micropegmatitic intergrowths of quartz and orthoclase, and an elongated plagioclase lath, which is broken at one point, trending through the centre of the section. Crossed nicols. X 38.

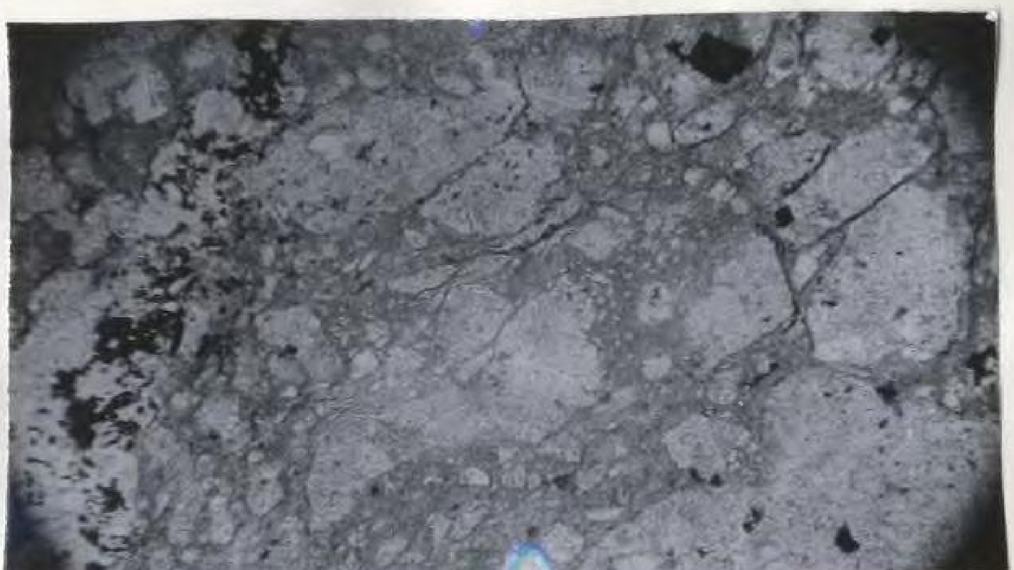


Figure 51. Photomicrograph of sample from sheared micropegmatite in vicinity of fault zone near Rosie Brook. Rounded relics of originally angular fragments are embedded in matrix of smaller particles. Plane polarized light. X 38.

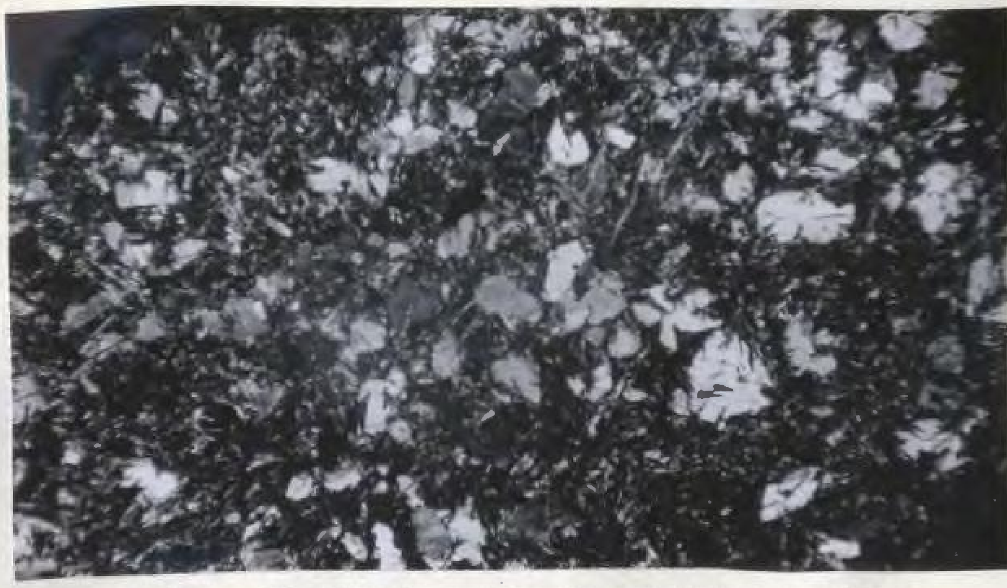


Figure 52. Photomicrograph of thin section from syenodiorite sill in Burnt Pond formation, consisting mainly of pigeonite, oligoclase and orthoclase. Crossed nicols. X 38.

Figure 53. Photomicrograph. Metadolerite, showing large tremolite crystal enclosing grains of zoisite and one anhedral plagioclase crystal which it partially replaces. The more irregular dark patches in the tremolite are the result of alteration to chlorite. Crossed nicols. X 38.

Figure 54. Photomicrograph. Boyd's Pond granite consisting of microperthite (turbid) and quartz (clear) with tiny disseminated flakes of muscovite. Crossed nicols. X 12.

Figure 55. Photomicrograph. Boyd's Pond granite exhibiting granophyric intergrowths of quartz and perthite. Note the peculiar, rounded shape of quartz and perthite grains which crystallized prior to the intergrowths and show corrosion effects. Crossed nicols. X 12.

Figure 56. Photomicrograph. Crushed granodiorite-greisin outcropping to the north of the Chickadee lava and showing fracturing of the plagioclase and irregular outlines of the quartz grains. Note tiny halo in prochlorite above the large plagioclase crystal. Crossed nicols. X 12.

Figure 57. Photomicrograph. Sericitized quartz-monzonite from stock on eastern boundary of map area showing high content of matrix derived through alteration of the plagioclase and a fractured quartz grain at centre. The dark patches in the top right - and bottom left-hand corners are orthoclase crystals covered with ferruginous carbonate. Crossed nicols. X 12.

Figure 58. Photomicrograph. Sericitized granodiorite from large stock on eastern boundary of map area consisting of fine-grained matrix, quartz (white), and showing fresh albite rim bordering sericitized felspar crystal. Fresh felspar crystal at bottom left. Crossed nicols. X 12.

Figure 59. Photomicrograph of sample from diorite plug in Pine Falls formation showing large plagioclase crystal surrounded by pyroxene. Crossed nicols. X 12.

Figure 60. Tiny minor folds in quartzite of Loon Brook formation, Northern Division (plan view).

Figure 61. Larger minor fold in siltstone of Loon Brook formation (plan view).

Figure 62. Minor fold in Southern Division of Loon Brook formation near the shore of Loon Lake, probably related to deformational effects of intruding granite (plan view).

Figure 63. Ptygmatic folding of quartz veins in Southern Division of Loon Brook formation near the shore of Loon Lake (plan view).

Figure 64. Minor fold in quartzite and siltstone beds in Southern Division of Loon Brook formation, showing development of axial-plane cleavage in less competent beds (plan view).

Figure 65. Mylonitized micropegmatite in vicinity of fault along southern part of Rosie Brook, near South Shore of Haven Steady.

Figure 66. Sedimentary rocks striking obliquely across Noel Paul's Brook, about a mile below Seven Mile Dam.

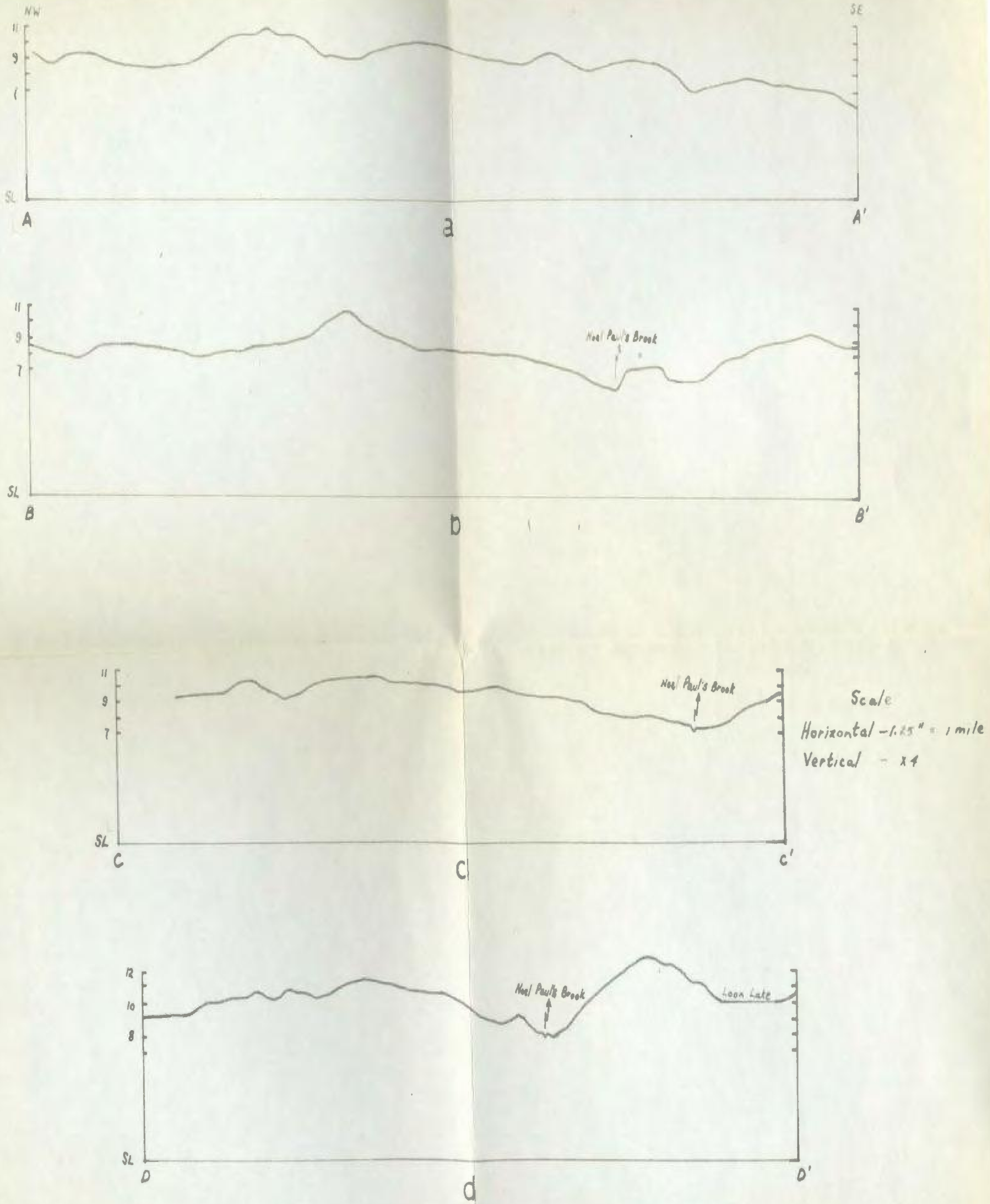
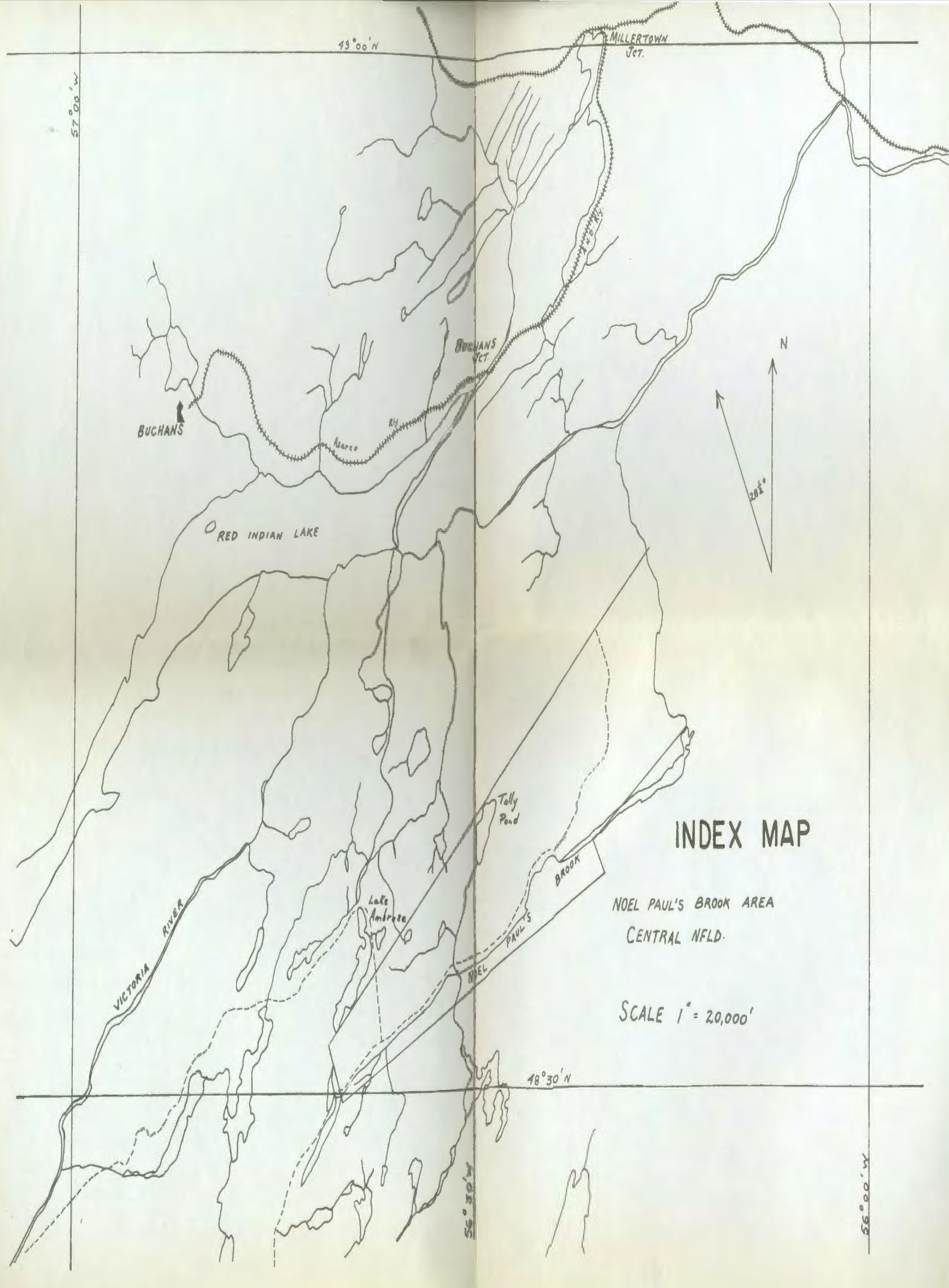


Fig. 4 Topographic profiles through Noel Paul's Brook area. A-A' easternmost, D-D' westernmost section. Note undulating plateau, higher hilltops.



49°00'N
MILLERTOWN JCT.
57°00'W
A.N.D. Rly
BUCHANS JCT.
BUCHANS
Asarco Rly
N
RED INDIAN LAKE
Tally Pond
INDEX MAP
NOEL PAUL'S BROOK
Lake Ambrose
NOEL PAUL'S BROOK AREA
CENTRAL NFLD.
VICTORIA RIVER
SCALE 1" = 20,000'
48°30'N
56°30'W
56°00'W