THE GEOLOGY OF PART OF THE "LABRADOR TROUGH" SOUTH OF LEAF LAKE NEW QUEBEC.

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NEW QUEBEC

INTRODUCTION

General

This thesis presents a description and interpretation of the geology of an area of approximately 225 square miles, located in the extreme northern part of the province of Quebec and covering part of the so-called "Labrador Trough". It is based on field mapping done during the summer of 1952 for Fenimore Iron Mines Limited and laboratory investigation at McGill University during 1952 and 1953.

As the exploration work on which this thesis is based was undertaken by a private corporation, no reference will be made to the economic potentiality of the region.

A series of maps, scale one inch equals one half mile, accompanies the report.

Location

The area is situated about 40 miles west and southwest of Ungava Bay in the south central section of the Fort Chimo topographic map sheet(1). It lies between latitudes 58° 05' and 58° 37' and longitudes 70° 00' and 70° 11', extending from a point 6 miles south of Leaf Lake, which is actually an indentation of Ungava Bay, southward a distance of 45 miles to Strain Lake. The width of the map area varies from three to eight miles and includes the total width of the usual iron-bearing sediments of the "Labrador Trough".

Access

The town of Fort Chimo, with its airstrip and port facilities sufficient for small vessels, is the nearest supply centre to the area. (See map No. 1) Float planes from here provide local transportation to the interior; while fishing vessels may navigate along the coastline. The harbour at Fort Chimo is usually ice-free from July until October.

During the summer of 1952, sea planes from the company air base at Ring Lake provided communication and supplies for the field parties.

The Chioack River, which empties into Leaf Lake, is readily navigable by canoe within the map area. However, the stretch from Finger Lake to Leaf Lake, a distance of six miles, is too rocky and shallow for water transportation.

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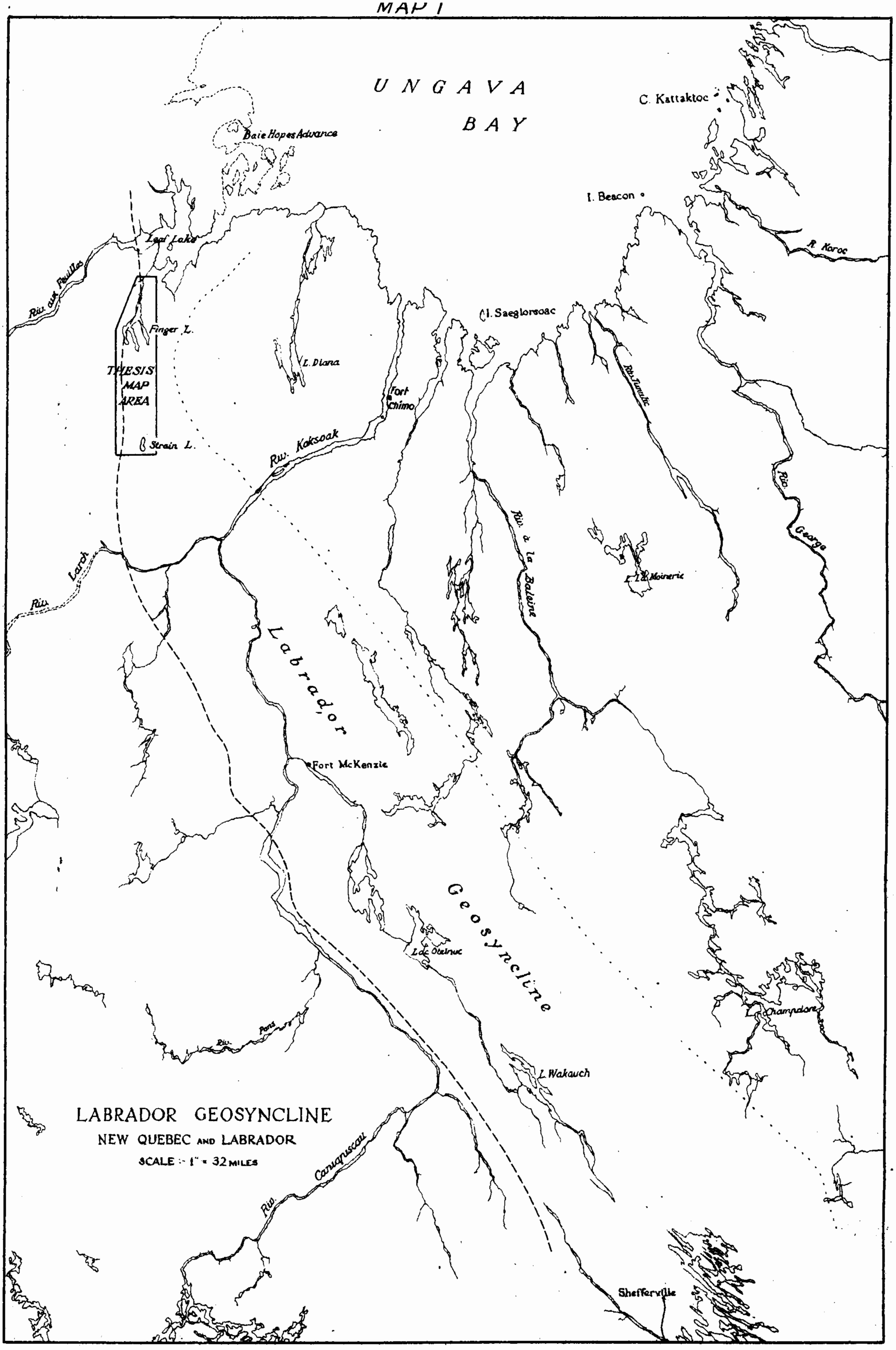
(1) Fort Chimo map sheet: National Topographic Series, Canada Department of Mines and Technical Surveys, Ottawa. Preliminary Edition 1946. Scale 8 miles equals 1 inch.

MAP I


UNGAVA
BAY
C. Kattaktoc
Baie Hopes Advance
I. Beacon
Leaf Lake
R. Koroc
Riv. aux Feuilles
I. Saeglorsoac
Finger L.
THESIS MAP AREA
L. Diana
Fort Chimo
Strain L.
Riv. Koksoak
Riv. George
Riv. à la Baleine
L. Moinerie
Riv. Larch
Labrador
Fort McKenzie
Geosyncline
Lac Otelnuc
Champdore
L. Wakauch
Riv. Pons
Riv. Caniapiscau
Schefferville
LABRADOR GEOSYNCLINE
NEW QUEBEC AND LABRADOR
SCALE :- 1" = 32 MILES

History

The earliest recorded travel by "white man" in this part of the Ungava peninsula was carried out by Dr. Mendry, who in 1827 crossed from Richmond Gulf on Hudson Bay by way of the Larch and Koksoak Rivers, to establish Fort Chimo as a trading post.

The first geological work in this district was carried out in the years of 1893 and 1896 by A. P. Low of the Geological Survey of Canada. In 1893 he descended the Koksoak River to its mouth and mapped various cross-sections of the formations along the banks. The results of this work were published in 1895(Low 1895). In the year 1896, Low made a journey from Richmond Gulf up the Clearwater and Stillwater Rivers to their headwaters and descended the Larch and Koksoak Rivers. He again mapped numerous cross-sections along the banks of the Larch and Koksoak and corrected some of his previous sections. Subsequent to this, widespread geological surveys by the Iron Ore Company of Canada have greatly clarified the geological picture in this region. The government surveys of Canada and the province of Quebec are at present examining sections of the "Labrador Trough"; their findings have been made available recently in preliminary report form. However, the geological information of this large region is largely the work of private companies.

The area covered in this report was staked for Fenimore Iron Mines during the years 1950 and 1951 and in the fall of 1952.

Climate

The climate during the field season of 1952, which was considered normal by the natives, was most agreeable. Exact measurements of temperature and humidity were not taken, but they were generally in a moderate range and the rainfall was light.

It is much milder with generally less overcast weather than farther south in the vicinity of Knob Lake, or as it is now named Shefferville. This is probably due to the difference in the elevation, as the map area is within 50 to 150 feet of sea-level, while Knob Lake is nearly 2000 feet higher. It is also possible that neighbouring Ungava Bay may be responsible for the milder temperature.

Very little snow remained after May in 1952, and "break-up" occurred shortly after the first of June. The first snow arrived during the second week of September, but the ground was mainly free of snow, and the temperature agreeable until the fourth week of October.

Timber

The country is completely barren of timber from Finger Lake northward. In the valleys south of this lake, there are small patches of trees, mainly tamarack, which provide sufficient tent poles and firewood for the requirements of a small camp.

There are no stands of trees suitable for commercial lumbering.

Methods of Mapping

The area was mapped by traversing the country at right angles to the strike, at half mile intervals. The geological details were marked on aerial photographs (scale 1/2 mile equals 1 inch) supplied by the Royal Canadian Air Force. This geological information, along with the topographic details, was traced onto a base map of the same scale prepared by the author from a series of aerial photographs joined in as undistorted a manner as possible.

This method proved to be fast, accurate and particularly suitable for observing and recording structural geological details.

Particular attention was paid to those areas adjacent to and including the iron formation.

Acknowledgements

I would like to express my sincere gratitude to the staff of the Department of Geology at McGill University for its assistance in this work, and in particular to Dr. J. E. Gill for his interest and helpfulness.

Also my thanks go to the Fenimore Iron Mines Limited and its chief geologist, Dr. P. E. Auger for the opportunity of collecting and using the material of this thesis.

GEOLOGY

General Statement

The "Labrador Trough" is a belt of folded and faulted late Precambrian volcanic and sedimentary rocks, surrounded by older gneisses. It is at least 600 miles long, extending from Ashwanipi Lake north to the northwest corner of Ungava Bay, and thence northward along its west coast. In the vicinity of Knob Lake, Labrador, Dufresne (1953) states that this zone is about 60 miles wide. The width on the area described in this report is unknown, although the zone of purely sedimentary rock is much narrower than farther south.

Gill (1952) refers to this belt of folded and faulted late Precambrian sediments as the "Ungava Mountain-built Belt". This is a more appropriate term than the "Labrador Trough", as this area is not a depression, but lies at the same elevation as the surrounding country.

Topography

The topography of the area concerned in this report has features typical of the "Labrador Trough" as described by Kirkland (1950), Hogan (1950), Harrison (1952) and Dufresne (1952). The predominance of low eastward dipping, north-south trending ridges and valleys is characteristic.

The ridges are generally underlain by resistant rocks, such as quartzite, iron formation, dolomite, or volcanic extrusives. These dip at low angles to the east. Thus the ridges have a steep western face and slope gradually into the valleys on the eastern side. The valleys are underlain usually by shales, schists, or friable contact zones. Except for local areas, there is usually only a thin cover of glacial debris.

The pre-glacial drainage system was well adjusted to the bedrock structure. It was later modified by glacial scour and the irregular deposition of drift. The crests of the ridges are generally of about the same elevation, forming the even skyline so characteristic of the Canadian Shield. On maps and aerial photographs the elongate north-south drainage pattern of the area may be readily distinguished from the rectangular pattern of the surrounding gneiss (see Plate 3.).

The region lies between 200 and 400 feet above sea-level, and local relief is commonly about 100 to 150 feet.

PLATE 1. Aerial photograph of eastward dipping, north-south trending ridges of resistant volcanic rock.

PLATE 2. View looking north along Labrador Geosyncline, note eastward dipping ridges with steep west faces on horizon.

PLATE 3. Aerial photograph showing rectangular drainage pattern of the gneiss (on the left of the photograph), and the north-south trending drainage of the sediments. (to the right).

PLATE 4. Glacial drift soil covering.

Glaciation

Pleistocene glaciation has modified details of the topography of this part of Quebec, however, its effect has not been of sufficient consequence to destroy the mature river system of pre-glacial times. Hill-tops are rounded, smoothed and polished; plucking probably took place along the sides of the ridges. The valleys may have been deepened, and small water-filled depressions on top of the hills probably owe their origin to the scouring action of the overriding ice. Glacial forms such as roches moutonnées, striae, and steepened slopes are common. The overburden of the area exhibits many interesting phenomana and figures prominently in the topography of the district.

Glacial striae are common, and are particularly well-preserved in the area of volcanic and intrusive rock. Their strike varies between N55°E and to S85°E, a variation of some 40°. There is some suggestion that the more easterly striking set is the older.

In the area south and east of Teeter Lake, there are very large, angular blocks of conglomerate (up to 30 feet square), which have been moved by ice. Their present location indicates that the resultant direction of movement has been between N 20°E and N 65°E.

PLATE 5. View of Finger Lake Area.

PLATE 6. View of the Granite Gneiss Area, west of Finger Lake.

Roche moutonnée structure is common in the gneissic areas. This feature suggests again that the movement was from south-west to north-east. It thus appears that the direction of movement of the main mass of ice was in an E N E direction. It seems probable that much of the movement within the rock valleys was deflected northward by the well-developed steep west-facing slopes.

This northward movement, particularly in the later stages, would in turn steepen and form cliff-like edges on the east side of the valley. Inasmuch as the river and stream-formed topography was not obliterated when the ice moved across the trend of the predominant feature, it is likely that glacial abrasion during the last glaciation was not sufficient to remove great thicknesses of rock.

The principal valley within the map area is that which includes Strain, Bones, and Finger Lakes, and the Chioack River. Glacial deposits along its edges, including kames and kame terraces, suggest that it contained a tongue of ice, which during later stages probably behaved as an inactive valley glacier.

The east bank of Strain and Bones Lakes is composed of typical glacial gravel. It rises steeply and evenly in a manner common to a sand or gravel slope. At an elevation of about 50 to 100 feet above the lake, it levels off and continues eastward to the rock ridges. Similar deposits occur at other localities along both east and west sides of this valley. It is perhaps most strikingly exhibited along the side of the North Arm of Finger Lake (Plate 7), where these gravel deposits are about 1 mile long and reach a height of about 80 to 100 feet above lake level; their lake faces lie at the angle of repose of gravel (about 35°). The tops of these deposits are even and level. They occur at approximately the same height on both sides of the lake. They are upstream from rock promontories which probably played a part in forming or preserving these structures. They have the properties of kame terraces ; in places they have been incised by small streams.

In Bones Lake there are two gravel points which are in line and separated by half of a mile of open water; their total length is 3 1/2 miles, their width is 1/4 mile, and they rise to about 30 feet above lake level. Their internal structures could not be studied from surface exposures, but they are composed of sand and gravel. Their shape suggests either an esker or a medial moraine. The form of the valley and the type of gravel deposit indicates that it is more likely an esker cut in half by later erosion.

In the vicinity of Strain Lake, there are eight cone-shaped mounds of gravel, some of which are islands (see Plate 8). Each is about 500 feet in diameter, and up to 80 feet high. The material composing these mounds is coarse to fine gravel. Boulders, one to two feet in diameter, are common particularly in their lower regions.

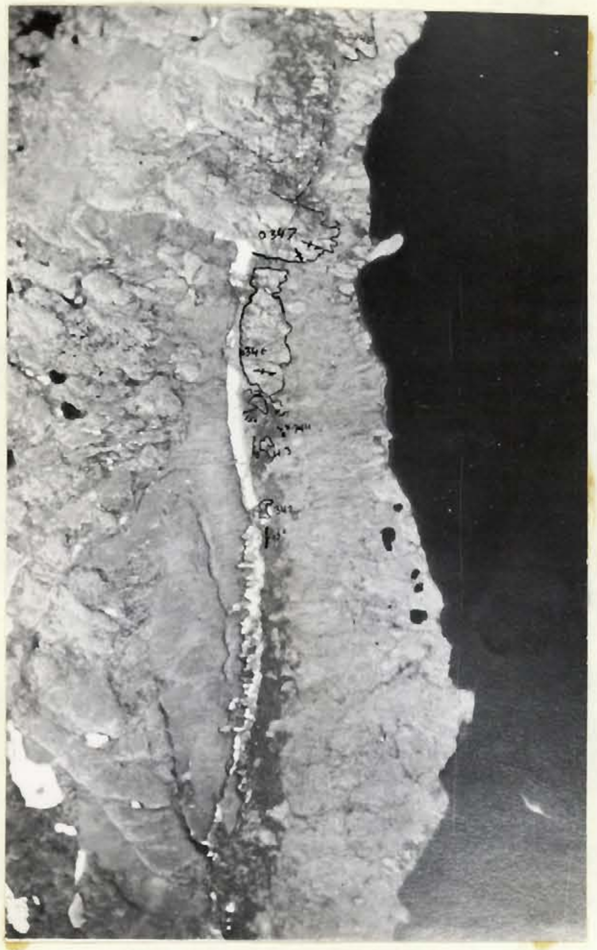


PLATE 7.

Aerial photograph of Kame terrace along the west side of the north arm of Finger Lake.

PLATE 8.

Aerial photograph of cone-shaped mounds of gravel as islands in Strain Lake.

It seems probable that these piles of gravel were formed by stream deposition in more or less circular holes in a residual stagnant ice mass. The term kame moulin has been applied to such deposits by Antevs and MacClintock (1934).

Between Teeter Lake and Bones Lake, there is a thick, stream-washed gravel deposit. Near its centre is a large, circular, flat-topped, gravel hill about 800 feet in diameter, rising about 75 feet above the surrounding plane. These deposits must have formed during the later stages of glaciation when Teeter Lake was filled with ice; otherwise it also would be gravel-filled. Later streams or rivers have removed part of this gravel barrier between Teeter and Bones Lakes. The eastern side of the present stream flowing through this partial barrier has two swing cusps (Plate12).

The combination of kames, kame terraces, and eskers, within the Strain, Bones and Finger Lake valleys indicate that this valley must have been the site of a thin residual mass of ice at the close of the continental glaciation, and that there must have been movement by water of glacial debris through or over this ice mass.

Generally speaking the gravel accumulations on the high areas are thin. The hill-tops are bare and the broader high areas have only a thin covering of glacial gravel. This material generally has the nature of a ground moraine. Plate 10 shows this feature well.

It is impossible to know whether the scarcity of material on the hill-tops is due to nondeposition or erosive action. The general lack of boulders in these areas suggests nondeposition, although it may be due to their removal by streams, late in the glacial period.

East of Strain Lake, there is a striking and unusual area containing numerous very small parallel lakes (see Plate 9). They are usually less than a quarter of a mile long, and there are hundreds of them in an area 3 miles wide and 8 miles long. They occur in depressions on a gravel-covered shale bedrock surface. The gravel is relatively thin and consists of small river-washed pebbles and sand. Scattered outcrops of shale indicate that the lakes are orientated parallel to the attitude of the underlying shale. It appears that a thin mantle of river-washed gravel covers, relatively evenly, an undulating shale surface. The fairly well-sorted nature of the gravel indicates that it was stream deposited. It is postulated that small thin tongues of ice lay in the depressions, or over much of the surface, and that gravel was deposited on, or around this ice, and later the melting of the ice lowered it to its present position. Perhaps lateral flooding from the Strain Lake river channel played a part in this process.

PLATE 9. Small parallel lakes to the east of Strain Lake.

PLATE 10. Typical view of hilltops.

Drainage

The drainage of this map area is typical of the Canadian Shield. Flowage of the surface water to the sea takes place through a series of attenuated lakes connected by short stretches of fast water. This condition of drainage is generally recognized as being the result of the disturbance of a pre-existing river drainage system by Pleistocene glaciation.

The principal drainage artery is the system including Strain Lake, Bones Lake and Finger Lake. These bodies of water are joined by short stretches of rapids and falls. The connection between Finger Lake and Leaf Lake is called the Chioack River ([1]). It consists of a stretch of boulder-strewn rapids and is more than 10 miles long. The outlet of Finger Lake is unusual. Instead of the water passing through a narrow channel, it flows through a 1000 foot wide dam of boulders. These boulders are between 1 and 3 feet in diameter, and most of the original fine material, if such was present, has been washed away, allowing the main volume of water to leave the lake through these boulders. Much of the flow of water is below what appears to be the river bottom.

The gravel along the rest of the channel is very coarse and as there is a considerable drop, this is a rough stretch of water.

([1]) Chioack:-pronounced chē o͞o ăk which in the local Eskimo tongue means gravel.

The upland areas are drained by evaporation, surface runoff, underground flow, and surface streams. Because of the predominance of gravel and lack of vegetation there are no muskegs and few swamps; instead the shallow depressions fill with water and are lakes.

Aerial photographs of the shore of Leaf Lake, actually an indentation of Ungava Bay, were studied to ascertain whether similar shore line structures existed further inland at elevations above the present sea level.

The shore line of Leaf Lake is characteristically one of bare rock promontories and intermediate gently sloping tidal flats composed of fine gravel, sand, and clay. On these tidal flats where the tide rises and falls about 30 vertical feet, there is a readily discernible, well-developed trellis drainage pattern (see Plate 11). With the aid of aerial photographs, similar structures above sea level could be traced inland a distance of ten miles to the region north of Finger Lake. This area is probably about 150 feet above sea level. Inland the terrain has been slightly modified by the growth of moss and the large spring run-off. However, there is no mistaking the appearance of these old tidal flats.

Accompanying the tide flats are bare rock promontories which have been denuded by tidal currents and waves. The contact between these two units is sharp and of uniform elevation. This is in marked contrast to the rock ridges found further inland which have a gradually diminishing

PLATE 11. Trellis drainage pattern on the mud flats of Leaf Lake; note continuation of this pattern on the old tidal flats above the present sea level.

PLATE 12. Two, two-swing cusps, Chioack River north of Teeter Lake.

soil mantle towards their top.

Thus those areas which were below sea level and which were exposed to wave and tide action may be readily distinguished from those which have characteristics denoting glacier deposition. From this study it has been estimated that the land has risen about 200 feet relative to the present sea level since the ice sheet melted away. This figure is considerably lower than that suggested by Low and other authors who mention marine terraces several hundreds of feet above sea level.

The amount of solution of carbonate since the departure of the glacier is shown on the outcrops in the Abner dolomite. It is more susceptible to solution than other rocks in the map area, and surface exposures show that up to 1 inch of dolomite has been removed by solution since glacial times. This figure was determined by measuring the relief of glacially polished and striated quartz stringers. Determination of relief was made in places where rainfall, moisture in the air, and snow were the only agents eroding the rock surfaces.

About one mile west of Bones Lake in the Abner dolomite there is a small area with underground drainage. Here there is a large depression, which must have been formed by glacial scour and subsequent solution, which resembles and is similar in size to a football stadium (Plate 13).

The bottom of this depression is about 150 feet wide and 400 feet long and is surrounded by steeply sloping walls of dolomite from 30 to 70 feet high. The drainage from this area is by way of a small stream through a tunnel in the dolomite wall. This tunnel is about 10 feet wide, 4 feet high at the upstream end, and 10 feet high at the downstream end. Solution of the dolomite along the joints must have been the cause of the tunnel. An interesting feature of the tunnel is the large blocks of dolomite which have evidently been spewed out of its mouth (see Plate 14). These boulders are between 1 and 5 feet in diameter and are too large to have been moved by normal stream processes. However, as they have obviously come from the tunnel, the only satisfactory explanation seems to be that they must have been moved to their present position by a great force of water. This force would far exceed the present capacity of the present stream, but such a force might have resulted when a large mass of dolomite gave way suddenly, after being weakened by solution along joints, releasing a body of water in a glacial-formed depression. Another possibility is that the exit from the depression might have been blocked by ice during the winter and when melting took place in the spring, the restraining block of ice suddenly gave way; the terrific force of water released could then move blocks of dolomite loosened by freezing and solution.

PLATE 13. View of the Abner dolomite showing large depression with underground drainage through a tunnel.

PLATE 14. Close-up of tunnel shown in Plate 13.

Probably a combination of both conditions played a part, beginning with solution along joints and ending with a collapse of a section of the wall.

Half a mile further west there is another similar but smaller depression with underground drainage.

Frost Action

The action of frost is an important factor in the cycle of erosion in this region. Frost wedging is an important force in rock breakup in a region such as this where freezing and thawing take place during relatively long spring and fall periods.

Another less appreciated factor in the erosional cycle in this type of area, is the reworking of gravels due to ice stratification. In this regard Beskow (page 28, 1947.) points out that silt with a grain size less than .1 millimeter has the ability to become ice stratified by "sucking up" water. This phenomenon is dependent on the surface tension of the water about such a particle. Apparently as ice crystals grow towards a particle, the surface tension of the water is great enough to suck up surrounding water if it is available. The observed result is that layers of ice will form in a moist silt or gravel with an appreciable quantity (not necessarily a major proportion) of particles 0.1 millimeter diameter or less.

PLATE 15. Frost wedging.

PLATE 16. View of frost heave gravel creeping down slope towards the observer.

These layers of ice vary between one millimeter and several inches in thickness. There may be many such layers in a thin band of silt increasing the volume of the original band up to 80 percent. In this manner the volume of the water in the soil is considerably increased, and the soil will be lifted above its normal level. When this mass thaws in the spring, the water is free to move and will be under hydrostatic pressure due to the overlying soil, with the result that the tendency will be for it to move upward towards the zone of diminished pressure (gravel surface).

This process will cause a reworking of the gravel, and in combination with frost wedging, solution and disintegration will tend to move broken fragments of bedrock towards the surface.

This feature is important in prospecting for iron ore, as often indications of an underlying ore body may be found in the overlying gravel, in the form of red soil and small chunks of ore. Evidently the porous nature of the ore makes it particularly susceptible to frost wedging.

The increased water in the soil, due to melting of ice stratification, causes the aggregate to flow down slopes of 1 to 10 degrees (see Plate 16). The added moisture content decreases the viscosity of the soils (gravels with an appreciable percentage of material finer than 0.1 millimeter) to the point where they are able to flow.

Usually the surface layer of gravel is fairly dry and solid, but under this there is a mass of water with fine material suspended therein. The whole slope does not move at one time in a sudden or violent manner; rather sections about 2 to 6 feet in diameter behave as individual units and slowly creep down hill (perhaps a few inches each spring). These units are apparently areas where the water collects after melting, in its attempt to get to the surface.

These features are probably connected with the formations of soil polygons as described by Washburn (1952) and others.

PETROLOGY

The rocks underlying the area included in this report consist for the most part of a relatively flat-lying assemblage of sediments resting on older gneisses. The sedimentary assemblage is similar to rocks described as Huronian.

TABLE OF FORMATIONS

FORT CHIMO GROUP	volcanics shales
UPPER SHALES AND SCHISTS	shale, tuffs, schists
ABNER DOLOMITE	dolomite
CHIOACK FORMATION	conglomerates greywacke arkose sandstone, etc.
LOCAL UNCONFORMITY	
FENIMORE IRON FORMATION	Spotted Silica Carbonate - Chocolate weathering Blue weathering (Layer chert) Magnetite Blue weathering (nodules chert) Thin-bedded Thinly-bedded Chert Cherty Metallic Thin-bedded Jaspery Ferruginous Shale
ALISON QUARTZITE	black quartzite grey quartzite blue quartzite
LOWER DOLOMITE	
UNCONFORMITY	
GNEISS	

Overburden is thin and structural details relatively simple, facilitating lithological examination of the members of the series. They have been divided into stratigraphic units as shown in the preceding table.

Lower Dolomite

There are three small outcrops southwest of Strain Lake which are tentatively classed as part of a Lower Dolomite horizon. A horizon such as this is found further south on the Fenimore property and as part of the sequence on the property of the Iron Ore Company of Canada. There are dolomitic pebbles and boulders in the Chioack conglomerate which indicate that there is a dolomite older than the Chioack.

These outcrops consist of a very fine-grained, dense, medium green-coloured, massive rock, composed mainly of dolomite. It is easily distinguished from the Abner dolomite because of its lack of quartz stringers and its green colour. Also the lower unit of the Alison quartzite in this district has a green dolomitic cement; a further suggestion that the dolomite is an earlier sediment.

West of the south end of Finger Lake along a river bank, the lower dolomite is overlain by a massive dark chert unit. This chert consists of a very fine mosaic of quartz. It is fractured in places and cut by thin quartz and carbonate stringers.

Alison Quartzite

General Statement

The Alison quartzite underlies the iron formation and is widely distributed along the western border of the map area. It resembles the Wishard quartzite of the Knob Lake area and occurs in a similar position in the stratigraphic sequence.

Distribution

As this member is resistant to erosion, it is usually found wherever the base of the series is exposed; mainly along the western border of the "Labrador Trough".

The thickest exposure of the Alison quartzite occurs west of the centre of Strain Lake, where the true thickness is about 75 feet. North of this locality at Irony Lake, the greatest exposed thickness in a single outcrop is 30 feet. West of the North arm of Finger Lake the exposed thickness is 20 feet. However, in these two last mentioned areas, the base of the member is not exposed, although the relation of the underlying gneiss suggests that the quartzite is probably about 75 feet thick.

Petrographic Description

The Alison quartzite is usually medium grey to blue in colour on fresh surfaces, and light grey on weathered surfaces. It is composed almost entirely of rounded grains of quartz between 1/4 and 1 millimeter in diameter. These grains are clear, fresh, and usually frosted. The frosted surfaces of the grains can usually be observed on weathered surfaces. The grains are closely packed and commonly cemented by silica, mainly in crystal continuity with the original grains (see Plate 17 & 18). No feldspar or ferro-magnesium mineral grains were observed in the rock, but small chert grains are common. Fragments of rock other than chert were not observed, nor could grains be found with abraded secondary quartz growth.

The quartzite is hard and resistant to erosion. Beds are usually about 1 to 2 feet thick. Ripple marks, cross-bedding, conglomerate beds or such structures were not observed. The Alison quartzite is generally a massive, uniform, thick-bedded,evensized, rounded-grain rock with readily discernible characteristics, both in the field and in the laboratory,which make it a good horizon marker.

Its most variable characteristic is the intergranular material. While it is usually silica, small amounts of carbonate, iron oxide, and iron silicate minerals may be present. These minerals change the colour of the rock; however, the rounded frosted quartz grains and the massive texture are constant features.

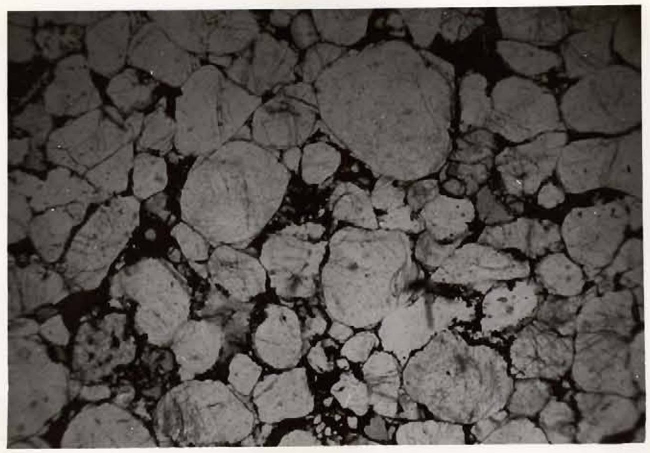


PLATE 17. Microphotograph of thin section of Alison quartzite, x 18, ordinary light.

PLATE 18. Microphotograph of thin section of Alison quartzite, x 18, polarized light.

PLATE 19. Microphotograph of thin section of Alison quartzite west of Strain Lake. x 60, ordinary light.

PLATE 20. Microphotograph of thin section of Alison quartzite west of the North Arm of Finger Lake. x 60, polarized light. Note needles of stilpnomelane cutting the edges of the quartz grains.

In the area west of Strain Lake, the quartzite may be subdivided into three sub-members depending upon the intergranular material.

Black quartzite

Grey quartzite

Green quartzite

The green quartzite is the lowermost member; its green colour is due to a percentage of green carbonate as part of the cement. This carbonate is similar to that of the underlying dolomite. It probably represents gradual change of conditions of deposition in the basin.

The grey quartzite is as previously described; the intergranular material is principally silica with small amounts of iron oxide and minnesotaite, and it is similar to that in other parts of the map area.

The black quartzite is the uppermost member and is about 20 feet thick. The black colour is due to a thin iron oxide coating around many of the quartz grains. This black quartzite also occurs interbedded with a black chert in the lower part of the overlying iron formation.

East of Irony Lake the upper part of the Alison quartzite is interbedded with a massive shaly iron formation.

West of the North Arm of Finger Lake the quartz grains of quartzite are surrounded by needles of stilpnomelane. These prismatic grains cut the edges of quartz grains (see Plate 20) and evidently they developed by diagenetic metamorphic change in the sediment.

Origin

Krynine (1941) considers that high quartz sandstones may form in three different ways:

(1) First-cycle orthoquartzites which are the product of intense chemical decay and destruction of all original minerals except quartz.

(2) Second-cycle orthoquartzites which are the product of reworking of the first-cycle type.

(3) "Cleaned greywackes", a very local accumulation which is the product of washing out of clay and silt portions of greywacke.

He further states that type (1) may be differentiated from type (2) inasmuch as the latter usually has much detrital chert, contains fragments of earlier quartzites, and many quartz grains show abraded secondary growth (first-cycle cement).

On this basis, the Alison quartzite would be classified as first-cycle as it is of too great an extent to be type (3) and has few if any of the distinguishing characteristics of type (2).

The highly rounded nature of the quartz grains indicate that the sands which formed the Alison quartzite may have been washed and reworked many times. The relatively uniform size of grain, degree of roundness, and composition indicate a high degree of maturity for this quartz sand.

Pettijohn (1940) states that grain frosting is a feature little understood. It has been attributed to aeolian action, though proof that water action is incapable of producing frosting is lacking. He also says that the similarity of the surface to that produced on glass by hydrofluoric acid suggests that frosting might be the product of prolonged action by natural solvents. Roth (1939) believed that it might be the result of incipient secondary enlargement.

Twenhofel (1939) states that rounding of grains less than 1/10 millimeter in diameter does not take place in water, as the viscosity and the surface tension of the media are such as to protect grains of this size from abrasive contact. He postulates that frosting of this size of grains is due to aeolian action.

In the light of present knowledge on the subject, it appears that the Alison quartzite formed as a result of complete chemical decay and destruction of all original minerals except quartz and chert. The weathered material so produced was thoroughly reworked probably by aeolian action, during Pre-cambrian times when no vegatation was present. Possibly it took place on a relatively stable old landmass, and was subsequently deposited by water and wind in an extensive basin.

Fenimore Iron Formation

General Statement

All the exposures of iron formation within the map area belong to the same stratigraphic unit and have been folded and faulted into their present position.

The thickness of the formation is commonly about 100 feet,although north of Finger Lake it thickens to about 150 feet. The thickness is readily determined on the sides of cliffs where the whole formation is exposed and where there is no complication due to folding or faulting.

This formation rests conformably on the Alison quartzite and is overlain by the Chioack formation. There is a local disconformity between the Chioack and Fenimore iron formations.

The Fenimore iron formation is a sedimentary rock composed of chemically precipitated, banded, ferruginous cherts. The principal minerals are quartz, chalcedony; carbonates of calcium, iron, magnesium, and manganese; silicates:- iron chlorite, minnesotaite, stilpnomelane, and riebeckite; and oxides:- magnetite, hematite and limonite.

COMPOSITION OF IRON SILICATES

	Minnesotaite[1]	Stilpnomelane[2]	Greenalite[3]	Chamozite[4]	Glauconite[5]
SiO_2	51.29	44.77	32.02	22.28	51.11
Al_2O_3	.61	6.32	1.0	25.46	4.88
Fe_2O_3	2.00	20.79	22.95	0.96	22.67
FeO	33.66	12.83	29.15	37.41	3.20
MgO	6.26	4.01	5.34	3.12	3.52
MnO	.12	.21		.21	
CaO	none	.10		.31	.52
Na_2O	.08	.07			.63
K_2O	.03	3.31			6.88
TiO_2	.04	.04			
H_2O^+	5.54	5.64	9.52	10.25	6.34
H_2O^-	.24	1.96			

Iron Silicates - Formulas:

(6) Minnesotaite (talc)
$(OH)_{22}\ (Fe^{++},Mg)_{22.3}\ Si_{30.4}(Al,Fe^{+++})_{1.4}\ O_{74}$

(6) Stilpnomelane (mica-chlorite)
$(OH)_4(K,Na,CaO)\ (Fe^{++},Mg,Al,Fe^{+++})_{7.8}Si_8O_{23-24}\ 2\text{-}4H_2O$

(6) Greenalite (serpentine)
$(OH)_{6-x}(Fe^{++}Mg)_{6-x}\ Fe^{+++}\ x\ Si_4O_{11+x}.H_2O$

(7) Glauconite (mica)
$(K,Ca_2,Na)_{.84}(OH)_2\ Al_{.47},Fe^{+++}{}_{.97},Fe^{++}{}_{.19},Mg_{.40}Si_{3.65}$
$Al_{.35}O_{10}$

(8) Chamozite (chlorite)
$H_6\ (Fe,Mg)_3\ Al_2\ Si_2\ O_{13}$

(1) (2) (3) Gruner, J. W. - 1946, Table 1, p.10.
(4) Hayes, A. O. - 1915, p.59 (recalculated to 100 after Dufresne.
(5) Hendricks, S. B., Ross, C. S. - 1941, Table 1, No. 29
(6) Gruner, J. W. - 1946 - pp. 9, 11, 17.
(7) Hendricks, S. B, Ross, C. S. - 1941, p. 683.
(8) Hayes, A. O. - 1919, p.62.

PLATE 21. Exposure of Fenimore Iron Formation east of Irony Lake.

PLATE 22. Outcrop of Fenimore Iron Formation, showing layers of chert and layers of iron carbonate.

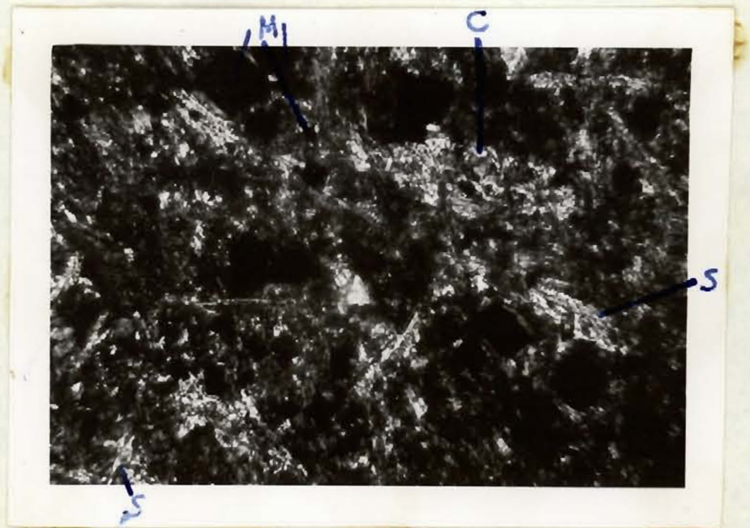


PLATE 23. Microphotograph of thin section of Ferruginous Shale east of Irony Lake. x 270, polarized light.

m - magnetite
s - stilpnomelane
c - chalcedony-iron chlorite groundmass

The Fenimore iron formation consists of a number of sedimentary units of different composition. These may be most logically divided into the following groups:

Spotted Silica iron formation.

Carbonate iron formation.

Thinly-bedded Chert iron formation.

Cherty Metallic iron formation.

Thin-bedded Jaspery iron formation.

Ferruginous Shale iron formation.

These divisions have distinct lithological characteristics which may be distinguished megascopically. In some instances one member may grade into another, but commonly the transition zone is sharp and well defined. Usually a given member may be traced for several miles along the strike, however, the thickness may vary and often units pinch out entirely. Actually the Fenimore iron formation consists of an assemblage of lenses of fairly well defined character and sequence, although one or more may be missing in any locality.

The divisions with the greatest thickness and aerial extent are the Cherty Metallic, Carbonate, and Spotted Silica iron formation.

Ferruginous Shale

This is a relatively thin member of the series, exposed only in the northern part of the map area. Outcrops of this unit appear to be normal fine-grained shale, however, closer examination reveals that it is composed of the same minerals as the rest of the iron formation, and consequently belongs to the iron formation series.

Distribution and Thickness

East of Irony Lake the Alison quartzite is overlain, and in part interbedded with a dark brown massive shale. This shale, classified as the Ferruginous Shale, is less than ten feet thick but it occurs consistently along the base of the iron formation for a distance of three miles.

West of the west arm of Finger Lake the base of the iron formation is not exposed and the presence of this member could not be determined.

West of the north arm of Finger Lake the Alison quartzite has a high percentage of intergranular material similar in composition to that of the Ferruginous Shale, which would seem to indicate that similar minerals were deposited but in different proportions.

North of Finger Lake there is a quartz-sericite schist along the base of the iron formation. It is believed that this is the metamorphic equivalent of the Ferruginous Shale.

Petrographic Description

East of Irony Lake the fresh massive shale is dark grey to black on fresh surfaces, and dark grey to brown on weathered surfaces. The rock is fine-grained, soft and readily scratched with a knife. Bedding is apparent only due to bedding plane fissility as there is no colour gradation across the stratification.

In thin section the rock is seen to be composed of:

30% magnetite

35% stilpnomelane

35% very, very fine-grained chalcedony and iron chlorite.

Chip samples across the formation assayed[1] as follows:

Fe	Mn	SiO_2
30.7	.95	34.78
24.3	1.25	44.78
24.3	.85	45.46

The rock consists of a groundmass of extremely fine-grained chalcedony and a pale green mineral (0.002 to 0.01 millimeters in diameter) containing coarser grains of magnetite (0.003 to 0.07 millimeters diameter) and grains of stilpnomelane (0.01 to 0.1 millimeters diameter) (See Plate 23). Much of the magnetite is present as octahedrons 0.01 to 0.07 millimeters in diameter. These grains may be original, or the products of recrystallization.

(1) Assayer: Fenimore Iron Mines Limited.

The grain size of the chalcedony and the pale green mineral is less than the thickness of the rock fragment forming the thin section, so that these minerals produce a combined effect when viewed with the microscope. However, with high magnification (800x), and a very strong source of light, the individual grains may be observed. The pale green mineral occurs in aggregates of minute flakes; it has parallel extinction, and is pleochroic (X-pale yellowish green, Y-pale green, Z-light green). X-Ray diffraction pattern by the Dept. of Mines, Ottawa, indicates that it is a chlorite, however, because of the finely dispersed magnetite mixed with the chlorite, specific identification of the type of chlorite was not possible.

The stilpnomelane occurs as randomly orientated needles and plates, with a greater than normal concentration in the vicinity of the octahedrons of magnetite. The stilpnomelane resembles biotite to some extent, but it is more transparent and occurs as thin prismatic grains rather than thick sheaves. These grains cut the chalcedony iron chlorite masses and the finer grains of magnetite. These textures and coarse grain-size indicate that the stilpnomelane, in part at least, crystallized later than the iron chlorite, chalcedony, and some of the magnetite, probably as the result of reconstruction of matter after original precipitation. It is difficult to interpret this as a metamorphic change because the size and texture of the grains of the iron chlorite and chalcedony strongly suggests that they are original. It would be difficult to have this material survive a metamorphic change[1] of any consequence. This matter is more fully treated in the section entitled "Origin of the Iron Formation".

Generally the groundmass contains an evenly distributed amount of randomly orientated stilpnomelane and magnetite, but in places there remain small pods about two millimeters long and half a millimeter thick, of cryptocrystalline chalcedony and iron chlorite (grain size 0.002 to 0.01 millimeter) with fine grains of magnetite (0.003 to 0.01 millimeter). The borders of these masses grade into an assemblage of coarser-grained magnetite and stilpnomelane.

There are a few grains of quartz in the sections studied, but these are conspicuous by their rarity, particularly as they are so common in the other members of the iron formation.

Thin-bedded Jaspery Iron Formation.

This member is essentially a thin-bedded part of the Cherty Metallic iron formation, however, in the southern section of the map area it is convenient to treat it as a separate unit.

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(1)- The term metamorphism is used in the paper to designate changes taking place after lithification due to thermodynamic processes of endogenetic origin.

Distribution and Thickness

The only exposure of any consequence is west of Strain Lake where it forms the base of the iron formation. It is about 30 feet thick. In other regions the Cherty iron formation tends to grade into the thinly-bedded member.

The conditions of origin of the Thin-bedded Jaspery iron formation evidently were local in extent and closely allied to those producing the Cherty Metallic member.

Petrographic Description

This rock consists of alternate thin layers of jasper or chert, interbedded with thin layers composed principally of fine-grained magnetite and intergranular quartz. The jasper or chert layers are generally composed of many very thin beds of cryptocrystalline quartz, with small amounts of hematite and magnetite that give a reddish or blackish colour respectively to the layers. Black chert layers are also interbedded with the upper ten feet of the Alison quartzite (West of Strain Lake), and the upper 25 feet contain intergranular magnetite which imparts a black colour to the quartzite.

The iron oxide mineral layers are considerably thinner (1/8 to 1/4 inches) than the chert. They are composed mainly of magnetite and cryptocrystalline quartz with small amounts of hematite.

Cherty Metallic Iron Formation

The Cherty Metallic iron formation is the most extensive member of the iron formation series. It comprises a part of the iron formation throughout the map area and contains about 50 percent of the total iron in the formation. This member is characterized by alternate red to grey chert layers, and steel blue iron oxide layers.

Distribution and Thickness

Extensive exposures of the Cherty Metallic iron formation occur in the following areas:

West of Strain Lake	50 feet thick
East of Irony Lake	25 to 34 feet thick
West of the East Arm of Finger Lake	20 feet thick
West of the North Arm of Finger Lake	20 feet thick
North of the North Arm of Finger Lake	22 to 40 feet thick

The exposures where these measurements were taken are uncomplicated by faulting or folding, and the measurements may be taken as the true thickness of the original lithified metallic member. The reason for the thinness of this member and the iron formation as a whole is discussed in the section on structure and origin of the iron formation.

Petrographic Description

The Cherty Metallic rocks are composed essentially of iron oxide minerals and chert, but as the nature of the rock varies considerably, it is a difficult rock to describe accurately.

Generally speaking the rock consists of alternate even layers of chert and of iron oxides. The thickness of these layers varies from place to place, sometimes within relatively short distances (several hundreds of feet). The chert layers are between 1/4 inch and 12 inches thick, while the metallic layers are between 1/2 inch and 3 inches thick.

The rock is hard and resistant to erosion. The fresh surfaces are steel-blue to grey in colour, and the weathered surfaces are similar in appearance; the chert layers vary between olive-green and a grey-red in colour. In some cases the chert, as observed in hand specimens, is crystalline, and in others, it is a dense cryptocrystalline mass which breaks with a conchoidal fracture.

The important exposures of this member of the iron formation series are listed on page 47. Because of the diversity in nature from area to area it can best be described by a detailed description of its nature in each area.

<u>West of Strain Lake</u> the Cherty Metallic rocks are dark steel-blue in colour with olive-green chert layers (about 1/8 to 1/2 inches thick). The metallic layers are usually between 1/2 and 1 1/2 inches thick and consist of granules(1) of magnetite between 0.1 and 1 millimeter in diameter in a matrix of cryptocrystalline quartz and iron chlorite.

(1) Granule: fine elliptical concentration of material in a sedimentary rock, no concentric structure.

PLATE 24. Microphotograph of polished section of Cherty Metallic iron formation west of Strain Lake. x 60, granules of magnetite.

PLATE 25. Microphotograph of polished section of Cherty Metallic iron formation west of Strain Lake. x 60, grains of magnetite.

PLATE 26. Microphotograph of polished section of Cherty Metallic iron formation west of the East Arm of Finger Lake. x 60, oolite of hematite.

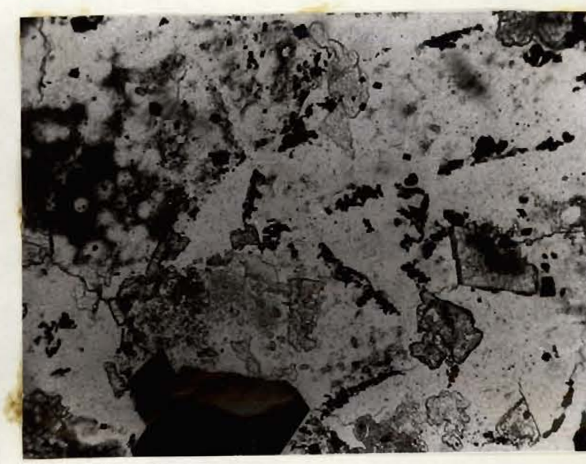


PLATE 27. Microphotograph of thin section of Cherty Metallic iron formation east of Irony Lake. x 60, ordinary light.

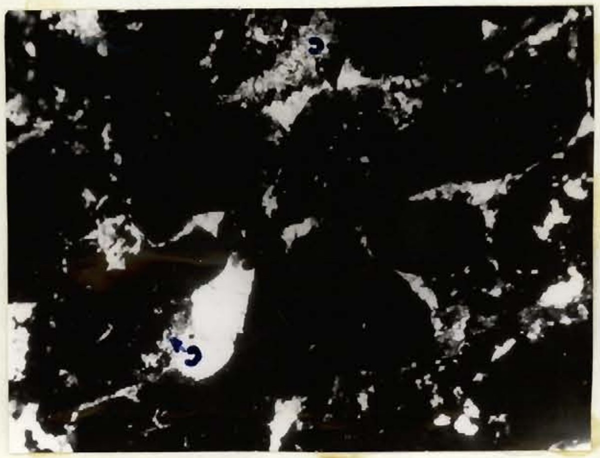


PLATE 28. Microphotograph of thin section of Cherty Metallic iron formation west of Strain Lake. x 60, ordinary light. Note granules of magnetite filled with chalcedony (c)

PLATE 29. Microphotograph of polished section of Cherty Metallic iron formation west of Strain Lake. x 18, Note metallic and chert layers.

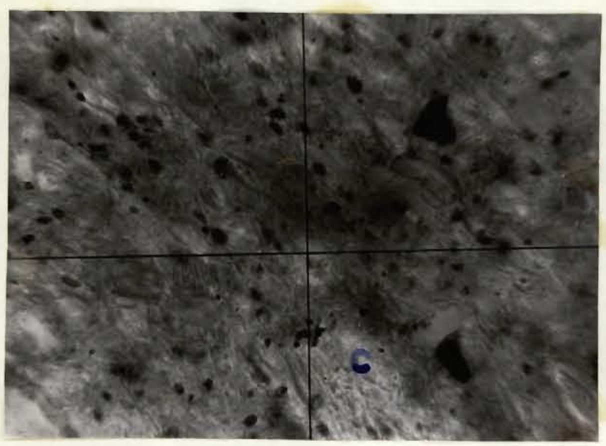


PLATE 30. Microphotograph of thin section of iron chlorite (c),(Cherty Metallic iron formation west of Strain Lake). x 600, ordinary light.

PLATE 31. Microphotograph of thin section of iron chlorite (c) filling granule of magnetite, from Cherty Metallic iron formation west of Strain Lake. x 60, ordinary light.

PLATE 32. Microphotograph of thin section of chert layer of Cherty Metallic iron formation west of Strain Lake. x 60, polarized light.

PLATE 33. Microphotograph of thin section of Cherty Metallic iron formation west of the East Arm of Finger Lake. x 60, ordinary light. Note oolite of hematite in chert groundmass.

PLATE 34. Microphotograph of thin section of Cherty Metallic iron formation north of Finger Lake. x 60, polarized light. Note fibrous cummingtonite in chert groundmass.

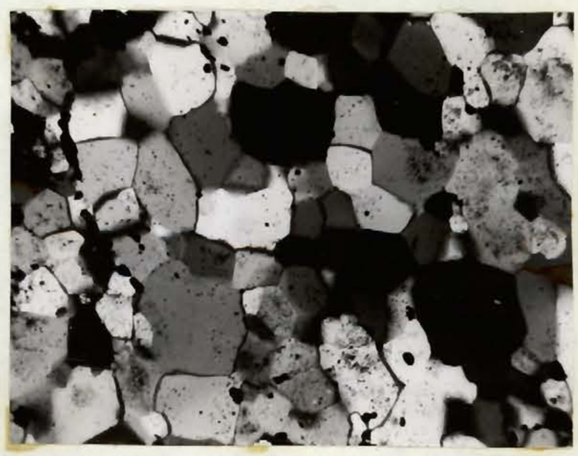


PLATE 35. Microphotograph of thin section of Cherty Metallic iron formation north of Finger Lake. x 60, ordinary light. Note black octahedra of magnetite & even size of quartz grains.

Generally speaking the mineral composition of the rock is as follows:

Metallic layers	60% magnetite 10% iron chlorite 30% cryptocrystalline quartz
Chert layers	60% chalcedony to cryptocrystalline quartz 40% iron chlorite

The magnetite granules (see Plate 24) are made up of numerous very fine grains (0.005 millimeter diameter) of partially crystallized magnetite and a small percentage of cryptocrystalline quartz and iron chlorite. The magnetite portion may constitute all of the granule in some cases, but usually it occurs as irregular patches constituting more than 50% of the granule.

The outline of the granules vary from regular, perfectly elliptical shapes to irregular forms. Rarely do the grains of magnetite cut across granule boundaries. No hematite was observed in polished sections.

The olive-green to pale green chert layers consist principally of cryptocrystalline quartz (indistinct masses about 0.002 millimeters diameter) and a pale green mineral. In some cases the fibrous chalcedony structure was observed.

Within this chert material under very high magnification (X800) indistinct grains of acid resistant pale green minerals may be discerned. This, as explained earlier, is an iron chlorite.

The borders of the chert layers are sharp, regular, and well defined, in contrast to chert layers in other areas. Also no oolitic structures were observed. The rocks contain few, if any, openings, and porosity is very small. Application of warm hydrochloric acid suggested that only very small amounts of carbonate were present.

East of Irony Lake the cherty metallic stratigraphic horizon is composed of chert layers between 1/4 inch and 12 inches thick, separated by thinner metallic layers.

The average mineral composition is shown in the following table.

Jasper layers	85% quartz 10% magnetite 5% hematite, carbonate and silicates
Metallic layers	45% magnetite 5% hematite 35% quartz 10% iron carbonate 5% stilpnomelane and minnesotaite

The following table gives the result of five chip samples across the Cherty Metallic members.

	Thickness	%Iron	%Manganese	%Silica
Minimum	8 feet	23.9	0.7	34.8
Maximum	35 feet	35.9	3.4	53.1
Average	25 feet	28.7	1.1	45.7

The chert layers consist of cryptocrystalline to fine-grained quartz with small amounts of dustlike hematite, octahedrons of magnetite, iron carbonate, and iron silicates.

The grain size of the quartz ranges from indistinct grains about 0.005 millimeters in diameter to well developed grains about 1 millimeter diameter. Generally the coarser grains are randomly distributed in bunches or as separate grains in finer-grained quartz. The average grain size varies from layer to layer, and in the Irony Lake area it is noticeably coarser than in the Strain Lake area.

The chert commonly contains an appreciable percentage of prismatic grains of minnesotaite about 0.1 millimeter long. These have random orientation and are more or less uniformly distributed throughout the layer.

A small amount of magnetite is present as fine octahedra (less than 0.1 millimeter diameter) sparsely scattered through the chert. This material is most plentiful towards the edges of the chert layers. In some cases it forms a gradational contact between the chert and metallic layers. A fine red dust, which is probably hematite, is present in some specimens of the chert. There is not enough of this material to give a deep red or scarlet colour as is necessary for true jasper or as is present in the Thin-bedded Jasper member west of Strain Lake.

In places within the chert layers, there are thin beds of chert containing well developed granules and poorly developed oolites (maximum of three concentric rings). These beds consist principally of quartz and the structures are indicated by sub-microscopic dust. A slightly higher than normal magnetite content is present, usually as part of the granules.

The metallic layers are usually composed of semi-elliptical granules between 0.1 and 1 millimeter in diameter consisting principally of magnetite grains (0.002 to 0.02 millimeter in diameter) in a matrix of cryptocrystalline to fine-grained quartz. The magnetite may occupy the total volume of the granule, but more commonly it composes a section of, or the outer edge of the granule. Often the magnetite occurs as distinct octahedrons between 0.01 to 0.5 millimeters in diameter most commonly as part of the granules, but in some cases cutting across granule boundaries, or in the matrix. These grains suggest two possibilities (a) slower lithification and more highly developed crystals or (b) later recrystallization. The close association of very fine-grained material and rocks with unaltered carbonate and silica minerals suggests the first possibility. In some cases the sections of the metallic layers are similar in composition to the Ferruginous Shale, although they usually have a higher magnetite content.

The iron carbonate is close to siderite in composition; its appearance is similar, and it is as resistant to acid as the carbonate of the carbonate iron formation member. It is present as patches with a grain size between 0.004 and 0.5 millimeters, as finer grains which are parts of granules, or as an intergranular material. Well developed crystal outlines are rare; usually the borders are irregular, and the grains contain particles of sub-microscopic dust.

A very small percentage of stilpnomelane is present and is usually associated with the carbonate minerals and the quartz.

West of the East Arm of Finger Lake the Cherty Metallic member is different from that in other areas, inasmuch as the iron oxide minerals are principally hematite, and the chert layers have a dull red colour (jasper).

The percentage composition is as follows:

Jasper layers	80% quartz 10% carbonate 5% hematite 5% stilpnomelane
Metallic layers	40% hematite 15% magnetite 40% quartz 5% carbonate and stilpnomelane

Average chemical composition:-

Iron 35.7% Manganese 0.7% Silica 43.3%

The formation consists of about 40 percent jasper layers, and 60 percent metallic layers and is about 25 feet thick. The jasper layers vary in thickness between 1/2 and 2 inches. Generally speaking a given layer is of uniform thickness through distances of several feet. They consist of cryptocrystalline to fine-grained quartz (less than 0.05 millimeter in diameter), scattered dust-like to very fine-grained hematite, and scattered fine grains of calcite. The red dust-like hematite gives a pronounced red colour to the layers. The presence of calcite was determined by application of cold, dilute hydrochloric acid.

The metallic layers are composed of oolites and granules consisting principally of hematite and quartz. In contrast to other exposures of Cherty Metallic rocks, oolites are common and consist of alternate rings of hematite (grain size 0.001 to 0.01 millimeter) and cryptocrystalline quartz. The oolites are up to 2 millimeters in diameter. The inter-oolite or granule material is principally cryptocrystalline quartz and hematite. There are fine octahedra of magnetite (0.005 to 0.012 millimeter in diameter) scattered through the hematite masses. Scattered patches of carbonate, principally calcite, are present. The soda-magnesium-iron amphibole arfvedsonite is present at various localities within this area of iron formation. It is a dark blue-grey mineral; light green in thin section; with prismatic crystal form (1 to 3 millimeters long); hardness about 5; specific gravity 3.2; extinction angle $X \wedge C = 7^{\circ}$; refractive index close to 1.68; pleochroism:- X - medium blue, Z - pale green.

The striking feature of this rock is the presence of hematite as the principal iron oxide mineral, and the preponderance of oolitic structures instead of granule forms. Oolities are commonly regarded as being formed by a rolling action produced by waves. The presence of oolites and hematite suggests that oxygenation of the water by wave action took place.

The chert and metallic layers are cut by fine-grained veinlets of quartz. They do not cut the series of layers as a whole, but are restricted to individual beds. They are inter-bed features, apparently an indication of local movement of quartz during lithification.

<u>West of the North Arm of Finger Lake</u> and to the north of the lake, the Cherty Metallic iron formation is apparently the same type only more altered. The quartz grains are coarser and the magnetite octahedra are better developed.

This area consists of alternate jasper to chert layers (between 1/4 to 1 inch thick) separated by a thicker amount of metallic material. The following list indicates the mineral composition of these layers.

Jasper layers	90% quartz 10% magnetite, hematite, and arfvedsonite
Metallic layers	25% quartz 30% magnetite 5% hematite 10% minnesotaite 10% arfvedsonite 20% calcite and iron carbonate

The cherty layers may be either a dense red colour (jasper) or dull grey. In the case of the red layers, the colour is due to a noticeable quantity of red hematite dust, while the grey layers contain only very fine magnetite grains.

The metallic layers consist of octahedra of magnetite between 0.005 and 0.1 millimeter~~s~~ in diameter, disseminated through a chert matrix, or arranged in a granule form. Particles, which in the areas west of the East Arm of Finger Lake, would have appeared as indistinct dust-like material, are in this area very fine, perfect to imperfect octahedra.

The quartz occurs as fine distinct grains between 0.01 and 0.2 millimeter~~s~~ in diameter. The grain size of the quartz in this rock is coarser and more uniform than in the less altered exposures further south where only occasional patches of coarse grains are present in a cryptocrystalline groundmass.

Iron carbonate is present as granules, and patches (1/4 inch across) of grains about 1 to 2 millimeters in diameter.

Arfvedsonite is present as prismatic grains up to 3/8 inche~~s~~ long. These grains cut magnetite and quartz and are obviously later than both. They commonly cut across the chert-metallic layer boundary forming a ring of needles or nodules about chert layers.

Minnesotaite is present as disseminated grains of random orientation, usually closely associated with the quartz grains.

The large grains of arfvedsonite, and the coarser grains of quartz and magnetite indicate that this rock has been changed by metamorphism, and the size of the grains suggest that it is the most altered of all the iron formations in the area. This observation is based upon (a) the size and the even texture and outline of the quartz grains and (b) the uniform size and distribution of the well-developed octahedra of magnetite and (c) the large size of the arfvedsonite prisms.

Chert, which is considered primary, contains iron chlorite and is composed of a mosaic of irregularly-sized quartz grains. On the average they are very fine-grained (less than 0.01 millimeter in diameter), but occasionally there are clusters of coarse grains (o.5 millimeter in diameter) with irregular outline. The recrystallized material on the other hand is more uniform in size (greater than the 0,1 millimeter in diameter) and with a more regular outline to the grains. The average size of the grains appears to indicate the degree of alteration. James (1950) noticed similar features in the Lake Superior iron formations. He states that quartz grains of about 0.01 millimeter in diameter occur in cherts in low grade metamorphic zones, while grains about 1 millimeter are more typical of high grade zones. He considers this to be an exceedingly delicate indication of metamorphic grade when used with caution.

North of the North Arm of Finger Lake the picture is much the same, except that no arfvedsonite is present. The principal minerals are as follows:

Chert layers	50% of whole	90% quartz 10% magnetite and iron silicates
Metallic layers	50% of whole	35% magnetite 1% hematite 5% carbonate 10% iron silicate 50% quartz

The following table gives the results of six chip samples across the Cherty Metallic member.

	Thickness	%Iron	%Manganese	%Silica
Minimum	22 feet	21.2	0.1	40.6
Maximum	56 feet	48.6	5.2	58.1
Average	35 feet	33.0	1.5	48.1

The chert layers consist principally of grains of quartz about 0.1 millimeter in diameter and a few scattered fine distinct octahedra of magnetite.

The metallic layers are similar in texture, but contain a higher percentage of iron minerals noticeably magnetite, iron carbonate and the iron silicates, stilpnomelane and cummingtonite.[1] They consist of octahedra of

(1) Cummingtonite: (MgFe)SiO3, fiberous, commonly in radiating cluster, pale brown, optically positive, Z∧C - 18°, high birefringence. X - pale brown, Y - pale brown, Z-light brown.

magnetite between 0.01 and 0.3 millimeters in diameter in a groundmass of quartz and stilpnomelane. Within this mass are scattered spots of iron carbonate about 2 to 5 millimeters in diameter.

As is common throughout this member, there is a relic granule structure, which is indicated by the distribution of magnetite octahedra and the presence of dust-like particles. However, north of Finger Lake this structure is less distinct, apparently due to a higher degree of recrystallization of the minerals composing the rock.

The eastern exposure of the Cherty Metallic rocks is considerably folded and faulted. Besides the usual minerals of the above-mentioned grain size, there are radiating clusters and disseminated fibrous grains of cummingtonite. These grains are up to 1/4 inch long. In places there are also narrow fine-grained quartz layers suggesting mylonized conditions.

The area north of Finger Lake evidently contains the most highly altered Cherty Metallic rocks. This is indicated by the relative obliteration of the granule texture, coarser more uniform size of the quartz, more perfectly formed octahedra of magnetite, less fine magnetite dust, the presence of cummingtonite, and presence of mylonized quartz along some chert boundaries.

PLATE 38. Microphotograph of thin section of fine-grained chert layer typical of those rocks found west of Strain Lake. x 60, polarized light.

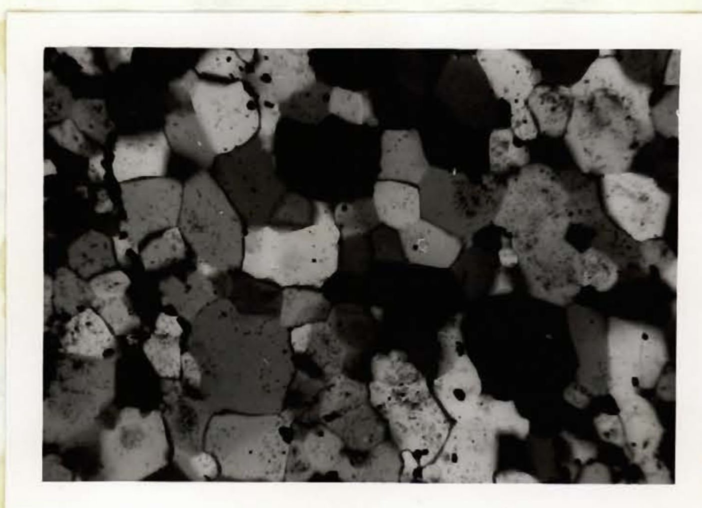


PLATE 39. Microphotograph of thin section of chert layer typical of those rocks found in the Finger Lake area. x 60, polarized light.
Note: Larger even size of the quartz grains of this metamorphosed chert layer in comparison to the unmetamorphosed chert layer of Plate 38.

Thinly-bedded Chert Iron Formation.

The thinly-bedded Chert iron formation is not widely exposed and not of great thickness, but it is included for the sake of completeness. In the southern part of the area it is a well defined unit, and it may serve to indicate the variations in the iron formation in the local areas; variations which are principally differences in the amount of minerals present and the nature of the silica.

Distribution and Thickness.

This stratigraphic member is exposed only north and east of Alison Lake (west of Strain and Teeter Lakes). As there are continuous outcrops across the iron formation further north, and as this member is not present, it is assumed that the Alison Lake area is the only locality in which this rock type was deposited.

It is between 20 and 40 feet in thickness.

Petrographic Description

This cherty rock consists of beds of chert less than 2 millimeters thick. It is dark grey to black on fresh surfaces due to a fine intermixture of a small amount of magnetite with the chert. On weathered surfaces it is light grey to black in colour. While the magnetite gives a pronounced dark colour to the fresh rock, this seems to be

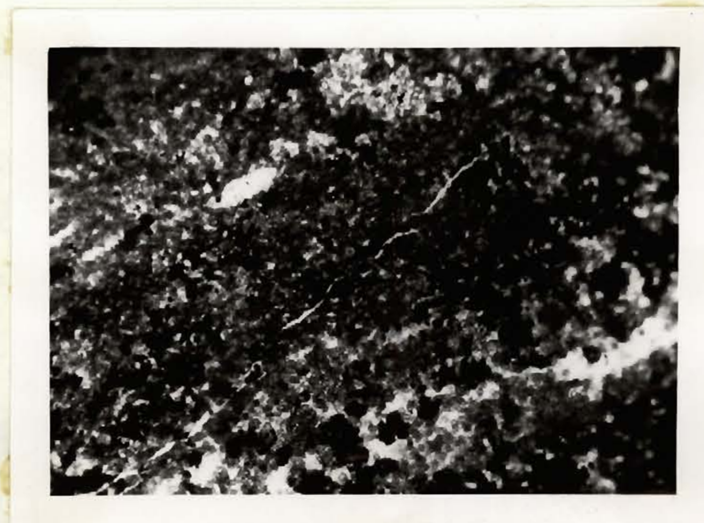


PLATE 36. Microphotograph of thin section of Iron-rich bed of Thinly-bedded Chert iron formation west of Strain Lake. x 270, ordinary light.

primarily internal reflections, as it consists of about 90% cryptocrystalline quartz (less than 0.01 millimeters in diameter).

Bedding is apparent in this section because of slight variations in the grain size of the quartz, and because of variations in amount of magnetite and iron chlorite in different beds.

Magnetite occurs either as indistinct grains less than 0.005 millimeters in diameter, distributed through the chert layers, or in some cases, as narrow beds (0.05 to 0.5 millimeters thick) of almost pure magnetite.

Iron chlorite occurs in amounts of less than 5 percent and is generally associated with the magnetite-rich sections.

There is no granule texture to the rock.

Evidently this rock occupies the same position in the depositional sequence as the Thin-bedded Carbonate iron formation described in the next section; the difference in nature is probably due to small changes in the Eh and pH of the basin of deposition and to an increase in amount of silica supplied to this part of the basin.

Carbonate Iron Formation

The Carbonate iron formation, because of its brilliant blue or chocolate weathered surface, is the most striking horizon of the iron formation. It occurs in the upper part of the iron formation throughout the map area, but the largest and best exposures are in the northern half of the area. This member contains about half of the total iron in the whole formation.

Distribution and Thickness.

This stratigraphic horizon is exposed continuously for a distance of 3 1/2 miles north of Finger Lake and for a distance of 4 miles east of Irony Lake. Besides these areas there are large outcrops east and west of the West Arm of Finger Lake, and smaller exposures northwest of Bones Lake and west of Strain Lake.

The thickness of the Carbonate iron formation in these exposures varies between 10 feet (north of Finger Lake) and 25 feet (west of the East Arm of Finger Lake and east of Irony Lake). The thickness in the vicinity of Strain Lake is unknown.

Petrographic Description

This horizon is a uniform, continuous stratigraphic horizon which may be subdivided into several units, most of which are present in all areas. The petrographic details of this rock are most easily discussed by describing each of the following sub-types.

Chocolate weathering Carbonate Iron Formation.

Blue Weathering Carbonate Iron Formation with layers of chert.

Magnetite Iron Formation.

Blue Weathering Carbonate Iron Formation with nodules of chert.

Thin-bedded Carbonate Iron Formation.

The Thin-bedded Carbonate Iron Formation is stratigraphically the lowest sub-member. It is between 6 and 11 feet thick and occurs in all areas of iron formation in the northern part of the area.

The rock consists of beds of carbonate, less than 1 millimeter thick, with lesser amounts of quartz, minnesotaite, stilpnomelane, goethite, hematite and magnetite. The average percentage mineral composition is shown in the following list:

carbonate (siderite-calcite)	45%
quartz	15%
stilpnomelane	25%
minnesotaite	3%
goethite	5%
hematite and magnetite	7%

The carbonate material consists principally of calcite, with small amounts of iron carbonate. The fine-grained nature of this material makes specific identification difficult, if not impossible. The calcite fraction was identified in thin section under the action of cold dilute hydrochloric acid.

PLATE 38. Outcrop Blue Weathering Carbonate iron formation layers of chert.

PLATE 39. Blue Weathering Carbonate nodules of chert with septaria cracks.

The grain size of all minerals in the rocks is about the same, usually less than 0.01 millimeters in diameter. The fine bedding is the result of variations within narrow limits in the proportion of minerals present; particularly the ratio of stilpnomelane to carbonate.

Bedding is very difficult to discern on fresh surfaces, however, on weathered surfaces the variation in the iron and manganese content, and the difference in solubility of the different beds shows up the structure.

Some beds contain a considerably higher quartz content than usual; however, generally speaking the quartz is relatively evenly distributed.

The next overlying sub-member is the Blue Weathering Carbonate with nodules of chert. This stratigraphic unit is found only east of Irony Lake and for practical purposes it may be considered as part of, and similar in composition to, the Blue Weathering Carbonate with layers of chert. The well developed nodules of chert, however, readily distinguish this member, and their development may throw some light on the origin of the iron formation.

The composition and texture of the matrix are similar though slightly higher in silica than, the Blue Weathering Carbonate iron formation and will be described under that heading. Its percentage composition is as follows:

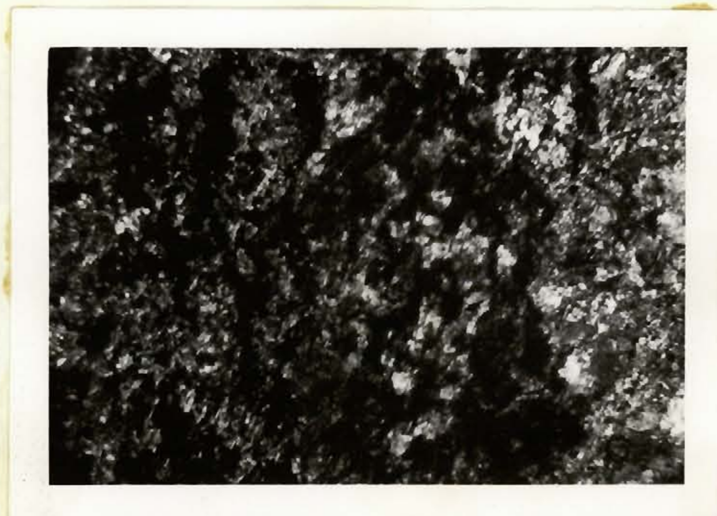


PLATE 40. Microphotograph of thin section of Thin-bedded Carbonate iron formation west of the West Arm of Finger Lake. x 60, polarized light.

	Thickness	%Iron	%Manganese	%Silica
Minimum	2 feet	24.3	0.06	31.9
Maximum	17 feet	34.7	3.0	55.2
Average	10 feet	29.1	1.8	38.0

The nodules are between 6 and 14 inches long, 4 to 10 inches wide, and about 2 to 6 inches thick. Their shape is usually oval, and they are elongated parallel to the bedding. The surfaces are relatively smooth and free from knobs. Commonly they have a series of radiating cracks which widen towards the centre. These cracks are filled with white quartz and usually occupy one quarter to one third of the volume of the nodule. They are not crisscrossed by a series of cracks concentric to the margins, and the cracks do not cut across the edges of the nodule. (See Plate 37). Pettijohn (1948) refers to such structures as "septaria". He states that their formation involves the following:

(a) formation of a body of gel.
(b) case-hardening of the exterior, dehydration of the interior, and the formation of shrinkage crack pattern.
(c) partial or complete filling of cracks by quartz, thereby producing the vein network of the nodule.

The author adds that this evidently requires conditions different to those forming the rest of the iron formation, particularly in regard to case-hardening and subsequent dehydration.

Genetically related to these structures is an 18-inch thick band of cross-bedded granule and oolitic chert . The composition of rock is 5 percent siderite, 15 percent stilpnomelane, 80 percent quartz. The cross-bedding structure is well formed (top up). The upper surface also shows small stream channels which are filled with chert conglomerate similar to the overlying bed.

This conglomerate is about 18 inches thick and consists of rounded to angular fragments of chert about 1/2 to 3 inches in diameter in a matrix of granules of chert and iron carbonate. It and the underlying crossbedded member is exposed for a distance of 100 feet along the face of a cliff. North of Finger Lake there are further exposures of similar material (about 4 feet thick), although it is composed principally of angular fragments of chert. The chert fragments are between 1/2 and 6 inches long and about 1/4 to 2 inches thick. They appear to be fragments of broken beds of chert and it is likely that they represent an intraformational conglomerate. It occurs in the same position in the stratigraphic sequence as the exposure described east of Irony Lake. These units indicate subaerial weathering for a short period of time during the emergence of the sediments. In other words, the basin was subjected to limited elevation at this time, and the iron formation material of the matrix of these sediments must have formed in shallow waters.

Between the two members of Blue Weathering Carbonate iron formation lies the Magnetite iron formation sub-member. It is between 2 and 10 feet in thickness. This sub-member is rather thin but the carbonate iron formation contains a persistent magnetite-rich horizon at this point in the stratigraphic sequence.

It consists of alternate 1/2 to 2-inch thick beds, rich in magnetite, and of thinner beds or nodules of chert. In some localities, notably where the member is thin, the magnetite layers are composed largely of magnetite. In other places, usually where it is thicker, there is an appreciable amount of iron carbonate. West of the West Arm of Finger Lake and in places east of Irony Lake, the percentage of magnetite is particularly high.

The following table shows the average mineral composition of the formation:

Magnetite layers	55% of whole	60% magnetite 20% iron carbonate 10% quartz 10% stilpnomelane
Chert layers	45% of whole	60% cryptocrystalline quartz 30% stilpnomelane or minnesotaite 10% magnetite

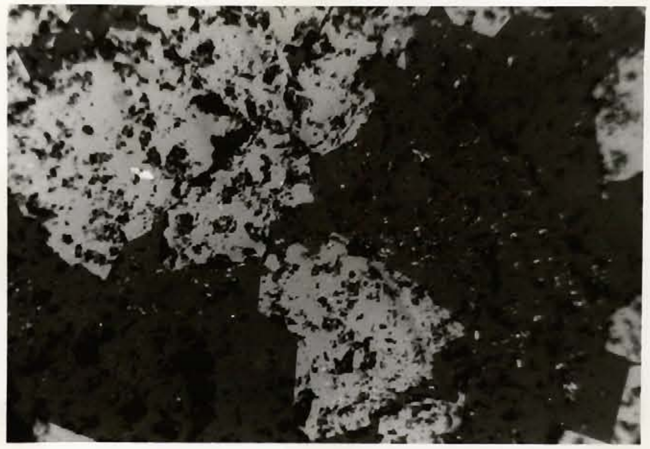


PLATE 41. Microphotograph of polished section of Magnetite iron formation east of Irony Lake. x 60,
Magnetite - grey
Hematite - light grey

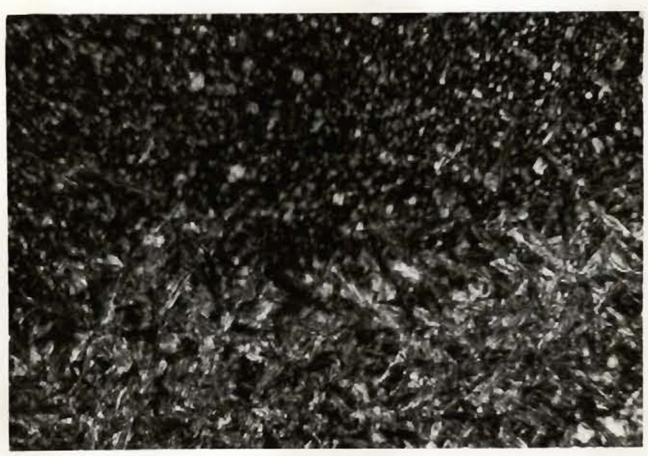


PLATE 42. Microphotograph of thin section of Carbonate iron formation, east of Irony Lake showing chert layer iron silicate layer boundary. x 60, polarized light.

The partial chemical composition, as determined by the analysis of 5 chip samples, is as follows:

	Thickness	%Iron	%Manganese	%Silica
Minimum	2 feet	39.9	0.3	32.2
Maximum	15 feet	46.0	0.6	40.6
Average	7 feet	43.0	0.5	36.1

A grab sample of a magnetite-rich bed assayed as follows:

Iron	63.5%
Manganese	.5%
Silica	8.7%

The magnetite layers of the rock consist of granules between 0.13 and 0.65 millimeters in diameter, and are composed principally of subhedral to euhedral octahedra of magnetite (0.01 to 0.1 millimeters in diameter), a few scattered grains of hematite about 0.002 to 0.04 millimeters in diameter, and a small percentage of very fine-grained iron silicates. Cryptocrystalline quartz is contained in the granules as inter-granular material and also as distinct layers and nodules which contain a small percentage of the minerals mentioned above. As throughout the iron formation, there is no sharp mineralogical difference between the chert layers and the iron-rich layers; only the relative proportions of the minerals differ.

The magnetite is greatly in excess of the hematite, except locally east of Irony Lake where it occurs as coarse distinct grains. The very fine-grained hematite occurs along certain bedding planes irregularly distributed in the quartz stilpnomelane groundmass, and small amounts appear as grains less than 0.01 millimeter in diameter within magnetite grains. In the beds and series of beds east of Irony Lake referred to above, hematite predominates over the magnetite; the relations between the two minerals being exactly reversed. The grain size of the hematite is the same as the magnetite mentioned above, and the percentages of each present are reversed to the usual. This suggests a change in degree of oxygenation of the basin of deposition, rather than a metamorphic change.

Granule structure is common in the magnetite layers, and as throughout the iron formation, is discernable because of the distribution of the dust-like material, or magnetite grains. In the hematite-rich localities referred to previously, oolites are common, further suggesting agitation of depositional environment and attendant increased oxygen content.

There is also an appreciable quantity of minnesotaite and stilpnomelane, which appears as distinct needle-like grains about 0.1 millimeter long. These have a random orientation, and their greatest concentration is in the quartz-rich areas, particularly near the boundaries between the chert and metallic layers. This relationship suggests an inter-reaction between the iron oxide-rich material and the quartz to form the iron silicate.

While this sub-member is widespread, it is never very thick, and the percentage of magnetite and iron carbonate per unit of volume, varies between fairly wide limits. In those cases where little magnetite is present, the formation thickens and grades into the Blue Weathering Carbonate member. Where the percentage of magnetite is high, the sub-member is usually about 3 to 5 feet thick with sharply-defined upper and lower limits and sharp boundaries between chert and metallic layers.

The <u>Blue Weathering Carbonate iron formation with layers of chert</u> consists of alternate layers of chert and iron carbonate. The carbonate layers, which weather to a deep steel-blue colour, are between 1 and 4 inches thick, while the chert layers are usually about 3/4 of an inch in thickness. The boundaries between these units are sharp when viewed megascopically, however, in thin section there is distinct gradation in percentages of minerals present.

The mineral composition of the two layers is shown in the following table:

Chert layers	40% of whole	70%	cryptocrystalline quartz
		15%	stilpnomelane
		15%	iron carbonate
		2%	goethite
Carbonate layers	60% of whole	80%	carbonate
		10%	stilpnomelane
		2%	goethite
		5%	magnetite
		up to 10%	quartz

The average of the results of partial chemical analysis of twelve chip samples across the sub-member is as follows:

	Thickness	%Iron	%Manganese	%Silica
Minimum	3 feet	20.2	0	17.5
Maximum	15 feet	30.9	4.1	32.6
Average	11 feet	27.6	2.2	30.1

The average composition of nearly pure iron carbonate material is as follows:

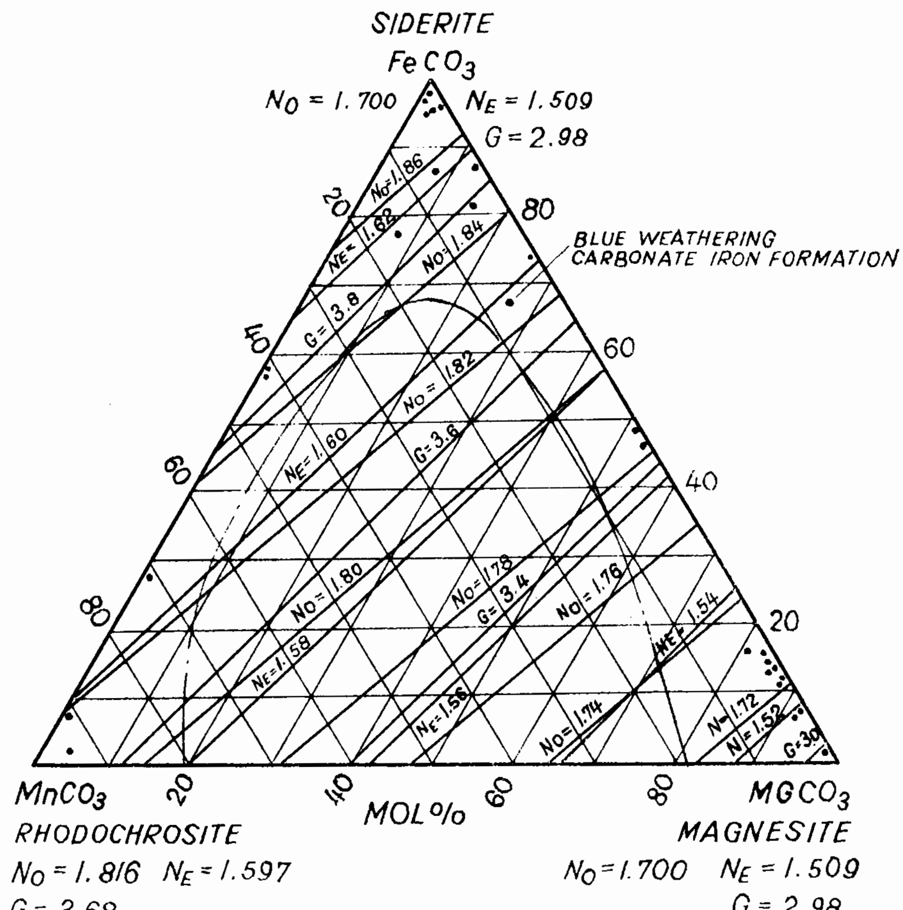
Iron	36.4%
Manganese	2.8%
Magnesium	4.2%
Calcium	0.75%
Silica	2.7%

The fine grain size and the cloudy irregular outline of the carbonate material prevents exact determination of the optical properties. However, the following were determined:

Rhombohedral crystal form,
Uniaxial negative,
Extreme birefringence,
N_e generally greater than 1.59
N_o greater than 1.82
H 3.5,
Grey to colourless.

It is also difficult to establish the exact iron carbonate mineral by the stain test method. Undoubtedly part of the material listed in the analysis above is present in the form of iron silicates and magnetite, but microscopic

FIGURE 1.



BY A N. WINCHELL 1951

PROPERTIES OF THE $MgCO_3$-$FeCO_3$-$MnCO_3$ TERNARY SYSTEM. EACH DOT REPRESENTS AN ANALYSIS. THE CURVED DASH LINE INDICATES ESTIMATED LIMIT OF MISCIBILITY.

examination of the aforementioned samples indicated that this percentage is very small, and that all carbonate minerals were of similar composition. Assuming that the percentages listed above are part of one carbonate mineral, it would consist of:

$FeCO_3$	73%
$MgCO_3$	16%
$MnCO_3$	7%
$CaCO_3$	2.5%

The calculated composition of the carbonate material indicates that it is close to siderite in composition, but that it contains important quantities of magnesium and manganese. This composition falls within the zone of estimated miscibility of the $FeCO_3$, $MnCO_3$, $MgCO_3$ system suggested by Winchell (1951) (See figure I).

Rapid chemical reaction under the influence of dilute cold hydrochloric acid (observed in thin section) of a small part of the carbonate material indicates the presence of calcium carbonate, at least in part, in the form of calcite.

The texture of the carbonate layers of the rock is largely determined by the carbonate material. This material consists of cloudy crystals of irregular outline about 0.5 millimeters in diameter. Cleavage faces are rarely seen in hand specimens, and the presence of small amounts of iron silicates and quartz is not apparent when viewed magascopically.

PLATE 43. Microphotograph of thin section of Blue Weathering Carbonate iron formation east of Irony Lake. x 60, polarized light. Groundmass of iron carbonate with black prismatic veins of stilpnomelane.

PLATE 44. Microphotograph of thin section of Chert layers in Carbonate iron formation. x 60, polarized light.

PLATE 45. Microphotograph of thin section of massive iron carbonate material of Carbonate iron formation east of Irony Lake. x 60, polarized light.

PLATE 47. Microphotograph of thin section of Carbonate iron formation east of Irony Lake. x 60, ordinary light. Note: Granule structure indicated by "dust-like impurities".

PLATE 48. Microphotograph of thin section of Carbonate iron formation east of Irony Lake. x 60, ordinary light. Note: Oolitic structure indicated by "dust-like impurities".

The arrangement of the fine submicroscopic impurities indicate oolitic and granule structures. These range from poorly to perfectly developed forms and are between 0.2 and 0.7 millimeters in diameter. (See Plate No. 47)

The carbonate grains are often as large, or larger, than either the granules or oolites. Recrystallization after precipitation is indicated.

Oolites are more common than granules; in this respect they differ from the underlying formations where granules predominate. Evidently conditions of formation of the carbonate are more favourable for development of oolite structure.

The carbonate is partially altered to goethite in places, although this may be only an outcrop surface feature. Small quantities of magnetite and/or hematite are present in some areas; and near the magnetite iron formation the percentage of magnetite may be quite large.

The iron silicate stilpnomelane is a common constituant, although it is generally present only in small amounts. It occurs as prismatic grains about 0.1 millimeters long. As in other sub-members, this mineral is found in the highest concentration in the more siliceous sections.

The chert layers consist of cryptocrystalline quartz (indistinct grains less than 0.01 millimeters in diameter) scattered carbonate, iron silicates, and occasionally scattered octahedra of magnetite.

The boundaries of the layers are fairly sharp, although the percentage of iron minerals increases towards the edges of the chert layers. Individual layers may be traced for a considerable distance along the strike, although they may pinch and swell in width. In places these layers consist of a series of connected nodules. However, nodules as such are more characteristic of the underlying Blue Weathering Carbonate iron formation with nodules of chert, In the stratigraphically higher formations the chert layers are usually well developed, thin, regular sheets.

The Carbonate iron formations are remarkably uniform in composition. Ninety-five percent of the minerals present are either iron carbonate, quartz or stilpnomelane. Variations in percentage composition is due to variations in the relative proportion of these minerals; particularly those of the first two.

The Chocolate Weathering Carbonate iron formation is similar to the Blue Weathering Carbonate iron formation except that the carbonate material contains less iron and more calcium. Grain size, proportion of minerals and texture are very similar. The iron silicates are usually minnesotaite rather than stilpnomelane.

The mineral composition of the rock is shown in the following table:

Chert layers	50% of whole	75% cryptocrystalline quartz 15% minnesotaite 10% carbonate 2% magnetite
Carbonate layers	50% of whole	70% carbonate 5% minnesotaite 15% quartz 5% goethite

Partial chemical analysis of five chip samples is as follows:

	Thickness	%Calcium	%Iron	%Manganese	%Magnesium
Minimum	10 feet	5.1	2.0	0	40.1
Maximum	40 feet	12.0	9.1	0.7	75.0
Average	25 feet	9.3	7.2	0.3	55.2

The analysis of two samples of massive carbonate material is as follows:

	%Calcium	%Silica	%Iron	%Manganese	%Magnesium
Sample #1	20.1	7.8	13.0	1.9	7.9
Sample #2	10.0	15.0	8.0	1.5	4.5

These samples were examined in thin section and were observed to consist essentially of carbonate, although the second one had a notable quantity of quartz. Thin sections of this material were tested with cold dilute hydrochloric acid, and they were observed to slowly dissolve. There was no difference in the solubility of grains, and the colour and relief of all the grains were similar. It thus appears that the composition of the grains in a given carbonate layer is the same. On this basis, and assuming that the above-mentioned elements are all present in the carbonate mineral, the composition of the carbonate in the Chocolate Weathering Carbonate iron formation is about:

$CaCO_3$	50%
$FeCO_3$	14%
$MnCO_3$	3.5%
$MgCO_3$	30%

Winchell (1951) refers to such material as parankerite e.g. dolomite with Mg:Fe about 2:1, ($CaCO_3(MgFeMn) CO_3$).

The carbonate grains are similar in size and texture to those of the Blue Weathering Carbonate iron formation; that is about 0.5 millimeters in diameter, irregular in outline, and containing scattered submicroscopic dust particles. Twinning is common; the grains are uniaxial negative; highly birefringent; high relief and colourless to a very light grey in colour on fresh surfaces. The weathered surfaces, as the name of the member implies, are pale chocolate to pale rust-brown in colour.

The silica in the rock is present as cryptocrystalline quartz in chert layers, and to a much lesser degree, as fine grains of quartz disseminated through the carbonate material. In places west of Irony Lake, this rock contains about 75% chert layers. It is relatively thin and grades into the Spotted Silica iron formation. Elsewhere it consists of about 40% chert layers and about 60% carbonate layers.

Minnesotaite is present as prismatic grains about 0.1 millimeter long and is usually restricted to certain chert layers.

PLATE 49. Microphotograph of thin section of Carbonate iron formation east of Irony Lake, showing chert-carbonate layer interface. x 60, polarized light.

PLATE 50. Microphotograph of thin section of Carbonate iron formation east of Irony Lake, showing fibrous minnesotaite in chert groundmass. x 60, polarized light.

In one thin section of a rock sample taken east of Irony Lake, there is about 20 percent of a cryptocrystalline, pale green material. This occurs as bunches (about 0.1 millimeters across) of very poorly formed grains 0.003 millimeters in diameter, having the characteristics of iron chlorite.

Oolitic and granule structures are present in certain layers of the rock, but as with most members of the Fenimore iron formation, they are not present throughout the structure, because in most cases they were not present in the original sediments. The oolite forms are more common in the chert layers. It is noteworthy that they are more common in the carbonate members than in the iron oxide-rich members, except where the hematite is abundant.

Apparently the Chocolate Weathering Carbonate iron formation represents the transition to more normal conditions of chemical sedimentation, i.e. a calcium carbonate precipitate with lesser amounts of iron and magnesium.

Spotted Silica Iron Formation

Distribution and Thickness

The spotted Silica iron formation is the uppermost unit of the iron formation. Its thickness is usually about 30 feet, and it is found in all areas from Strain Lake to the area north of Finger Lake. As it is resistant to erosion it serves as a good horizon marker, and also serves to protect exposures of carbonate iron formation from erosive action.

Petrographic Description

The average mineral composition of the rock is shown in the following table.

quartz	85%
carbonate	10%
stilpnomelane	2%
magnetite, goethite and hematite	2%

The rock is pale blue in colour and may be very, very fine-grained, massive and dense, or fine-grained, almost sugary. It consists of quartz less than 0.01 millimeter in diameter, containing an irregular concentration of larger grains (up to a 1/4 of a millimeter in diameter) in the very fine-grained groundmass. In places a faint relic of granule structure is evident, either as a distribution of dust, or as a mass of very, very fine-grained quartz.

The carbonate occurs as bunches of grains about 1/4 to 1 inch across, more or less evenly distributed throughout the rock (about 1 per square inch). The composition of the carbonate is close to that of the Chocolate Weathering iron formation. The grains are usually about 1/4 of a millimeter in diameter, although there is an appreciable amount between 0.005 and 0.02 millimeter in diameter closely associated with the larger grains. Twinning and the presence of fine impurities are common in the larger grains. The grain boundaries are irregular. Granule structure is indicated by dust-like impurities and the distribution of very small amounts of magnetite and geothite. These carbonate clusters are grey on fresh surfaces but weather to a chocolate colour. Weathering of these clusters produces the brown spotted texture of the rock.

Minnesotaite, and to a lesser degree stilpnomelane, is present in small amounts, as widely distributed prismatic grains (0.2 millimeter long).

The iron oxide material is largely geothite and is produced by weathering of the iron carbonate; however, a small amount of magnetite is disseminated through the mass.

PLATE 51. Microphotograph of thin section of Spotted Silicate iron formation east of Irony Lake. x 60, polarized light.

PLATE 52. Microphotograph of thin section of Carbonate spot in Spotted Silicate iron formation east of Irony Lake. x60, ordinary light.

Origin

Many features indicate that the Fenimore iron formation is of sedimentary origin. It has sedimentary texture, bedded character, great areal extent, and lies between two sedimentary strata. The textures, mineral compositions, and structures indicate that the iron and silica are primary constituents of the strata. There is nothing in the textures or compositions of these beds to suggest origin by replacement of pre-existing formations, of radically different composition, such as postulated by Collins and Quirke (1926) to explain the origin of the Michipocoten iron range of Ontario, or by Dunn (1941) to explain certain iron-bearing formations in India.

The possibility that any considerable part of the formation was produced by detrital accumulation is remote. No grains of detrital matter were found, except for a local conglomerate of iron formation itself. It is possible that some fine grains of iron silicate were carried in by rivers, but those present have random orientation, and are commonly clustered in concentrations at the boundaries between silica and iron-rich material, thus indicating crystallization at the expense of these two materials (probably gels). Also the composition of the iron silicate material is unusual in rocks other than those of the iron formation. It is concluded, therefore, that the bulk of the materials of the iron formation was deposited from solutions in bodies of surface waters. The problems to be discussed in what follows have to do with the sources, manner of transport, and deposition of the elements found in sediments, and subsequent changes that may have contributed to the development of the iron formation as presently constituted.

Fossil-free banded Precambrian iron formations are widely distributed They have aroused much interest and considerable controversy. There are no known counterparts of the rock formations forming today, so that direct inference from processes taking place at present is not possible.

The iron formations of the Lake Superior region have received a great deal of examination and study. Van Hise and Leith (1911), Gruner (1922), Gill (1927), Moore and Maynard (1929), and James (1954) have studied the area west and south of Lake Superior. These men conclude in a logical and convincing manner, that the iron formation is a chemical sediment which was deposited in a shallow offshore basin. Gruner, Gill and James consider that the material of the sediment was derived by the weathering of a normal landmass, while Van Hise and Leith, and Moore and Maynard suggest that it was derived in part at least, from direct contributions from magmatic sources.

Van Hise and Leith based their opinions on the close

Table showing comparison of formations in the Labrador Trough and Lake Superior area:

LAKE SUPERIOR DISTRICT (Marquette district)	LABRADOR TROUGH Shefferville Area (Iron Ore Co. of Canada Property)	LABRADOR TROUGH (Finger Lake Area)
Keewanawan Acid and basic intrusive	Diabase dykes Sawbill granite Evening Gabbro Sims quartzite	Intrusive dykes and sills?
UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
Upper Huronian Michigamme slate Clarksbury volcanics Greenwood iron formation Goodrich quartzite	(Point series) Menihek shales	Fort Chimo Group Volcanics Upper Shales and Schists Shale Black shale Abner Dolomite Chioack Formation Conglomerates Sandstone Greywacke
UNCONFORMITY	DISCONFORMITY ?	DISCONFORMITY
Middle Huronian Negaunee iron formation Siamo slate Abyik quartzite	(Ferriman series) Sokoman iron formation (Nimish volcanics) Ruth slate Wishart quartzite	Fenimore iron formation Carborate facies Oxide facies Ferruginous Shale Alison quartzite
UNCONFORMITY	DISCONFORMITY	DISCONFORMITY ?
Lower Huronian Wewe slate Kona dolomite Mesnard quartzite	(Hamilton River series) Fleming chert breccia Denault dolomite Attikamagen shales (Nimish volcanics) Seward grit	Chert Dolomite
UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
Laurentian granite and gneiss	Archean Complex Orthogneisses and paragneisses	Gneiss

associations of volcanic rocks with the iron formation. Subsequent work however, has shown that vulcanism is not closely associated in space and time with the iron-rich sediments. Ordinary weathering was considered by the early workers, to be inadequate to supply sufficient iron to form iron-rich sediments, however, Gruner and Gill have shown that modern rivers may transport sufficient iron and silica to form thick deposits.

Gruner considers that tropical conditions with abundant organic matter may produce iron and silica-rich rivers, and points out that the Amazon is presently carrying sufficient iron and silica to form a deposit such as the Biwabik of the Lake Superior region in 176,000 years. Gill points out that rivers in a temperate climate such as the Plata, Loire, Garonne and Om, are also carrying as large an amount of iron as the Amazon (about 5 parts per million).

Those who have studied in detail the iron-rich rocks of the "Labrador Trough" have concluded that they are chemical precipitates formed in a marine basin, and that the iron-rich material was derived from the normal weathering of the landmass.

Dufresne (1955), after widespread detailed study of the Sokoman iron formation of the Schefferville area of the "Labrador Trough", concluded that it was a sedimentary chemical precipitate originating under the following conditions:

> "The iron formation is part of a marine assemblage, and is believed to have collected in a restricted basin where the salinity of the sea was kept low by an abundant supply of fresh water, so that the pH was nearly neutral. Organic and bacterial life were sufficiently developed to maintain generally reducing conditions in the area of deposition; most of the iron and silica was probably derived from weathering of an old land surface, and organic matter provided colloids to bring them to the basin of deposition. The iron may have been reduced upon deposition, to form a ferrous mineral, or again it may have been precipitated directly as ferrous silicate or carbonate, depending on whether the upper limit of the reducing environment coincided with the sea bottom, or whether it was somewhere above it. In extreme reducing conditions the latter case is more likely. Vulcanism may have been instrumental in enclosing the basin of deposition and may have contributed minor quantities of iron and silica."

Huber and Garrels (1953) show that the amount of iron which may be carried in solution, is dependent on the Eh and pH of the water. Under natural conditions of pH in normal streams (6.5 to 7 in fresh water regions, and 7.5 to 8 in calcareous regions), iron may be carried only under strongly reducing conditions, such as are most likely to occur in sluggish bodies of water containing abundant organic material. Water has its greatest carrying capacity where the pH is low. For this reason, rivers that drain areas which are without carbonate rock would be the most favourable for the transportation of iron in solution. Huber and Garrels suggest that this may have been a factor in the extensive development of the Precambrian iron formation. It is noteworthy in this regard, that there are no known carbonate rocks in the pre-Huronian rocks of the Ungava Peninsula.

Experiments of Moore and Maynard show that (a) Ferric oxide hydrosols are completely precipitated, or coagulated by salts present in normal sea water within a few days after being mixed. (b) Ferric oxide and silica hydrosols when separate are quite stable, but when mixed, mutual precipitation occurs. (c) Iron and silica may be carried in solution without mutual precipitation if as little as 4.5 parts per million of peat solution are present. (d) When hydrosols of iron and silica, stabilized by organic matter, come into contact with electrolytes of the sea, iron is precipitated in a few days, whereas silica is not completely coagulated after several months.

Iron will be precipitated from ferrous bicarbonate solutions as iron carbonate, if carbon dioxide is removed. This may be effected by diminished atmospheric pressure, utilization of carbon dioxide by plants in photosynthesis, or by an increase in temperature. Change of temperature maybe an important control in the precipitation of iron in the carbonate members of the iron formation.

The presence of septaria cracks in chert nodules, intraformational breccia of chert fragments, and cross-bedding in deposits of chert and carbonate in the Carbonate iron formation stratigraphic unit, indicate that the sedimentary basin was relatively shallow, and thus susceptible to changes of temperature of the atmosphere.

Moore and Maynard showed that "banding of iron and silica can be produced by the differential settling in sea water of freshly precipitated and well agitated hydrous ferric oxide and silica. The greater portion of the iron and considerable silica settled first, followed by the deposition of a layer of almost pure silica. New supplies of material will cause a repetition of banding."

These experiments produced a band of ferric hydroxide, the upper surface of which consisted of spherical and elliptical globules of silica gel. They also produced globules, which when agitated and rolled around on an iron layer, picked up a coating of iron dust. These experiments explain the granule and oolitic forms found in the Fenimore iron formation.

Sakamoto (1950) attributes the banding of the chert and ferruginous material to rhythmic changes of pH due to seasonal weathering changes. Chert would be quantitatively more important at low pH and iron at high pH.

Huber and Garrels (1953) point out that rhythmic changes may be produced by a variety of mechanisms. They state: "The superimposition of such changes on changing oxidation potential values, gives a rational basis for the mineral associations found in iron-rich rocks. Siderite-chert alteration reflects rhythmic fluctuations of the pH in the de-oxygenated basin with little organic material and essentially no inorganic clastics. With increasing pH the carbonate precipitates, with decreasing pH, the silica. The chert-hematite association is the oxygenated equivalent with the iron oxide forming during the increasing pH stage.

Mineral Species Precipitated.

R. M. Garrels in co-operation with J. R. Castano (1950), W. C. Krumbien (1952), and N. K. Huber has considerably clarified the information concerning the controls of the mineral species (oxide, carbonate, or sulphide) in which the iron is deposited.

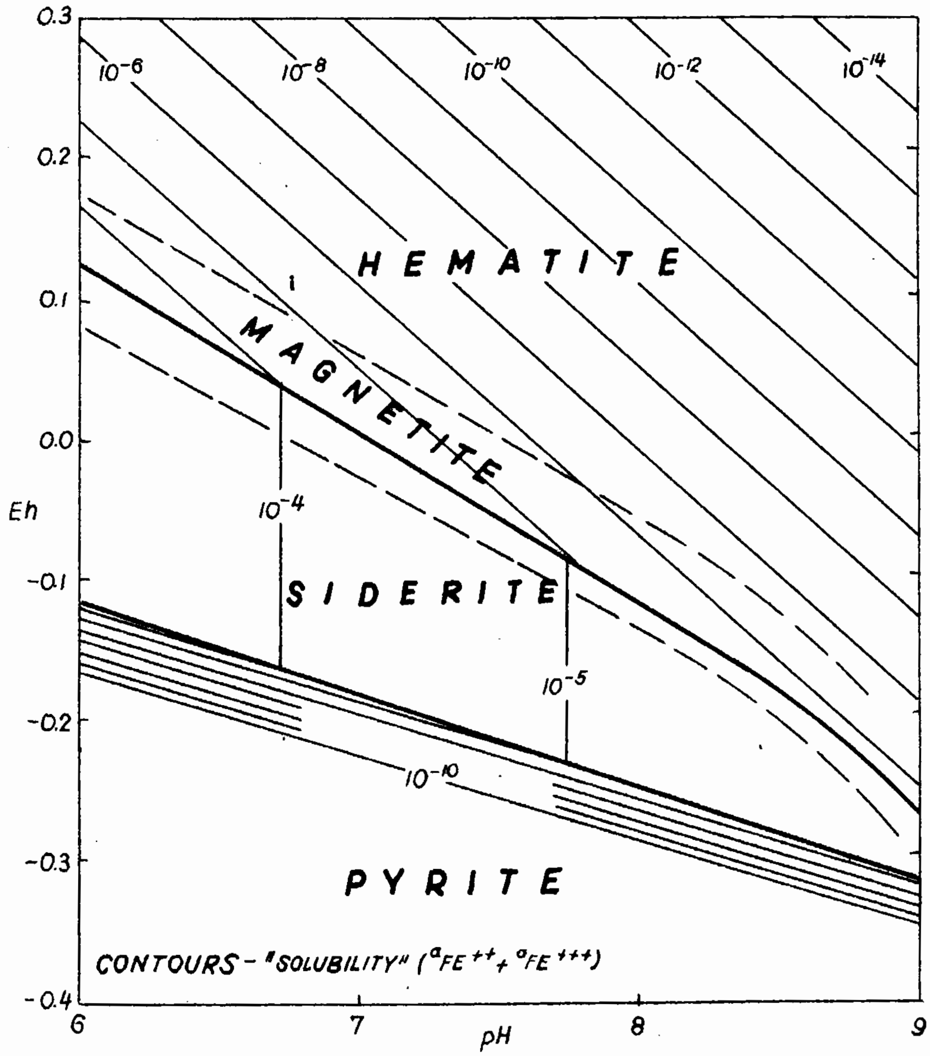
They derived a theoretical outline for the physical-chemical controls for the transportation and precipitation of iron, and subsequently verified them by experimentation. Their work is based on the premise that "iron solubility in natural waters is predictable within rather narrow limits, if the hydrogen ion concentration (pH) and the oxidation potential (Eh) of the environment are known." They assume iron was transported in true solution. If the iron was transported in a colloidal state, these deductions are still valid, if applied to the actual material composing the sedimentary deposit. Earlier formed minerals would either be replaced by the minerals in equilibrium in the sediment, or they would be taken into solution and reprecipitated under the presumed conditions.

In essence those studies show that the particular iron mineral to be deposited with depend on the Eh and pH of the water.

Figure 11, a summary of the results of this work, shows that the iron mineral, which can exist in equilibrium with conditions in the basin, is largely dependent on the oxidation-reduction potential, and to a lesser extent on the hydrogen ion concentration. The concentration of the Fe^{+++}, Fe^{++}, CaO (OH), and S determines the amount of precipitate which may form, but has no effect on the composition of the iron mineral formed. Changes of temperature and pressure would only slightly modify these results by broadening the transition zone between the bordering minerals.

They state that the pH of normal marine waters ranges between 7.5 and 8.5, while the Eh ranges from 0.4 at the surface to 0.1 at the bottom. The results summarized by the graph previously mentioned, show that iron carbonate and iron sulphide do not form under these conditions. Also abnormal concentrations of salts are unlikely to form in free-circulating marine environments.

FIGURE 11.



Eh-pH STABILITY FIELDS FOR HEMATITE, SIDERITE AND PYRITE IN SEA-WATER

(AFTER KRUMBEIN AND GARRELS 1952)

However, a restricted basin may accumulate an abnormal amount of iron in solution, and at the same time contain Eh and pH favouring the precipitation of iron oxides, carbonates, and sulphides.

The role of magnetite is not discussed in this work, but in all probability it would form where conditions in the hematite zone were close to those of the carbonate zone, or where bottom conditions, which were originally in the hematite field, became progressively more oxygen-deficient, due to bacterial action, as burial progresses.

James (1954) summarizes the result of the deductions of Garrels and fellow workers rather appropriately when he states that, "in iron formation, the iron is at once an indicator of environment and a major constituent." Thus a classification of iron formation based on primary differences in predominent mineral type, is also a classification of original environment.

The Fenimore iron formation is composed principally of quartz, magnetite, iron carbonate, and the iron silicates; stilpnomelane, minnesotaite, and iron chlorite. Different stratigraphic horizons contain these minerals in various proportions. Broadly speaking, the lower or earlier-formed units consist of chert and iron carbonate. Iron silicates occur throughout the unit, but are found mainly in the Thin-bedded Carbonate iron formation and the lowermost member, the Ferruginous Shale.

The oxide, carbonate, and to a lesser extent the silicate facies represent a predominance of the particular mineral mentioned, but variation in predominant facies from horizon to horizon is common. In the case of the silicate facies, variation in degree of importance from bed to bed is common.

The oxide facies consist of alternate layers of magnetite and chert, in which granule structure is common. The occurrence of small amounts of carbonate within this unit suggests that, within the basin, conditions ranged from midly reducing to mildly oxidizing. It is significant that in the one exposure of this unit where hematite is in excess of magnetite, the granule structures give way to oolitic structures, thus suggesting oxygenation by wave action. Also in this locality there is no carbonate present in the oxide facies.

The iron carbonate facies which in places contains considerable magnetite indicates that weakly reducing conditions existed within the basin of deposition. There was sufficient oxygen to remove all organic matter and to form some oxygen-deficient oxides. The lower iron content and the relative increase of the calcium and magnesium content of iron carbonate material of the upper section of the carbonate member, indicate that the basin became less restricted towards the close of the period of formation of the carbonate facies.

Krumbein and Garrels have shown theoretically that there is little overlap in the fields of stability of the oxide and carbonate minerals. This is broadly substantiated by the details of the Fenimore iron formation, however, it is common to find a mixture of iron carbonate and magnetite in the same rock.

Evidently magnetite forms at the boundary between the carbonate and oxide facies, and to a small extent within those conditions which favour precipitation of iron carbonate. The chemical make-up of magnetite suggests that this is not an unlikely phenomenon. Huber and Garrels' work shows that ferrous hydroxide is easily precipitated from solutions deficient in oxygen. Ordinarily it combines with oxygen in the air to form ferric oxide, however, where oxygen is excluded, magnetite could form.

The conditions of origin of the iron silicate facies is not clear. The predominance of minnesotaite, stilpnomelane, and iron chlorite in certain beds indicates that there must have been definite conditions which favoured the formation of a specific iron silicate. It seems probable that these conditions were determined by the presence of a silica gel, iron-rich material, and particularly by the availability of potash, alumina, sodium, and calcium(1) Probably as suggested by Gruner, "if the necessary

(1) - a fine dust-like impurities.

material of the proper charge is present to combine with the always present siliceous fraction to form a particular silicate." The textural relation of minnesotaite and the stilpnomelane indicates that they formed at the expense of the silica. The availability of iron, aluminum, magnesium, potassium, sodium, and calcium depends on the nature of the basin and the nature of the weathering of the landmass supplying material to the basin. The author considers that iron chlorite is a primary chemical precipitate. It has the texture, grain size and approaches the composition of greenalite, which in the Lake Superior District is considered primary. The difference in mineral species is probably a result of slight change in composition of the dust-like impurities in the sediment.

Chert, which is quantitatively the most important material of the iron formation, occurs throughout the formation as layers, nodules and disseminated small masses. Septaria cracks in chert nodules, and an intraformational breccia of chert, indicate dehydration of the chert before burial. The uniformity of amount of chert in a given bed, in a given member, and throughout the iron formation as a whole, further indicates that this material is a primary precipitate.

It appears to the author that the Denimore iron formation represents continuous deposition of a silica gel, and that the variations in percentage of this material making up the total unit reflects (a) seasonal variations in the relative amount of silica supplied to the basin, (b) seasonal changes of pH, (c) differential settling of this material relative to that of the iron-rich fraction, (d) seasonal variation in the amount of iron added to the basin.

The iron-rich material was deposited at the same time as the silica, but in irregular amounts, due to variations in supply. It was initially deposited as a very fine-grained amorphous mass, with granule[1] and oolitic structure, composed of iron carbonate and/or iron oxide depending on the Ph of the basin. This in turn recrystallized into grains of iron carbonate, magnetite, or hematite, or combined with the silica gel and associated impurities such as aluminum, potassium and the like, to form iron silicates. The fine grains of magnetite so formed are clustered in granules or, if the granules contained some chert they often occur around the outer edge of the granule. The hematite grains are largely restricted to oolites or associated fine beds of iron oxide. The grains of iron carbonate are coarser than the oolites and granules, however, these structures are preserved by fine dust-like impurities.

Any discussion of the origin of iron formation raises the question as to which textures and minerals are of primary origin, and which are the result of diagenetic change, or change within the sediment before lithification.

(1) The writer believes, as suggested by Gill (1927) that portions of the amorphous mass, which was essentially gelatinous, produced granules by collecting into roughly spherical masses, under the influence of surface tension.

Diagenetic changes probably include crystallization of quartz from a siliceous gel, formation of magnetite and/or hematite from a hydrous ferric oxide, crystallation of iron silicates at the expense of silica, iron and finely dispersed magnesium, aluminum, and potassium-rich material.

It is commonly presumed that diagenetic modification results in a noticeably coarser grain size and a change in the texture of the later minerals. In this respect coarse grains such as magnetite cut across granule boundaries, and needle-like silicate grains cut across chert nodules and bordering iron-rich layers. In some cases crystallization of quartz and magnetite all but obscures granule and oolitic textures, which are only preserved by fine dust-like impurities. These changes appear to be an integral part of the lithification of the Fenimore iron formation, and are thereby not changes due to outside agents. They are not included by the author in the term metamorphism.

Of importance in these diagenetic processes, in areas where the redox potential is favourable, is the possibility that magnetite was originally hematite and was changed to magnetite, as the sediment settled to the bottom of the basin; or during burial, decomposition of included organic material, as pointed out by Brujewicz (1938), cause a reduction of the oxygen in the sediment, and thus favour the growth of magnetite at the expense of hematite. As was mentioned earlier, where well preserved oolitic structures are present, the iron oxide mineral is predominantly hematite, while where fresh granules or indistinct oolitic forms are present, magnetite is the predominant mineral. In the first case oxygenation by wave action apparently produces hematite, while where less agitation and bottom ventilation takes place, granules of magnetite occur. This leads the author to the conclusion that the magnetite is the primary precipitate and that hematite occurs where oxygen has been added by agitation.

Metamorphism.

Metamorphic modification (formation of new minerals as a result of solution, heat, and pressure) of the iron formation is clearly shown in the north Finger Lake area. In these areas, coarse silicates, arfvedsonite and cummingtonite have developed, and the grain size of the quartz gradually increases as the amount and size of the arfvedsonite and cummingtonite increases, and the grain size of the quartz is more uniform in the more highly metamorphosed rock. Shearing and folding are also more common in these more altered areas.

It is noteworthy that the formation of secondarily enriched iron material has not occurred to any extent anywhere within the Fenimore iron formation, either in the more highly metamorphosed section, or in the very fresh rocks.

Conclusion.

The extensive well-exposed areas of the Benimore iron formation rest in an undisturbed manner, probably with initial dips, on the stable gneiss basement. This relationship has protected these units from alteration to a great extent, permitting a study of the original minerals, textures, and structures of the rocks.

The texture and stratigraphic relations of the iron formation indicate that this rock is a marine sedimentary chemical precipitate. The iron contained therein was probably dissolved from an old land surface by the leaching of carbonated water and organic acids. It seems likely that both the iron and silica were transported in colloidal form and were protected from precipitation by organic matter. This iron-rich material and accompanying silica was deposited in a restricted marine basin by electrolytes of the sea or by mutual precipitation of iron and silica hydrosols. Restricted conditions are necessary to produce Eh and pH in which iron minerals can be precipitated and to concentrate sufficient iron and silica to form the thick iron-rich units. The rate of precipitation is dependent on the amount of iron or silica in the basin and on the rate of settling, while the type of material precipitated is dependent on the Eh and pH of the basin. Iron carbonates are the predominant minerals where the basin is oxygen-deficient, and hematite where excess oxygen is present. Magnetite indicates conditions intermediate between these two facies. Silicates form where sufficient impurities of the right composition are present to combine with the silica and iron fraction.

Banding of iron and silica in the sediment may be produced by a variety of mechanisms, such as differential settling, seasonal oscillation of pH, or seasonal variations in amount of the particular material supplied to the basin.

The Fenimore iron formation, except in the region north of Finger Lake, has been little affected by metamorphism. The mode of origin of the sedimentary series of the map area as a whole, and the role of the iron formation in this sequence of events is discussed in the section entitled "Origin of the Sedimentary Series."

Chioack Formation

General Statement

The Chioack formation is predominantly a clastic formation. It consists of conglomerates, arkose, greywacke, minor shales, and sandstones.

The formation cannot be divided into a sequence of continuous horizons of different rock types, as it is made up of thin to thick lensitic units; a particular type may occur at any position in the formation and is often repeated. To illustrate this, the section west of Strain Lake consists of 100 feet of friable arkose, mainly buff-coloured, overlain by 100 feet of alternate, 2 to 20 feet thick beds of red conglomerate and red sandstone; while the area west of Chioack Lake contains 180 feet of well-bedded greywacke and then more than 100 feet of well-lithified arkose and granule conglomerate.

With such contrasting rock types there is a considerable variation in the cement of the Chioack rock. It may be anything from silica and iron oxide to clay material. Authigenic chlorite and sericite are common in the greywacke.

Each of the main rock types is treated in a separate section.

PLATE 53. View showing Chioack arkose overlying sandstone, southwest of the West Arm of Finger Lake.

PLATE 54. Chioack shale east of Strain Lake.

Greywacke

The author uses the term greywacke in the manner of Pettijohn (1943 p.944) who, after reviewing work by Krynine, Atwater, Bruce, Bayley, Irving, Van Hise etc. concluded that greywacke connotes a type of sandstone marked by (a) large detrital quartz and feldspar "phenocrysts" set in a (b) prominent to dominant "clay" matrix (and hence absence of infiltration of mineral cement) which may in low grade metamorphism (diagenisis) be converted to chlorite and sericite and partially replaced by carbonate (c) extreme angularity of the detrital components (microbreccia). (d) presence, in the smaller or larger quantities, of rock fragments mainly chert, quartzite, slate, or phyllite and (e) certain microscopic structures (graded bedding, intraformational conglomerates of shale or slate chips, slip bedding etc.) and (f) certain rock associations.

Nature and Type

The greywacke is dark grey on fresh surfaces and a brownish-grey on weathered surfaces. The rock is hard, fairly tough, and usually massive. It is composed of angular quartz, chert, and feldspar grains set in an argillaceous matrix or "paste". The matrix comprises about 15 to 40 percent of the rock. Generally with the fine-grained clastic material, a higher proportion of argillaceous matrix is found. The

PLATE 55. Microphotograph of thin section of Chioack greywacke south of Finger Lake. x 18, polarized light.

matrix contains an authigenic mixture of chlorite and sericite.

Bailey (1930 p.86-88) emphasizes the argillaceous nature of the cement of greywacke, and Pettijohn (1948 p.244) repeats this characteristic as a diagnostic feature. This clay matrix has been used as the determining feature for the greywacke of the map area.

Composition

The clastic fragments in the greywacke consist of 30 to 60 percent quartz, 15 to 40 percent feldspar, 5 to 25 percent chert, 0 to 15 percent mica, 0 to 10 percent granite rock chips. A typical sample would contain 40 percent quartz, 25 percent feldspar, 15 percent chert, minor quantities of pyrite, graphite, and rock fragments. Part of the matrix , which comprises about 25 percent of the rock, consists of rock "flour" i.e. finely ground rock debris.

The quartz and feldspar grains are mainly sharp and angular to subrounded, with the quartz usually having undulating extinction. There are a few grains of quartz with secondary silica deposited in crystal continuity with the original grain; the abraded nature of these indicate that they are of detrital origin.

The feldspar grains are mainly microcline with subordinate amounts of orthoclase and plagioclase. The plagioclase shows albite twinning and perthitic structure. About 20 percent of the feldspar shows slight alteration to sericite; the remainder is very fresh.

The chert grains are usually well-rounded to subrounded and consist of a microcrystalline aggregate of quartz.

Rock fragments when present, consist of quartz and feldspar, showing granitic texture and composition.

Ferromagnesian minerals are usually absent, but a few flakes of biotite were observed in several thin sections.

The dark colour of the rock is due to the clay material surrounding the mineral grains. Microscopic study of thin sections of greywacke shows abundant fine green flakes of chlorite with lesser amounts of colourless sericite, and some carbonate and talc. Finely-ground rock debris is also present.

The authigenic nature of the chlorite and sericite is clearly indicated, as crystals of these minerals penetrate the borders of the quartz and feldspar grains ("chevaux de frise" structure after Pettijohn 1948). The chlorite shows little, if any, preferred orientation, but the sericite usually grows parallel to the grain boundaries.

The composition, amount, and texture of these minerals are usually inferred to indicate changes in the rock caused by deep burial and folding. Pettijohn (1948) suggests that "this readjustment takes place upon the least provocation".

Pyrite and graphite are visible in most thin sections. The pyrite occurs as euhedral to subhedral cubes, which replace the matrix and the grains of the greywacke. The graphite which occurs in very small quantities, is present as scattered flakes.

Texture and Structure.

The greywacke is generally massive and devoid of closely spaced bedding planes or cleavage. The bedding planes are usually indicated by a change in grain size i.e. a thin,fine conglomerate lens or a slightly coarser bed. The rock tends to have a uniform dark grey colour.

Usually quartz and feldspar can be observed by the naked eye in a rock specimen, but in all cases they are visible with a hand lens. Microscopic study reveals that these grains are sharp, angular,and elongated.

The greywacke near the western boundary of the "Trough" is more coarse-grained and contains a lower proportion of clay matrix. The grains show a high degree of packing similar to an arkose. Greywacke seems to grade into arkose in places, particularly as observed in thin section.

In some cases the perfection of the packing of the sand grains is due to crushing of the individual grains, while in other cases it is due to normal sedimentary processes.

In any particular bed, the coarse grains are remarkably uniform in size. In adjacent beds they may be considerably finer or coarser.

No ripple-mark structures or cross-bedding were observed in the greywacke.

Origin and Conditions of Deposition.

The angular detrital quartz, feldspar, and granite fragments existing together with clay material in the greywacke, requires definite conditions of origin and deposition. Chemical weathering must be incomplete in the source area, and there cannot be much chemical weathering during transportation of rock material. Sedimentary classification must not progress to such an extent as to separate the fine-grained material from the coarse, as both are deposited at the same time. Rapid erosion accomplished by running water is a condition whereby the fine grains are relatively protected from erosion, while the coarse grains are abraded.

The thick massive beds comprising the greywacke suggest either (a) rapid deposition of material of constant type and proportion, or (b) reworking more thinly bedded deposits by strong shore currents, slumping, storm currents and the like.

Concerning the mode of origin of grits (used to refer to a greywacke type of rock) A. W. Woodland (1938 p.453) comments as follows:

The materials forming the grits fall into two classes, relatively coarse detrital fragments and very fine-grained uniform matrix material. In the coarser grits the detrital fragments form approximately one half to two thirds of the rock, while in the finer-grained rocks the matrix material tends to preudominate. That the two components were laid down contemporaneously is obvious from their closely intermixed relations; it is also clear that they belong to two different phases. There was little or no separation of the two phases by the ordinary means of grading under gravity or by lateral transportation. If both the detrital fragments and the fine-grained material represented ordinary suspended material, settling under the laws of gravity, there would at least be present all grades of material from very fine to coarse, in a sediment containing both, and in addition there would be a tendency for the ordinary laws of grading to operate. Both these conditions tend to be absent. The coarser grained grits contain only coarse fragments and the exceedingly fine-grained matrix. If, then, the fine-grained matrix represents a phase different from that of the ordinary detrital materials, that phase being fine-grained, must be one of colloidal suspension. It is postulated therefore, that the matrix of these grits represents a colloidal suspense of clayey aluminous and siliceous materials, which were subject to constant flocculation, so becoming a constant component of all the rocks of this group from fine-grained to coarse grits. Since it forms upwards of 50 percent of even the coarse grits, it follows that accumulation of this material by flocculation must have been taking place very rapidly. Prof. Boswell (1930) has suggested that co-precipitation of these fine-grained colloidal materials takes place by the action of electro-positive colloids and that in an enclosed or partially enclosed basin, precipitation of fine-grained sediment may take place "at such a rate that even where the supply is not continuous, and the depth of water not small, the sediment remains undifferentiated into grades". Flocculation of the fine-grained materials took place continuously and so they became intimately mixed with the coarse detrital material that was periodically laid down within the basin of deposition.

The last part of the Woodland discussion is of particular interest i.e. "the flocculation of the fine-grained material must take place continuously".

As long as the supply of fine material and coarser detrital grains is constant, a uniform rock consisting of intermixed fine clay material and coarser clastic material, closely intermixed will form. Relatively rapid continuous deposition and the reworking of the sediment by currents would produce a massive rock rather than a layered rock. In the Chioack formation this type of structure is typical.

Boswell (1930 p. 378) states as follows: "as soon as the supply of suspensate (clay material) ceases, that which is already in the water settles out, in accordance with the action of gravity and of electrolytes, and becomes differentiated in the process. According to its mechanical composition the resulting deposit may show banding." The last mentioned case applies to the lower Chioack horizon found west of Chioack Lake.

Pettijohn (1948) considers that greywacke can form under diverse climatic conditions. Krynine (1937) describes greywacke in northwest India. He believes, on the basis of both lithologic and faunal evidence, that it originated under tropical conditions that varied from savannah through prairie to steppe.

Pettijohn quotes Fischer as stating that the greywackes of Germany are not characteristic of any particular climatic regimen.

Eskola (1932) points out that the absence of iron oxide concretions in the Archean greywacke of Finland suggests a nontropical climate for these deposits.

Pettijohn (1943) reached a similar conclusion for the Canadian Archean greywacke.

If greywackes were to originate under tropic conditions, more critical conditions of origin would be necessary to prevent complete chemical breakdown of the minerals. The odds favour a cooler drier climate.

The small carbonate content of the greywacke of the present map area suggests a low pH factor of the water in which they were deposited, thus indicating a cool climate.

The presence of graphite in the greywacke suggests organic activity. Both Eskola and Pettijohn attribute an organic origin to the graphite of the Bothnian and Archean sediments.

Krynine regards the pyrite of the Bradford greywacke (Paleozoic) as the product of early penecontemporaneous diagenesis. The sulfate-reducing bacteria are thought to have acted upon the sulfate that was dissolved in the water between the constituent grains, thereby forming sulfites. These then react with carbon dioxide to form carbonates. If such an interpretation of the origin of pyrite and carbonate is correct, it furnishes strong evidence for a marine origin for the greywacke and for the presence of bacterial forms of life (Pettijohn 1948 p.249).

Trask claims that 1 percent carbon is the normal content for the average marine sediment. The greywacke within the map area appears to contain about this amount.

All graphite is not of sedimentary origin, and there is at least a strong possibility that weathering of rocks containing graphite could produce some of the graphite. However, detrital sedimentary graphite would hardly be as extensively distributed as that present in these rocks.

The presence of pyrite and graphite, if the above manner of origin be correct, necessitates reducing conditions, such as accumulation below the zone of oxidation.

The following factors indicate that the source of the detrital material of the greywacke was principally the granite and gneiss area to the west of the map area.

(a) similar composition of the detrital grains of feldspar.

(b) relative proportions of feldspar and quartz.

(c) associated arkoses conglomerates derived from granite and gneiss.

(d) source of material close to locale of present sediments.

The high chert content of the greywacke resting conformably above the iron formation, suggests that the chert was derived from erosion of the iron formation. The granite gneiss is probably the source of the clayey material, however, it is possible that this material came from a different source, perhaps even from the east.

The content of clay material in the greywacke increases from west to east. This might indicate that the source of this material was to the east; however, it could also be explained as deposition in quiet water at a greater distance from the source of supply. The presence of sandstones and conglomerates along the granite gneiss contact indicates rapidly flowing water. This precluded the deposition of clayey material in this locale.

Pettijohn (1948) after Fischer, considers greywacke as a "poured in" type of sediment requiring special tectonic environment. As evidence for this he mentions (a) muddy matrix indicating lack of sorting (b) massive non-stratified nature of the thicker beds (c) lack of cross-bedding, ripple marks, graded bedding.

Greywacke requires relatively limited chemical breakdown of the rocks in the original source area, short transportation, and relatively rapid constant deposition. "Pouring in" of great quantities of sediment in a special tectonic environment, however, seems less justified. Greywacke seems too extensive a formation to indicate a special environment. The muddy matrix indicates simultaneous deposition of clay material and sandy material. This could happen in a shifting marine basin of limited extent which is supplied with a constant continuous supply of clay and detrital material.

PLATE 56. Microphotograph of thin section of Chioack red sandstone west of Strain Lake. x 18, ordinary light.
Note: Dark matrix which gives red colour to the rock.

PLATE 57. Chioack sandstone west of the south end of Strain Lake, showing cross-bedded structure.

Lack of sorting in an individual bed indicates constant stable conditions for that bed only; there may be a lapse of time before deposition of the next overlying bed.

Stirring and mixing by bottom currents and/or slumping after deposition could produce massive beds of considerable thickness, although these agencies do not provide as simple, or as straightforward an explanation as that of relatively rapid constant deposition in a shifting basin.

Uplift of the adjoining landmass would initiate such conditions. This feature is strongly indicated by the beach-like uncomformity (page 157) at the base of the Chioack formation.

Feldspathic Sandstone

West of Strain Lake the greater part of the Chioack horizon consists of massive feldspathic sandstone. The colour of this rock may be buff, red, grey, or black depending upon percentage and type of iron oxide minerals present in the cement. In places west of the northern half of the lake it is buff in colour and it is interbedded with a red conglomerate. The cement is limonite and hematite respectively.

West of the southern half of the lake there is very little arkose or conglomerate present in the Chioack horizon, and the formation consists almost entirely of red and grey feldspathic sandstones. Some of the dark grey sandstones contain rounded grains of quartz or feldspar, 2 to 4 millimeters in diameter, set in a much finer sandstone matrix.

Composition

The rock consists of about 50 percent quartz, 20 to 40 percent feldspar, and a small percentage of sericite and chlorite.

The cement consists essentially of carbonate with variable proportions of limonite and hematite, and perhaps some magnetite. The megascopic colour of the rock is dependent on the iron mineral or minerals included in the cement. The grey sandstone cement is almost entirely calcite, and the dark grey variety contains an appreciable content of hematite and/or magnetite. The type that is buff-coloured contains a noticeable amount of limonite, while the red type contains hematite and limonite.

Texture and Structure

The rock is composed of massive beds between 2 and 16 inches thick. The variation in composition and grain size between different beds is very small and takes place in a very thin unit of rock so that the bedding plane is apparent, principally due to its cleavage rather than the changes in colour or composition.

Cross-bedding was observed at one place only in the Chioack sandstone. At this locality, west of the south end of Strain Lake (Plate 57) no colour banding was apparent, and the only visible indication of the structure was the cleavage. This produced excellent three-dimensional blocks with the structure of cross-bedding laminae. The upper and lower surfaces are concave.

Origin

The feldspathic sandstone grain is the normal erosional product of a granitic gneiss area which has been rejuvenated. This material was rapidly stream deposited in an offshore basin. The change in nature of the cement evidently indicates local variations of chemical conditions in the basin of deposition, or variations of the solutions present in the sediment during lithification. This points to restricted disconnected basins.

Arkose

The arkose horizon of the Chioack formation is exposed between the contact of the granite gneiss and the Strain-Bones Lake valley. It is not found farther than 1 1/2 miles west of the gneiss contact.

Nature and Type

The arkose beds are lensitic in form and vary between 10 and 100 feet in thickness. They are granitic in composition. Interbedded with the lenses of arkose are beds of sandstone, generally buff-coloured. Usually the arkose beds contain scattered pebbles of granite and iron formation. In places west of Teeter Lake the Chioack horizon is almost completely arkosic with a high content of boulders and cobbles (almost a conglomerate in this instance).

Composition

The arkose consists principally of quartz and feldspar. The quartz content is about 40 percent of the whole and the feldspar 60 percent. The feldspar content is made up of microcline, orthoclase, plagioclase, and perthite. The plagioclase is largely altered, although its original composition appears to be that of andesine.

The proportions of the various minerals present are nearly the same as the granite pebbles contained in the arkose. In these pebbles the plagioclase has the composition of andesine.

The cement of the arkose is calcitic and/or iron oxide.

PLATE 58. Microphotograph of thin section of Chioack arkose west of Teeter Lake. x 18, polarized light. Note: Close packing and brecciation of grains.

West of Strain Lake the cement is calcite, and thus the arkose is buff-coloured. West of Teeter Lake it is principally limonite with minor hematite, and the arkose and the conglomerate are dark grey in colour.

Texture

The arkose is extremely close-grained, so much so in fact that in places, the rock in some thin sections appears to be granite. This high degree of packing is due to two features (a) reworking during compaction (b) crushing and fracturing of the grains. (Plate 5b).

The latter feature is illustrated by the offset fragments of the feldspar grains which were later cemented by a thin film of carbonate. There is considerable variation in the grain size of the minerals composing the arkose, particularly in the case of the feldspar.

Origin

The source of the arkose appears to have been the granite gneiss to the west. The proportions and type of the grains are similar in both rocks. The presence of pebbles of granite is also indicative of this source.

The arkose appears to be a reworked feldspathic residuum which has been deposited in a basin parallel to the area of the granite gneiss. Partially disintegrated or decomposed granite may be formed under any climatic conditions, although a cool climate is most usual. A deposit of arkose could have been produced during a reworking of this rock debris, with the finer material being removed during the transportation of the residuum.

Conglomerate

Conglomerates are an important member of the Chioack formation. They occur as beds from 3 to 75 feet in thickness interbedded with sandstones and arkose (see Plate 59, a typical illustration of much of the Chioack formation). The conglomerate horizon may occur at any point in the Chioack succession.

Nature and Type

Generally speaking the conglomerate fragments are less than 8 inches in diameter. In several small areas, however, such as immediately overlying the iron formation west of Teeter Lake, the rounded fragments are up to 18 inches in diameter. In all cases the fragments larger than 1/4 inch are well rounded.

The matrix is sandy or arkosic, with a cement of carbonate or iron oxide.

PLATE 59. Chioack conglomerate northwest of Strain Lake.
Note: red jasper pebbles.

PLATE 60. Chioack conglomerate (red) overlying red sandstone
northwest of Strain Lake.

The colour of the rock depends upon the type of cement. West of Strain Lake it is red in colour due to a coating of goethite around the sand grains of the matrix. Other horizons may be buff or dark grey coloured.

The sand-size particles of the conglomerate are of the same composition and form as those of the sandstone.

The rounded fragments consist principally of granite, granite gneiss, and iron formation with minor quantities of quartzite, dolomite, sandstone, and vein quartz. The iron formation fragments are mainly pieces of chert or jasper; very little iron is present. The larger fragments are mainly iron formation, while granite forms the majority of the 1 to 6-inch material.

West of the centre of Strain Lake at the boundary of the iron formation and the Chioack formation, there occurs a conglomerate consisting entirely of iron formation. The rounded fragments are iron formation, and the cement consists of goethite and hematite.

Undisturbed iron formation may be traced along the beds (on the face of a modern cliff), to a point where angular fragments of iron formation occur in the rock, as at the base of an old erosional surface, these in turn grade into rounded boulder-sized pieces, so that in a lithified rock one can trace the development of the erosional debris,

PLATE 61. Conglomerate of iron formation northwest of Teeter Lake.

occurring at the foot of a Precambrian cliff. This feature indicates beyond a doubt that erosion of some consequence took place at the end of iron formation time, and that there was an abrupt change in the tectonic conditions of the area.

Textures and Structures

The pebbles and cobbles of the Chioack conglomerate are smooth and well-rounded. This well-rounded nature of the conglomerate fragments stands in marked contrast to the extreme angularity of the clastic particles of the matrix and associated arkoses and greywacke.

The pebbles and cobbles are more or less segregated as to size. Cross-bedding is not common, and cut and fill structures were not observed.

Origin

The source of the conglomerate debris is readily apparent. The granite gneiss occurring to the west is almost identical to the granitic debris of the conglomerate, and the similarity of the Fenimore iron formation to the iron formation debris of the conglomerate, is too marked to look farther for the source. Tectonic uplift is suggested to provide the conditions necessary to produce the conglomerate.

The well-rounded and crudely bedded, well-worn, characteristic of the pebbles indicates that the conglomerate was formed by an aequous agency.

The roundness of cobble-size fragments does not necessarily indicate that the fragments were transported a great distance. As Krumbien (1940) states, rivers can produce rounded debris in relatively short distances (granite fragments may be rounded in a distance of about 4 to 9 miles). The effect of currents at the site of final deposition is also an important factor in producing rounded debris. The cliff-like erosion surface of iron formation suggests beach conditions.

The relatively thin and extensive beds of conglomerate (usually 3 to 20 feet thick) suggests that the material supplied to the site of deposition was evenly spread out. The absence of cross-bedding and cut and fill structures indicates the probability that the material was added to a basin of deposition by rivers and spread out by off-shore currents.

Origin of the Chioack Formation

Each of the units making up the Chioack formation has been described, and deductions as to the individual mode of origin have been made. The formation as a whole is now considered to try to obtain some idea of the conditions which formed these rocks. It is felt that this may throw some light on the problem of the iron formation.

Krynine (1941) suggests that different types of "sandstones" such as arkoses and conglomerates on one hand, and greywacke on the other, indicate different stages in the tectonic and geomorphic processes which shape the successive stages in the development of the landmass.

Such is not the case in the present map area. The greywacke here is merely a sediment which obtained its constituents from the same source as the arkose and conglomerate and was formed at the same time, but under less drastic mechanical conditions.

The sand-size grains are angular and irregular in shape in the conglomerate, feldspathic sandstone, and the greywacke. All types of sediments of the Chioack formation show features of the others; they are all related and belong to the same stratigraphic unit (400 feet thick). For these reasons the conditions of deposition of each may be considered together to provide a more complete picture of the conditions at the time the Chioack formation was evolved.

This problem will be considered under the following sub-headings:

(a) Climate and degree of weathering of the source area of the sediments.

(b) Type and amount of transportation.

(c) Mode of deposition.

(d) Areal distribution of the sediments.

(e) Nature of the zone of deposition.

Climate and degree of weathering of the source area of the sediments.

Arkose debris may form under any climatic conditions. If, however, it forms under humid, tropical conditions removal must be much more rapid than if it were under a cool climate. Inasmuch as the formation underlying the Chioack formation is made up of relatively flat-lying chemical sediments, it is logical to assume that the nearby landmass or at any rate, the landmass draining into the basin in which the iron formation was deposited was low, flat, and relatively stable before Chioack times. The lack of angular unconformity between the Chioack and iron formation and the thinness of the Chioack formation, particularly that of the conglomerate, suggests that uplift preceding or occurring during Chioack times was slight, and that there was not sufficient relief to cause rapid removal of the arkosic material from the landmass. Escola (1932) and Pettijohn(1941) believe absence of iron oxide concentration in the greywacke suggests a non-tropical climate.

While no definite conclusions may be drawn from the present map area, it seems likely that the climate was not humid and tropical.

A feature which influences the author's opinion in this matter is the appearance of the red conglomerate which is very similar to present glacial outwash deposits south of Strain Lake. The sand and gravel in the present stream bed is similar in texture, and because of an appreciable iron content about the grains, has a similar red colour.

About 60 miles south of the present map area the author observed a dolomitic formation believed to be of the same general age as the Chioack formation. In the dolomite there occurred several one inch diameter granitic pebbles which could only have obtained that position by rafting by ice.(1) This again suggests cold climate or glacial conditions, and while no definite conclusions may be drawn from the present map area, it seems likely that the climate was not humid and tropical.

Type and amount of transportation.

The presence of rounded boulders in the Chioack formation indicates that water was the principal agent of transportation.

The angular irregular nature of the greywacke, sandstone, and arkosic fragments indicate that this transportation was limited as to time and distance.

As indicated in the foregoing section there is some suggestion of ice action at this time. One possible explanation for some of the conglomerate lenses within the Chioack formation could be the melting of tongues of ice.

(1) - Rafting by roots or other forms of vegetation seems to be precluded in Precambrian times.

Mode of deposition

The massive nature of the sandstone beds, the thin, even beds of interbedded conglomerate, and the lack of cross-bedding and cut and fill structures, suggest that streams or rivers were not the last agent of deposition of these members. It seems most probable that off-shore currents reworked and spread the material deposited in the basin by streams.

Areal distribution of the sediments.

The conglomerate and arkosic members are found within two miles of the gneiss contact. Within this zone there is a considerable amount of feldspathic sandstone. Further to the east the Chioack formation is principally greywacke and shale.

To the east of the gneissic area, there is a normal off-shore assemblage of clastic sediments probably derived from the weathering under cool climatic conditions of an elevated, though relatively stable landmass.

Nature of the zone of deposition.

The presence of graphite and pyrite suggests marine conditions for the deposition of the greywacke. The clay material in the greywacke indicates a reducing marine environment to flocculate the clay minerals.

The nature of the arkose and conglomerate bodies indicates that these are thin, evenly spread outwash deposits formed in a basin bordering the gneiss. The cement of the conglomerate and arkose is not the same in all localities, which suggests that the basin was divided into sections in which different physical-chemical conditions existed and where different concentrations of material in solution were present.

Abner Dolomite

General Statement

Conformably overlying the Chioack formation is a dolomitic stratigraphic unit referred to as the Abner dolomite. It is between 100 and 300 feet thick, relatively uniform, and continuous along the strike.

Petrographic Description

This unit is generally a very fine-grained, light grey rock which weathers to a light buff colour. It consists of fine, uniform grains (2 millimeters in diameter) of carbonate, and scattered concentrations of quartz. Crystallization of the carbonate mineral has all but obliterated original granule to oolitic structure, however, in some thin sections of about twice the normal thickness, it may be seen. Apparently the amount of dust-like material which indicates the oolite structure, is very small and unnoticeable in regular thin section. Staining tests and refractive index determinations indicate that the carbonate is dolomite. The buff colour of the weathered surfaces, however, indicate that some iron is present in the carbonate mineral.

Fine-grained or microcrystalline quartz is present either as a box-like network of stringers, as small blob-like concentrations (1 to 5 millimeters in diameter), or sometimes as scattered very fine grains intimately associated and intermixed with the carbonate. Solution of the dolomite as part of the weathering process, produces a characteristic network of stringers and point protrusions of the quartz on exposed surfaces of the rock. This feature is an important diagnostic feature of the rock.

Beds of dolomite are usually several feet thick. Joints are uncommon, making Abner dolomite a massive, unbroken rock.

Near the base of this member, however, sand-size impurities constitute a large percentage of the rock. These are mainly quartz grains. Bedding (1/10 to 1/4 inch thick) is well-developed and cross-bedding may be present (top determinations indicate that the beds have their tops up). These impure dolomites usually weather to a light rusty colour.

Nodules of black chert occur along certain horizons, notably near the top of the formation east of Strain and Teeter Lakes. The chert is an aggregate of microcrystalline grains of quartz.

PLATE 62. Microphotograph of thin section ofAbner dolomite east of Strain Lake, x 60, polarized light.

PLATE 63. Microphotograph of thin section of Abner dolomite east of Teeter lake. x 18, polarized light. Note: Quartz stringer.

The contact of the Abner dolomite with the overlying calcareous shale is not exposed, however, indications show that it is relatively abrupt, as in several localities a change is noted within a distance of a few feet. In the northern part of the map area (north east of Finger Lake) buff dolomite and shale are interbedded through a stratigraphic distance of several hundred feet, indicating an oscillation of depositional conditions.

Origin

The origin of dolomite has not been satisfactorily explained, even though dolomite is extensively distributed throughout the geologic system.

The most widely accepted theory postulates that dolomite, which has not been precipated in the laboratory, forms as a result of replacement of calcium carbonate by magnesium carbonate from marine waters during or shortly after deposition. In some cases it is recognised that dolomitization takes place after burial and uplift, and therefore occurs considerably later in the history of the sediment.

The intimate association of quartz with the carbonate suggests that is was precipated at the same time as the original carbonate. This feature, the composition, and the granule and oolitic texture of the rock resembles those of the iron formation.

Silicification of limestone and dolomites is not an uncommon feature; it has been described in the Oneota Dolomite, Owachita Chert, Shakopee dolomite, (Ordovician), and the Cambrian oolitic limestone of Tyrone, Pennsylvania. Those who have studied the afore-mentioned rocks consider that this process may occur early or late in the diagenetic process. There is no unanimity of opinion on the subject.

Pettijohn (1949) favours a relatively late metasomatic origin for chert nodules and beds in normal marine limestone and dolomite (page 322). He suggests that they are often associated with "dolomite, siderite, phosphate rock, and all metasomatites".

If silica were present in the original chemical precipate, as diagenesis takes place, it might be expected that re-arrangement of the silica would occur. Harlton(1953) suggests that alteration processes inaugurated during orogenetic movements (in sediments only partially lithified and still containing sea water) will affect the solubility of the silica in the sediments. Rocks under load tend to have most of the water expelled, however, some of it must remain. Solubility of silica is greatest under high pressure and during initial folding, pressure increases but as Harlton points out "where the over-thrust begins to move, stresses are instantly reduced, internal pressure is relieved and the ability of compressed waters to retain silica in solution is vastly reduced."

In accordance with this theory the most highly silicified beds must have been (a) those beds from which the water was most difficult to expel (b) those in which silica was in such a form as to be readily dissolved by water under high pressure and (c) beds in which water could have been forced from adjacent beds of type (a) and (b).

This suggests that a variety of degrees of silicification would occur within the rock.

Following Tarrs ( ) and Kays (1947) concepts of geosynclinal conditions, the author visualizes a considerable thickness of very fine-grained marine sediments still incompletely lithified, containing primary silica subjected to tectonic movement. These movements cause migration of part of the contained silica to form the box-like network of stringers of quartz. The remainder of the silica remains as a microcrystalline aggregate of grains of quartz in small blob-like concentrations.

Upper Shales and Schists

General Statement

Overlying the Abner dolomite is a thick assemblage of fine-grained detrital rocks which in many places are highly schistose and contorted. They may represent either a revival of finer-grained sedimentation of Chioack type, or consist of Chioack sediments faulted into their present position.

East of the centre and northern part of Finger Lake the Abner dolomite thins out and is interfingered with shales. The relations of the beds suggest that sedimentation of the detrital material was continuous, while the deposition of the dolomite took place in a more restricted basin and during a shorter period of time.

The schist and slate exposures east of Jones, Teeter, and the south end of Finger Lake are highly contorted due to folding and thrust faulting. Structural relations indicate that the attitude of such faults would be slightly steeper than the dip of the formations further west.

Petrographic Description

The composition of this stratigraphic unit varies from greywacke to shale(1). In places it is impossible to distinguish it from the Chioack formation, but generally it is fine-grained and has a higher proportion of clay material.

(1) - used to designate a fine-grained rock with an important content of fine-grained hydrous aluminum silicate.

The percentage mineral composition is usually as follows:

Quartz	40 to 60%
Feldspar	Almost nil
Hydrous aluminum silicate	40 to 60%
Graphite	0 to 60%
Pyrite	0 to 5%

The quartz commonly occurs as angular, fine grains about 0.01 to 0.05 millimeters in diameter, although in some beds coarser grains are present.

The hydrous aluminum silicates consist of the minerals sericite, talc, and chlorite. Grain size is less than 0.05 millimeters. In some cases there is random orientation of this material, but usually the grains are parallel to the bedding and concentrated in certain beds, Textural details suggest that some of this material is of detrital origin, though much of the parallelism is obviously due to metamorphic changes.

Interbedded with the volcanic rock east of Laura Lake on the Eastern edge of the map area, is a rusty weathering shale with beds containing an iron silicate, in a groundmass of fine-grained quartz.

The textural relationship of this rock is much the same as that of the iron formation members. Here, however, it is interbedded with siliceous beds with a high pyrite content. These rusty weathering units, which are about 100 feet thick and several miles long, are outside the area and scope of this thesis, but it is of interest to note that they occur closely associated, in position at least, with the volcanic rocks, and somewhat resemble the ferruginous shale horizons of the iron formation. However, they differ in that the iron silicates are commonly orientated parallel to the bedding, while those in the iron formation are always of random orientation. The author ascribes the orientation of the silicates of the iron formation to crystallization from a silica gel, and considers those of the "Shales and Schists" unit to be of detrital sedimentary origin, because of the uniformity of grain size, orientation, composition, and lack of metamorphism.

Graphite occurs as very fine grains concentrated in certain horizons lying to the east of Teeter, Bones and Finger Lakes. This material imparts a dark grey to black colour to the rock. Where the concentrations of the graphite is particularly high, as a few hundred feet east of the south end of Teeter Lake, pyrite is present in amounts up to 5 percent. In this locality the rock is a typical black shale (Plate 64), in that it is a black, extremely fissable, soft rock with a very high graphite content.

The graphite shale in this area is of particular interest inasmuch as all stages of alteration to a black

PLATE 64. Microphotograph of thin section of graphite shale east of Teeter Lake. x 18, ordinary light.

PLATE 65. Outcrop of graphite shale altered to black chert.

chert may be observed in the outcrop. A cross-section through a silicified section is as follows:

(a) black shale,

(b) black shale with scattered 1 millimeter quartz stringers,

(c) numerous 1 millimeter quartz stringers, some along bedding planes with silicification adjacent to them,

(d) black chert with scattered quartz stringers,

(e) conchoidal fracturing black chert with evidence of old bedding, and no quartz stringers.

It is interesting to note that the graphite content is less than half as great as the same bed five feet away.

These pods of chertified black shale may be as large as 500 feet long and 40 feet thick. They are not continuous uniform masses, but vary in degree of alteration within a few feet both across and along the strike. In all cases the alteration is connected with quartz stringers, although the end product is nearly devoid of them. The source of the quartz appears to be the underlying dolomite. Evidently during compaction of the dolomite silica was expelled in solution. It permeated the overlying shale and this resulted in local alteration to chert. The above-mentioned exposure is within 50 feet (perpendicular distance) of the dolomite contact. The dolomite in this area has an abnormally high content of quartz stringers. The subject of expulsion of silica from the dolomite is treated in the section on Abner dolomite.

Structure

The more contorted section of the Upper Shale and Schist sedimentary horizon is found in the vicinity of the Strain-Bones-Finger Lake trough. It is highly folded and schistose in contrast to the gently dipping, broadly folded shales and tuffs found further east.

The schistose series along the pronounced topographic valley strongly suggest thrust faulting. Flow and fracture cleavage, along with small scale flowage, and drag folds, are highly developed. These structures are orientated in such a way as to indicate movement from east to west along eastward dipping planes.

Origin

The main volume of shales originated as products of normal detrital sedimentary processes, and as volcanic tuffs. Thin section study indicates that the hydrous alumina silicate minerals owe their orientation to sedimentation and recrystallization; however, one exposure west of Canal lake where the horizon consists almost entirely of iron silicates, these minerals are of uniform size, orientated parallel to the beds, and concentrated in certain beds, suggesting that they are detrital grains. These features were never observed in the iron formation, further suggesting that the material of the iron formation is purely chemical in origin.

The presence of local accumulations of black shale, with an abnormally high graphite content, indicates the existence of local restricted basins with restricted circulation of bottom waters. Such conditions exist today in the Black Sea and Norwegian fiords.

Fort Chimo Group

General Statement

The central and western parts of the "Labrador Trough" are underlain by volcanics, interbedded shales and diorite-gabbro intrusives. These lie mainly to the east of the present map area, and are designated as the Fort Chimo group.

As mentioned in the preceding section there appears to be a gradation in the sedimentary facies from Chioack to this series. No evidence of an unconformity is known to exist; however, the contact regions are confused by folding, faulting, and the presence of the dolomite.

The rocks of this series have not been studied in detail either petrographically or structurally as they were largely outside the field of study.

Composition

The shales are similar to those described in the previous section on Upper Shales and Schists. They occur as stratigraphic horizons about 100feet thick separated by thinner horizons of volcanics. The shales underlie the valleys and are found outcropping along their sides.

The volcanics include andesites, basalts, agglomerates, and tuffs. Pillow lavas are present (tops up) but the majority of these rocks are massive andesites.

The sediments and volcanics are intruded by bodies of diorite and gabbro. For the most part these appear to be sills, although in many cases it is difficult to distinguish between these sills and thick volcanic flows. The intrusive rocks consist of varying proportions of mafic and femic minerals, all of which are highly altered. Commonly they are as follows:

Hornblende	45%
Epidote	40%
Zoisite	10%
Sphene	0 to 15%

The composition of the mafic minerals was fairly constant in all sections examined. Maximum interference colours are second order blue. They are optically negative, pleochroic in light green and bluish green, 2V is between 60° and 80°, and Z to C is a maximum of 22°. The optical properties and a well developed prismatic cleavage indicate that the mafic mineral is hornblende with the following composition[1]

Mg/Fe	3.6
Al/Fe	0.4
Na/K	7.0

The hornblende occurs as medium-sized grains with an irregular feathering border; it contains inclusions and appears to be secondary after pyrozene. The hornblende grains compose the majority of the rock.

There are no pronounced, well-developed, fresh grains of feldspar present in the rock. Apparently it has been altered to a felty mass of epidote, zoisite, and to some extent albite. Alteration is so highly developed that determination of the original feldspar is impossible. The mineral which has developed to the greatest extent is epidote. It is pale green, slightly pleochroic, and occurs as elongated crystals in bunches and aggregates. Its birefrigence is first order, and it has parallel extinction thus suggesting that it is epidote. Associated with this, is a colourless, non-pleochroic material of first order interference colour, suggesting zoisite. Present in small amounts is a felty mass of fibrous mineral so minute that determination of its properties is impossible. This assemblage suggests saussurite, a common metamorphic product of calcic feldspars.

Small amounts of quartz are present in places. Sphene is present in some localities, and at the centre of the grain it is commonly partially altered to ilmenite.

(1)- after U.S.G.S. Bulletin No. 848, Page 175.

PLATE 66. Microphotograph of thin section of basic volcanic rock, west of Laura Lake. x 18, ordinary light.

Structure

Essentially the sediments and volcanics consist of a monoclinal series dipping at an angle of 20° to 45° to the east. East of the map area there are normal fold structures.

Faulting evidently took place in numerous localities principally as reverse faults along steeply dipping planes outcropping in the valleys.

As is common throughout the "Labrador Trough" the stresses came from the east causing the Fort Chimo series to override the older sediments.

Structure

The area involved in this report lies along the western edge of the northern part of the so-called "Labrador Trough".

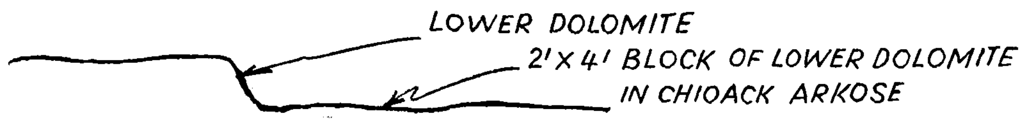
The term "Labrador Trough" implies an elongated basin containing an assemblage of sedimentary rocks. Inasmuch as the "Trough" consists of a younger sedimentary series overlying older gneiss, the term is applicable but far from descriptive, as the area is not topographically a depression, or structurally a simple basin. The author prefers the term "Labrador geosyncline" because the structure is, in effect, a folded series of sediments which formed in a geosynclinal basin, apparently in much the same way as the Appalachian geosyncline.

The sedimentary series involved in this thesis lies unconformably upon an older gneissic basement. This relationship is well shown in the area west of Teeter Lake, and North of Finger Lake. The Lower dolomite, Alison quartzite, and Fenimore iron formation are conformable units lying one on top of the other, however, the Chioack formation overlies the iron formation with locally disconformable relations. The Chioack formation, Abner dolomite, Upper Shales and Schists and Fort Chimo group are also conformable; although the Fort Chimo group represents a distinct break in the type of sediment, there is no indication of unconformable relationship.

Structurally speaking there is a distinct change in the amount of deformation of the rock series east of the areas of Abner dolomite. As explained in the section Origin of the Rock Series, this is believed to represent a change in tectonic conditions in the geosynclinal structure. Quiet conditions of accumulation give way to rapid accumulation along with vulcanism, and perhaps failure of the geosynclinal structure.

The disconformity between the iron formation and the Chioack formation is indicated by the following structures:-

(a) Large angular blocks of Lower dolomite lie in the Chioack formation arkose west of the south end of Strain Lake. In this locality there is an exposure of the Lower dolomite on a cliff. At its base is Chioack arkose containing a block of dolomite identical to that of the cliff (see Plate 57).



(b) West of the centre of Strain Lake and south of Alison Lake, an outcrop of iron formation occurs as follows (see Page 131 for description) which indicates erosion at the end of iron formation times.

(c) West of Teeter and Strain Lake are two localities where the Chioack sandstone lies directly on the Alison quartzite.

(d) Boulders of iron formation are common occurrences in the Chioack conglomerate.

(e) Conglomerate composed of iron formation fragments are found in a matrix of iron oxide and fine fragments of iron formation.

In all cases mentioned above there is no angular discordance between the Chioack and older formations, and in most cases the series is uninterrupted by any significant

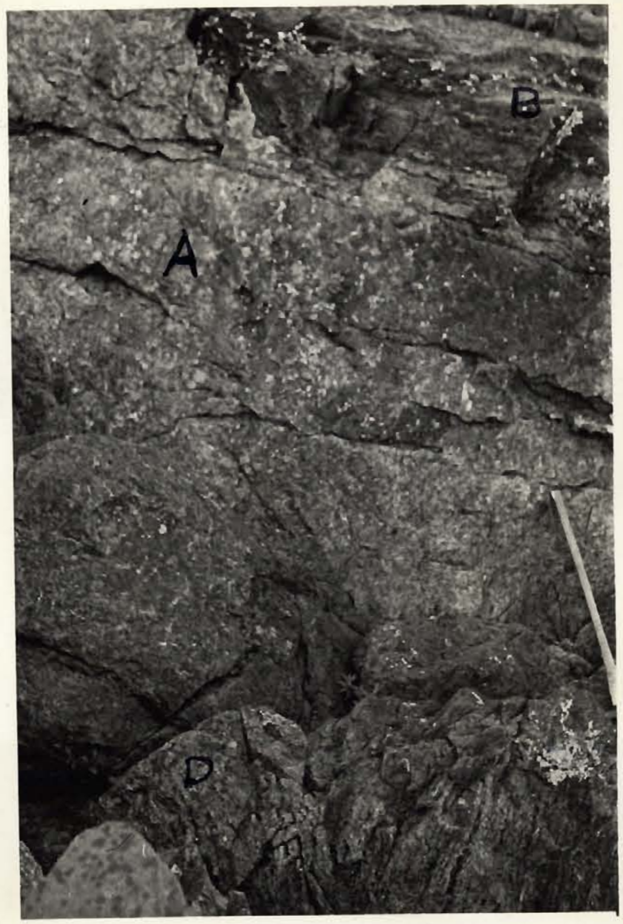


PLATE 67. Vertical view of Chioack arkose, taken from an eight foot high bluff of Lower dolomite (D), looking down at the bed of arkose (A), containing a large fragment of lower dolomite (B).

alteration in tectonic conditions in the basin.

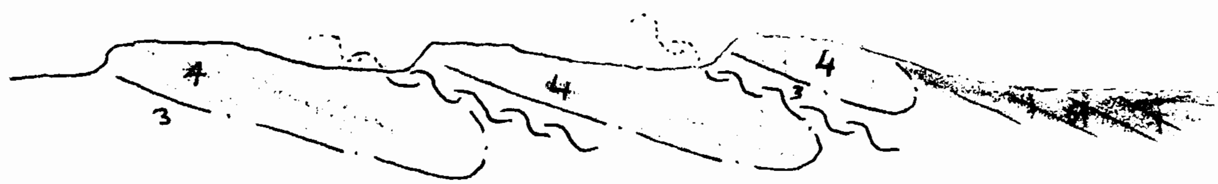
Structurally the rocks consist of a monoclinal series dipping eastward at about 8° to 15° at its western edge and gradually increasing to about 20° to 30° in the in the eastern areas. There are scattered localities which have steeper dips but these are local variations, and as far as could be determined are due to local features such as changes in thickness of formations, sedimentation about remnants of older formations left by erosion, faulting along the gneiss contact, differential movement of the basement, difference in competency in areas of volcanics and shales, and variation in amount and locale of overthrusting. These features will be discussed later.

The gentle dips and lack of metamorphism in most areas of the quartzite, iron formation, Chioack formation, and dolomite, along with gradual increase in dip eastward, suggests that these dips are the result of compaction of a gradually increasing thickness of sediments lying on the solid gneiss basement. The masses of iron formation west of the East Arm of Finger Lake and east of the West Arm of Finger Lake have been overturned by folding and in the former area, repeated by faulting.

West of the East Arm of Finger Lake the exposure of iron formation and Alison quartzite is repeated three times due to folding and faulting and the eastern edge is overturned by folding. There are numerous cross faults.

In places strong shearing may be observed between the Chioack formation and the overlying iron formations. These features point to a series of thrust faults and attendant folding of the formations. Figure [illegible] is a cross-section through this member. It should also be noted that the iron formation is bounded on the north by Chioack greywacke. There are signs of only slight movement between the two. Their structural relations suggest that it is an erosional contact. South and southeast (5 to 6 miles) of this contact there are scattered exposures of iron formation which are also believed to be erosional remnants of iron formation. It is possible that these relations indicate an angular unconformity between these two formations, however, it is more likely that the relationship between the two developed before folding and was subsequently influenced by the irregular mass of iron formation.

The iron formation east of the west arm of Finger Lake has been overturned over the younger Chioack rocks and the incompetent thinly-bedded units have been highly deformed into a series of flowage folds. The structure is of an overturned fold. This occurrence is the most westerly manifestation of the westerly thrusting of the easterly part of the Labrador geosyncline. It is possible that these structures originated shortly after deposition of the iron formation, perhaps before complete lithification



west east

Figure 3. East-west section through the folded and faulted rocks west of the East Arm of Finger Lake.

and before burial by younger sediments. Initial disturbance of the basin by tectonic forces would produce a change of type of sedimentation.

North of Finger Lake the Eastern exposures of iron formation are highly contorted and altered to schists. Here the undeformed part of the series is only about one mile wide and the "Trough" as a whole is reduced in width to about ten miles.

West of the Strain, Bones and Finger Lake valley, the shales are highly schistose and deformed, indicating folding and faulting as a result of a thrust from east to west. It seems probable that this valley is the locus of a thrust plane.

Concerning the northern part of the "Labrador Trough" Auger (1954) states:-

"The central portion and the eastern border are characterized by steep dips, overturned beds, and over-riding faults."

He further states:

"The structure of the "Trough" indicates everywhere that the folding and faulting was caused by a stress front coming from the northeast."

Thus the sedimentary rock along the western border of the "Trough" consists of a relatively undisturbed series lying on a depressed portion of the old gneiss; the central and eastern portions consist of a thick, complex series of rocks resembling those of a typical mountain-built belt.

This matter is pursued further in the section entitled "Origin of the Sedimentary Series."

In some localities, notably along the contact with the gneiss complex, the younger sedimentary group has been down faulted along steeply dipping normal faults. The sediments have been dragged up adjacent to the fault, clearly indicating the direction of last movement. Auger (1954) believes:- "that such faults are later than the main folding of the "Trough" rocks and are caused by a release of pressure at the end of the orogenic period which affected the "Labrador Trough"."

Although unrelated to the mountain-building period, other fault features of interest are post-glacial breaks occurring in the younger sediments adjacent to the gneiss along the strike of fault zones in the gneiss. These fault zones are of considerable extent, and on aerial photographs may be followed for several miles. The sediments overlying the extensions of these are fractured and broken. Good examples of this structure is found west of Strain Lake where steep-sided, narrow valleys (20 to 60 feet deep) occur in the iron formation and quartzite. These valleys are rugged and sharp, with post-glacial features, yet they could not have been formed by the streams running through them at the present time. The only explanation seems to be that during the end stages of glaciation a large volume of water ran along breaks in the rock which were formed by readjustment of the crust following the retreat of the ice mass.

ORIGIN OF THE SEDIMENTARY SERIES

This thesis is principally concerned with the Fenimore iron formation and its mode of origin. The author believes that this matter can only be fully examined by considering it as part of the sedimentary series, and studying the mode of origin of the series as a whole.

The iron formation is underlain by the Alison quartzite, which is the product of complete chemical decay and destruction of all original minerals except quartz and chert. These minerals were deposited in a stable offshore basin. The rounded, frosted grains, the thick consistent beds, lack of cross-bedding, and other stream characteristics show that they were deposited slowly and gradually, with wind acting as the principal agent.

The upper beds of the quartzite often contain either iron oxide, stilpnomelane, or beds of ferruginous shale. This indicates a gradual change of conditions to those which produced iron formation.

The iron formation is believed to have formed in a restricted marine basin, which acted as a trap for iron and silica brought in by rivers that were carrying the material of normal weathering of a landmass.

The ferruginous material of the upper Alison quartzite indicates the gradual development of the restricted basin. It seems likely that iron and silica were transported to the basin by sluggish streams at the time of formation of the Alison quartzite, however, because of the unfavourable physio-chemical conditions, the material was not precipitated. Later when a restricted basin formed, the iron and silica were trapped and conditions developed which caused their precipitation. The presence of about half a percent of rounded quartz grains (see Plate 67) within the iron formation indicate that sedimentation of detrital material did not stop entirely during iron formation times. This leads the author to believe that the Alison quartzite accumulated very slowly in a non-restricted basin, while the iron formation accumulated at a much more rapid rate in the same basin under restricted conditions. In this way the lack of clastic material was essentially a feature of the basin and not of the period of iron formation only.

The mineral facies of the iron formation depend on the Eh and pH of the basin. This is determined by the degree of restriction, supply of fresh water, amount of organic matter, and amount of agitation of bottom water. In the early stages the basin was deep and contained an Eh of about 0.0, so that magnetite was the principal mineral being deposited; towards the close of this era, the basin was much shallower as indicated by oolitic forms and intraformational breccia, but the basin was more restricted and the Eh was lower and ferrous carbonate was precipitated.

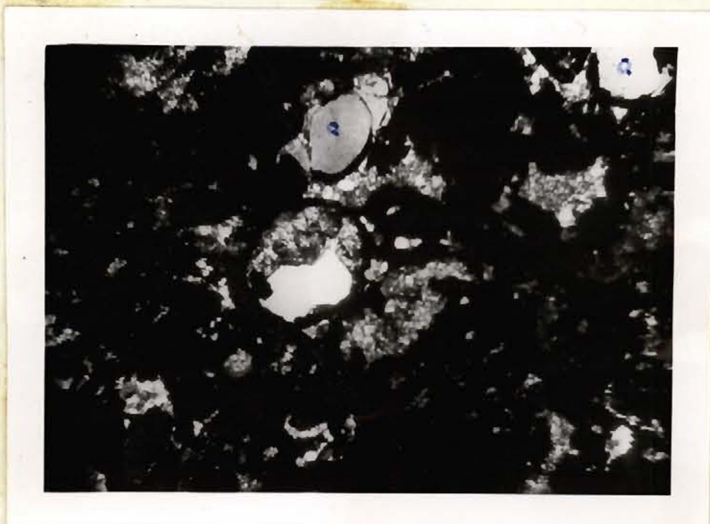


PLATE 67. Microphotograph of thin section of Cherty Metallic iron formation west of Strain Lake. x 60, polarized light. Note rounded quartz grains. (Q).

These conditions in turn give way to a less restricted environment and the development of more nominal iron, calcium, magnesium, carbonates.

The uppermost iron formation member consists of a 50 foot thickness of chert. This chert with the attendant lack of iron, is quite different from the rest of the iron formation. Perhaps this, and much of the rest of the chert of the iron formation, was contributed to the basin by hot springs, associated with later vulcanism. Such an explanation would avoid some of the problems of iron formation, such as lack of mutual precipitation of iron and silica during transportation, and the great quantity of silica present.

The iron formation period drew to a close with only slight uplift and no attendant angular discordance. Chioack conglomerates, arkoses and greywackes formed, indicating the initiation of a tectonic disturbance in the region. This was followed by the deposition of the Abner dolomite which represents a local return to quiescent times.

Subsequent to this, detrital shales and tuffs with interbedded volcanic rock, were deposited. These rocks are typical of an area of tectonic disturbance, such as a geosyncline. The sediments are folded and faulted in such a manner as to indicate regional thrusting from the east.

The author believes that these rocks represent a typical thick shale and volcanic geosynclinal accumulation, and that the iron formation represents a transition between stable shelftype rocks such as orthoquartzite and Lower dolomite, and an accumulation of shales and volcanics in a geosynclinal basin.

The writer, following the classification of Kay (1947) after Stille (1936), suggests that the western part of the map area represents sediments deposited in a basin adjacent to, and underlain by the stable shelf. In Kay's terminology this could be a miogeosyncline, while the folded and faulted volcanics and sills represent sediments formed in the more active main geosyncline (eugeosyncline).

The boundary between the rocks which formed in the eugeosyncline, and those which formed in the miogeosyncline appears to be the Strain, Bones, and Finger Lake valley. The rocks to the east, which include volcanic and thick clastic units, are schistose and dip eastward at 35° or more, while the rocks to the west free of volcanic and relatively flat-lying and non-schistose.

James (1954) in his study of the rocks of the Lake Superior region, similarly relates the iron formation to the development of the Huronian geosyncline. He suggests that an offshore buckle formed a restricted basin in which the iron formation developed. At the time of origin of the offshore buckle there would have been little effect on the craton;

though maybe the clastic load was briefly increased, in the basin however, the barrier to circulation would permit development of abnormal concentrations of material and unusual redox potential in the water. As the development of the geo-syncline progresses, the offshore buckle might gradually develop into island arc structures, and the restricted basin would gradually give way to more rapid detrital and volcanic sedimentation over a broader area, with perhaps small local irregular restricted basins(1). In this way James (1954) Cady, McKelvey and Wells (1950), and the author consider that the relationship between iron formation and volcanic rocks, is structural and not chemical, although both are related to the same tectonic conditions. In the present map area the volcanics and iron formations are a part of a continuous sedimentary series, and the iron formation formed immediately preceeding tectonic disturbance on the stable continental platform. The importent point is that the iron formation occurs where the break occurs in the sedimentary cycle; the break between stable continental shelf condition, and those of a rapidly subsiding geosyncline. A restricted basin formed. This may have been the sole agent responsible for the accumulation of iron and silica, or perhaps hot spring activity at this time played a part also. As suggested earlier, the mingling of iron and silica solutions from different sources could cause mutual precipitation and result in the deposition of a thick

(1)Containing such sediments as black shales or iron-rich sediments similar to those east of Teeter Lake.

accumulation of matter.

Summary

A summary of the sequence of events is: (a) During early sedimentation, the land area (largely granitic) to the west of the marine basin was one of low relief, which gradually shelved off into the sea. Orthoquartzite and dolomite were deposited on this stable shelf. (b) Structural disturbances and probably accompanying vulcanism produced an offshore buckle, more or less parallel to the edge of the low-lying landmass, giving a restricted basin, or more probably a series of restricted basins, in which limited circulation and an abnormal oxidation-reduction potential, permitted an unusual amount of iron, silica, and carbonate to be precipitated. This material is believed to be the product of weathering of a landmass; however, the possibility of the material being derived from hot springs is not excluded. (c) Following this clastic sedimentation, vulcanism and intrusion of dykes and sills became a major feature in the main geosyncline to the east, and some sediments from this source spread westward to cover the sediments in the shelf zone. (d) Profound structural disturbance of the great thickness of clastic and volcanic rocks followed. The layer of sediments lying on the stable shelf of the old landmass were largely protected from this folding.

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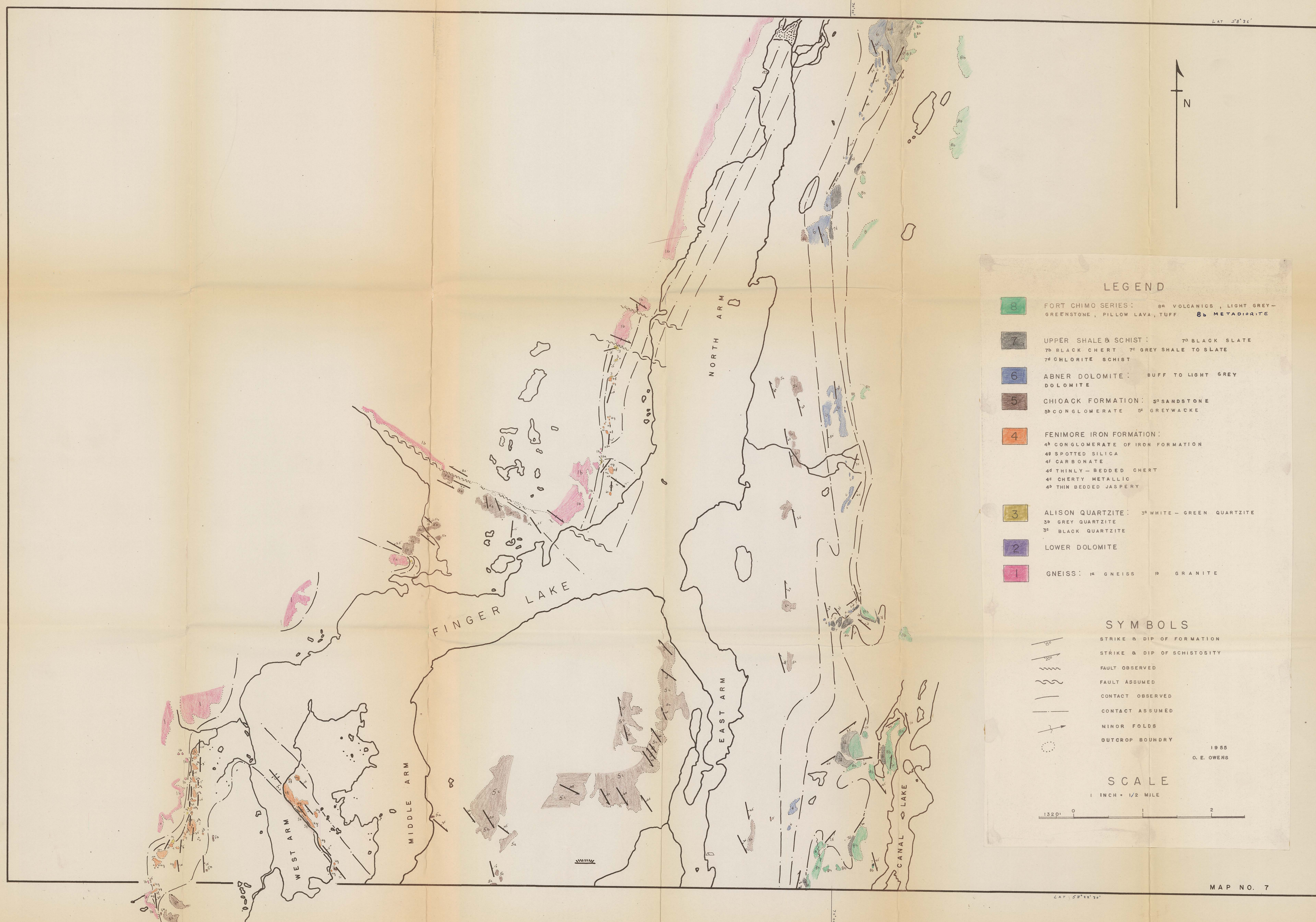

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7 UPPER SHALE & SCHIST: 7a BLACK SLATE 7b BLACK CHERT 7c GREY SHALE TO SLATE 7d CHLORITE SCHIST
6 ABNER DOLOMITE: BUFF TO LIGHT GREY DOLOMITE
5 CHIOACK FORMATION: 5a SANDSTONE 5b CONGLOMERATE 5c GREYWACKE
4 FENIMORE IRON FORMATION:
4h CONGLOMERATE OF IRON FORMATION
4g SPOTTED SILICA
4f CARBONATE
4d THINLY-BEDDED CHERT
4c CHERTY METALLIC
4b THIN BEDDED JASPERY
3 ALISON QUARTZITE: 3a WHITE-GREEN QUARTZITE 3b GREY QUARTZITE 3c BLACK QUARTZITE
2 LOWER DOLOMITE
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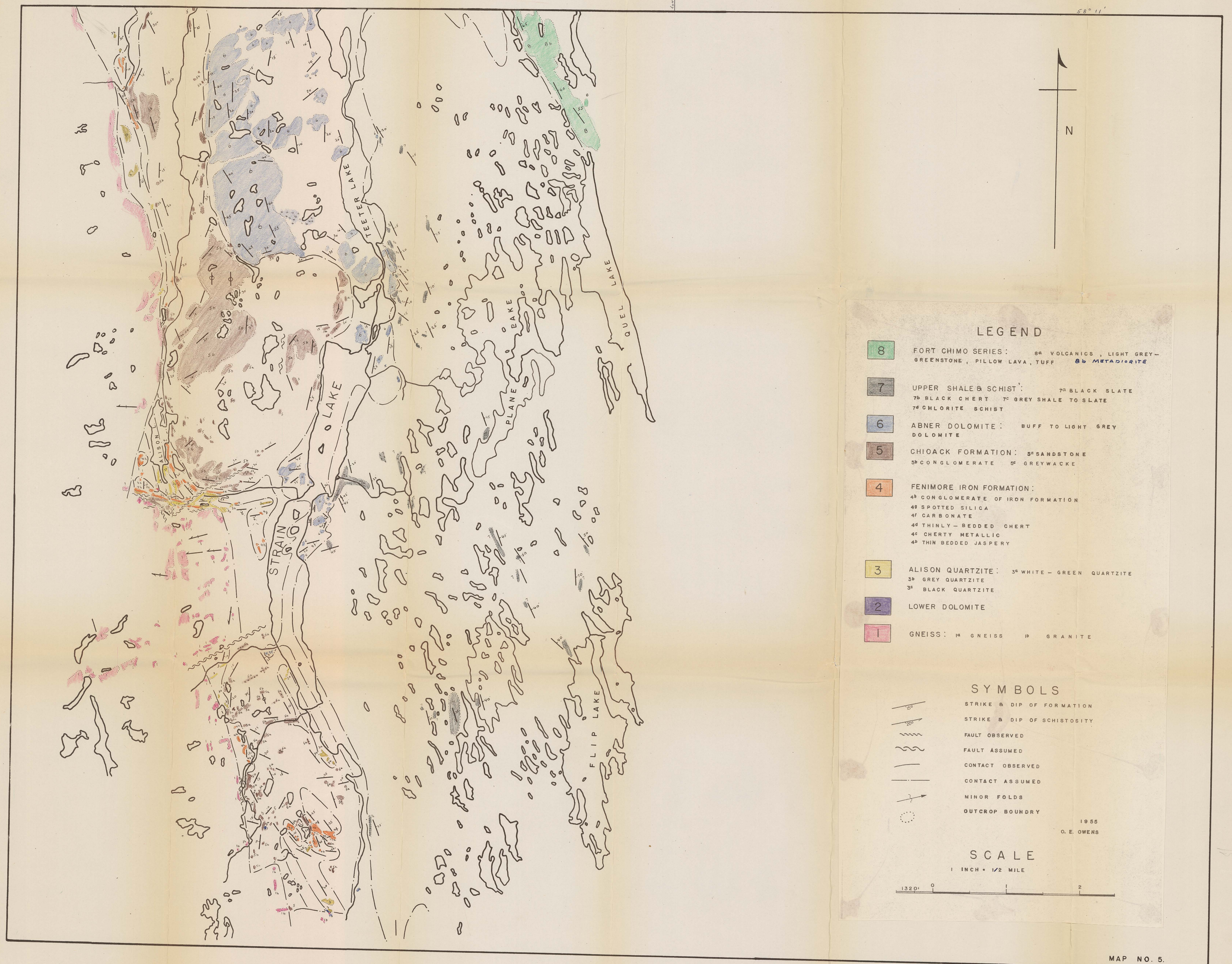
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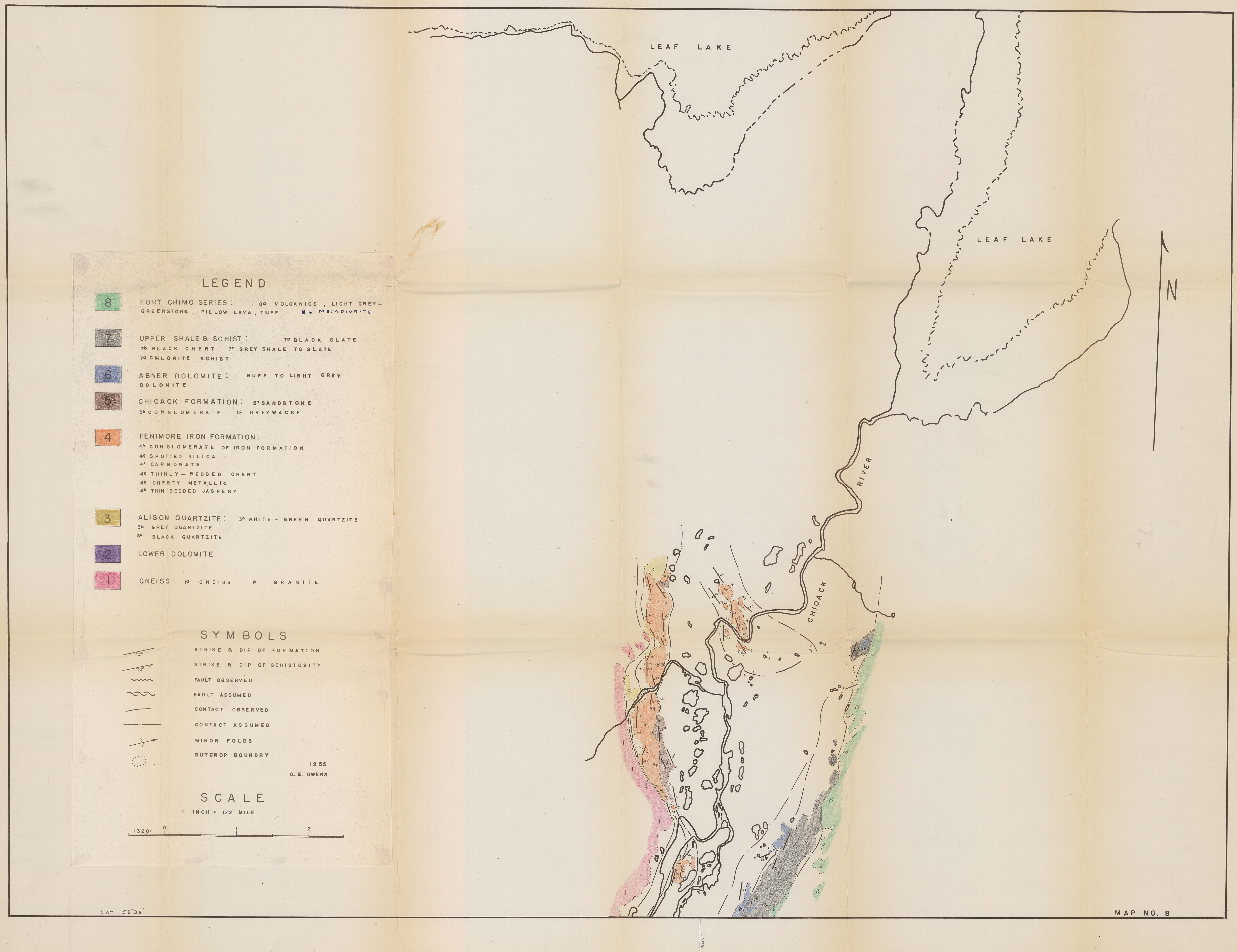
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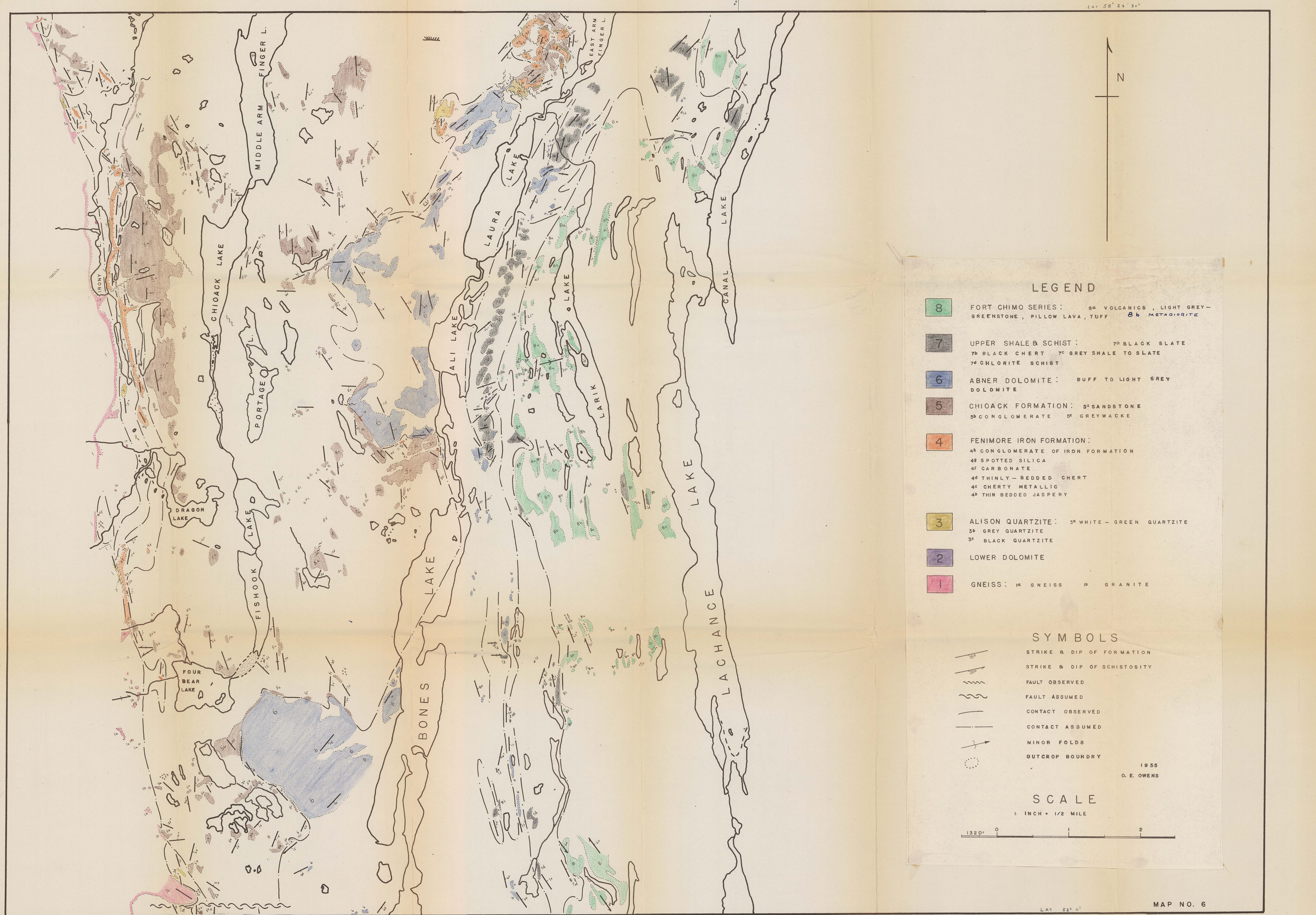
4c CHERTY METALLIC
4b THIN BEDDED JASPERY
3 ALISON QUARTZITE: 3a WHITE-GREEN QUARTZITE 3b GREY QUARTZITE 3c BLACK QUARTZITE
2 LOWER DOLOMITE
1 GNEISS: 1a GNEISS 1b GRANITE
SYMBOLS
15°
STRIKE & DIP OF FORMATION
20°
STRIKE & DIP OF SCHISTOSITY
FAULT OBSERVED
FAULT ASSUMED
CONTACT OBSERVED
CONTACT ASSUMED
MINOR FOLDS
OUTCROP BOUNDRY
1955
O. E. OWENS
SCALE
1 INCH = 1/2 MILE
1320' 0 1 2
LAT 58°36'
LONG 70°00'
MAP NO. 8


LAT 58° 22' 30"
N
MIDDLE ARM FINGER L.
EAST ARM FINGER L.
CHIOACK LAKE
PORTAGE L.
LAURA LAKE
ALI LAKE
LARIK LAKE
CANAL LAKE
IRONY
DRAGON LAKE
FISHOOK LAKE
BONES LAKE
FOUR BEAR LAKE
LACHANCE LAKE
LEGEND
8 FORT CHIMO SERIES: 8a VOLCANICS, LIGHT GREY-GREENSTONE, PILLOW LAVA, TUFF 8b METADIORITE
7 UPPER SHALE & SCHIST: 7a BLACK SLATE 7b BLACK CHERT 7c GREY SHALE TO SLATE 7d CHLORITE SCHIST
6 ABNER DOLOMITE: BUFF TO LIGHT GREY DOLOMITE
5 CHIOACK FORMATION: 5a SANDSTONE 5b CONGLOMERATE 5c GREYWACKE
4 FENIMORE IRON FORMATION:
4h CONGLOMERATE OF IRON FORMATION
4g SPOTTED SILICA
4f CARBONATE
4d THINLY-BEDDED CHERT
4c CHERTY METALLIC
4b THIN BEDDED JASPERY
3 ALISON QUARTZITE: 3a WHITE-GREEN QUARTZITE 3b GREY QUARTZITE 3c BLACK QUARTZITE
2 LOWER DOLOMITE
1 GNEISS: 1a GNEISS 1b GRANITE
SYMBOLS
15°
STRIKE & DIP OF FORMATION
20°
STRIKE & DIP OF SCHISTOSITY
FAULT OBSERVED
FAULT ASSUMED
CONTACT OBSERVED
CONTACT ASSUMED
MINOR FOLDS
OUTCROP BOUNDRY
1955
O. E. OWENS
SCALE
1 INCH = 1/2 MILE
1320' 0 1 2
LAT 58° 11'
MAP NO. 6