Structural Relations in the Grenville Province

by

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INTRODUCTION

The purpose of the present work is to present to the Grenville student an idea of the general structure at a scale of 8 miles to the inch, along with a description of the broad tectonic features and relationships existing between many physiographic and geologic components of the whole belt.

The work was originally planned to include Ontario as well but since J. Tuzo Wilson undertook the compilation of the structure north of the 45°30' parallel (with far better means than the writer had at its disposition such as aerial photographs, drauftsmen and secretaries) the part of Ontario that is compiled lies south of this parallel.

The arrangement of the written material was done along the following main topics.

a) Folding.

b) Flowage.

c) Faulting as to folding.

d) Faulting.

As one can see the author tried to respect a theoretical time scale and the topics are classified according to such. However some of the features did overlap over one another and they are not exactly true to that time scale.

Two maps (in pocket) were drawn at 8 miles to 1 inch. One called Map 1 shows a distribution of the geological boundaries, fold axes,faults, and strikes and dips of bedding and shistosity. The other map, called Map 2, made from the first one shows the trends of structure. Full lines do indicate trends corresponding to the actual interpreted geological structure while the dotted lines are trends of rivers, lakes, and other physiographic features which are thought to be influenced by the geological structures. Blank areas are where no geology has been done and where no lineaments can be traced off the topographical map.

The Grenville Province consists of a belt roughly 200 miles wide and at least 700 miles long paralleling the northern shore of the St-Lawrence River and extending from Georgian Bay northeastward.

It is made up of many metamorphosed lithological units both of sedimentary and of igneous origin with a large amount of rocks of the composite type, showing generally gradational or obscure relationship with the other members. While it is impossible on account of intense metamorphism to which the belt has been submitted to determine the origin of every rock types; it may be said to present a great series of sedimentary rocks of very ancien date (?) with subordinate igneous intrusions resting upon and invaded by an enormous development of granites and granite gneisses (2). The first comprehensive work done in the Grenville Province, after that of Logan in Quebec, was by Adams and Barlow followed by Miller and Knight in Ontario. Miller and Knight first advanced the hypotheses that some later series, namely the Hastings, are separated by a profound unconformity, i.e. by a granite, from an older series called the Grenville (64). From those studies the rock sequences proved different in Quebec and in Ontario. The Hastings series are not recorded in Quebec, as well as any unconformity between any two members of the one and only Grenville series. After all the sedimentary series were deposited, the igneous intrusion ages that accompanied a possible mountain-building period seem to be about identical in both areas.

Osborne and Faessler (50, 29) however maintain that in Quebec a granite period of intrusion antedated the Buckingham basic intrusives. The granite, the Mont Tremblant, was seen by Faessler in his Lake Simon area to intrude a Grenville paragneiss lit-par-lit fashion, and the whole assemblage is cut by a Pine Hill type of granite of the Morin series which are recognized as later than the Buckingham series. Dykes followed the plutonic masses and the intrusion sequence was closed by the Rigaud and the Grenville-Chatham stocks.

In the text, reference will be made concerning the Grenville belt as being a Province, as advocated by Gill, while mention will be made of the adjoining country to the north and west as being the Superior Province. Similarly the country to the south will be called the Appalachian Province.

FOLDING

In general.

It is possible that the Grenville has ungergone all types of folding (at one time or another) described in various textbooks. However only a few of these types were of such amplitude, (measured in miles) as to constitute major structures. Only these major structures were described in the reports and papers consulted which provided the basic facts for this study. None of these folds however, were consistent enough for accurate determination of the age relationship between the different members of the Grenville series.

A. Open Folding.

This type of folding is described by Faessler in his Lake Simon area (29) and by Adams in the Larentians north of Montreal (1). These open folds are inclined.

B. Overturned Folding.

These folds are described by J.A. Bancroft in his Geology along the Transcontinental R.R. (8). Adams (1) mentions overturning east of the Morin anorthosite batholith and isoclinal folding inclined at 45° is inferred to exist along the Hastings roas in the Haliburton-Bancroft area (2). Most of these overturned folds are usually interpreted and drawn as closed folds in geological section.

C. Plunging folds.

Pratically every fold has a plunge and most of them are doubly plunging. This is an assumption rather than a certitude but it is based on the fact that no folds are consistent throughout the whole area and they always ultimately disappear either from a change in rock facies or a change in strike which is usually accompanied by a steep plunge (36).

D. Cross-folding.

In the Ville-Marie and Lake Simon areas (33, 29) cross-folding was spotted from the attitude of drag folds and it is interpreted locally as a change in stresses directions.

Basins.

Two prominent basins are noted. One in Canica-Cawatose area and described by Wahl (57) while the other is located N.E. of Lake Kippawa and was outlined but not described by M.E. Wilson (61).

A. Cawatose Basin.

This elliptical shaped basin, 9 miles long and 7 miles wide is formed of interlayers of paragneisses with minor amounts of orthogneisses. The whole is very midly dipping. Dips of 45° are found but the average stands around 15°. The axis of elongation of the ellipse strikes N. 60° E.

B. Kippawa Basin.

This doubly plunging syncline is 16 miles long and 9 miles across. No dip values are available but strata on the northern rim are inclined to 70° and therefore it is thought that the basin may be steeper dipping than the Cawatose basin. The longitudinal axis across the structure strikes N. 40 E. The rocks which form it are assumed to be paragneisses.

C. Causes.

There are no simple ways to account for the occurrences of basins in the Shield. The only explanations we have concerning such structures apply to igneous rocks, and the rocks we are dealing with are mainly not igneous in origin. However in the case of the Cawatose basin which has been more throughly studied and where thin layers of igneous rocks are present we may assume that these layers acted as a backbone to the gneisses of sedimentary origin which themselves could have been deformed as if igneous. Balk states concerning igneous basins (57):

> "that these masses seem to be a part of larger gneissic intrusives, which have caused plastic movement of their surroundings so that outlying satellites were squeezed into local synclines or structural gaps between the margins of larger masses of folded wall rocks".

Inverted cones were also interpreted as magma chutes due to some kind of sinking or sagging.

The writer suggests in relation to the particular case of the Cawatose basin that such inverted cones could be merely eddies in a plastic mass in movement and could be caused by differential speeds of movement of such a mass if sagging occurred for a reason or another. It would be similar to a cone formed over the outlet pipe of a sink when the wateris drained off. The cone is the result of water escaping vertically under forces exerted in two horizontal directions at 90° with each other. In this particular case the so called basins are nothing more than doubly plunging synclines usually thought as formed under compression exerted in two different directions at 90° angle with each other.

Domes.

The so called domes are actually doubly plunging anticlines and are quite numerous but very little has been said about them and only one of them has been described.

Norman (40) believes that batholiths and stocks along the northern border of the Grenville Province do occupy anticlinal structures. Lowther (40) describes one whose axis trends parallel to the strike of a N.N.E. fault intersecting the Grenville front and whose center is occupied by an igneous body. Strikes and dips taken in the adjoining lavas show that this doubly plunging anticline is overturned to the S.E. This granite is of the Killarnean (?) age type and intrudes both the Keewatin lavas and the Grenville paragneisses. Such domal structures in other localities of the Grenville are inferred to be produced the same way i.e. intruded rocks are upheaved by an igneous intrusion, to an anticlinal structure usually doubly plunging.

There are some other areas which are not yet mapped in detail, but which present some evidence that they contain basin or dome structures; such an area occurs 25 miles east of the Kippawa basin and it is outlined by the following lakes and rivers: Lac Dumoine, Baie aux Chicots, Lac Tremblay and Baie de l'Orignal.

FLOWAGE

In general.

Flowage can be produced via three processes namely: shearing, rotation and recrystallisation, and plenty of evidence is available to assume that such processes went on at a given time. In fact every structure in the Grenville Province that is not linear in character is more or less due to flowage, and very few structures other than dislocations, are linear.

Lenticular structure.

First described by Osborne in the Labelle-L'Annonciation map area (49) this peculiar structure is also typical around the eastern margin of the Morin batholith.

In the eastern part of the Labelle-L'Annonciation area, all the rocks are present in elongated bands tapering off at both ends. Osborne presumes that the lenticular shape is also present in cross sections and states that inclusions as well as individual crystals are thought to assume such a shape through shearing. The cause of such a peculiar structure according to Osborne is due to the

> " action of permanent and constant stresses that acted since the first folding period of the Grenville till the coming of the Morin intrusions."

According to the writer, one must admit, in order to understand such a structure, that a rotational stress was exerted on already folded rocks. Straight non-rotational stresses were responsible for the initial folding. At that moment and contemporaneously with igneous activity they began to flow and to yield under stresses set off by a couple. The igneous intrusions supplied the vertical component which combined with the everpresent tangential stresses to form a couple whose resultant was inclined with respect to the horizontal and whose direction pointed upward and towards the N.W. The dips in that area are all to the S.E. This couple acted in conjonction with a minor stress whose direction was at 90° with it. This minor stress was the cause of the elongated bands to taper off. As everything was in aplastic stage, the whole rock assemblage was rolled (?) and sheared (laminated) to a lens shape structure and even the individual crystals were affected that way.

Folded folds.

To be convinced of what follows, one must examine Map 2 (in pocket) which is a compilation of trend lines wherever the actual geological or/and topographical evidence warrants it. We see that the overall trend of the Grenville Province is more or less to the N.E., varying from due E. to due W. However three major exceptions occur: the Coulonge-Black area, north west of Three-Rivers and east of Baskatong Reservoir, are to the N.W. Minor variations are numerous. From the above statement that wherever regional dips are present they plunge to the S.E., and that the overall trend is to the N.E. it is reasonable to think that these folds may at one time have been caused by mountain building movements. What are exposed today through successive uplifts and peneplanations are the roots of such a mountain belt, and possibly the zone of plastic flow. Evidence of flowage are numerous.

Adams (1) mentions many cases where bands of amphibolite due to stress were elongated till the plastic state could bot be maintained any more and they broke in many individual parts. The resulting cracks were filled in by an acid gneiss which was still flowing at that particular pressure and temperature. Glangeaud (31) affirms that the Grenville type of rocks are formed in a zone where diffusion processes operated at a maximum efficiency, and for maximum efficiency, he thinks that the flow state is necessary along with circulating pegmatitc juices. From experimental date, he deducts that where the pressure is $4 \cdot 10^3$ Kg/cm^2, the speed of diffusion is sufficiently high enough to form migmatites. This pressure corresponds to a depth of 15 km. or 10 miles. Adams (14) himself from experimental data concluded that the depth of flow could be 11 miles down. Furthermore measurements of the thickness of the sediments in the Haliburton Bancroft area (2) showed that 94,000 feet or 17.88 miles of sediments may have accumulated at one time. Of course repetition of the series by isoclinal folding is expected and, that may possibly cut the total thickness to 9 or 10 miles or even less (2 miles according to Dunbar (23). In some areas that much sediments were removed by erosion. Mountain Building movements would reduce such a depth as they contribute added stresses to the already existing stresses due to the weight of the overlying rocks.

Nevertheless, ample proofs exist that the area underlain today by the Grenville rocks may have been at one time mountain built, and that by subsequent uplifts and erosion periods a once plastic flow zone is now exposed. In such a zone movements occurred. The first series are probably the ones which were responsible for the original folding. Due to the overlying weight, part of the mass could bot be moved because it was not strong enough. These areas today are flat lying. Elsewhere folds were formed but they were soon modified or destroyed because of the ever increasing igneous activities under the form of batholiths or stocks which now are exposed at the surface in numerous places. This kind of contorted folds could be best called "folded folds", according to an expression first heard from Gill. Joliffe (36) reports that in certain areas of the Shield what had been open anticlines and synclines are now a confused mass of vertically or steeply plunging folds and that even anticlines with an overturned plunge, have been described in the Adirondacks (pseudo syncline - upside down anticline). Some of these highly folded strata are said not to be of the nature of drag folds formed by rotational stresses but appear to have been formed by essentially simple compression acting end-on to a series of beds already tilted to a vertical or overturned attitude.

Gill advances the hypothesis that maybe in such a plastic zone, isostatic compensation could be possible. If this is possible, flowage of the folds could be produced by movements engendered by the transfer of material from one isostatic block to another. These so-called folded folds are most probably a different expression of cross-folds.

Areas of Low Dips and Gentle Folding.

In an extensive area of the Grenville Province, paragneisses, crystalline limestones and quartzites do occur with little or no inclination of their shistosity or bedding planes.

Adams (1) mentions cases along the Mattawin River (outlet to the Toro Reservoir) where gneisses are near horizontal, and he sums up for the whole region N. and N.W. of Three Rivers by saying that over 750 sq. miles dips do seldom exceed 30°. His explanation was original though of no practical value today when he said, that such a feature could be interpreted as:

> "the gneisses were a thin layer floating on a fluid and subjacent molten mass."

He also states that obviously these gneissic rocks were subjected to a very strong vertical compression. At first sight it seems strange to notice that although the rest of the Province was submitted to strong stresses evidenced by contorted and intricate folding, such a wide area shows only mild dips or horizontal beds. The metamorphism of the whole rock assemblage is just as high-grade as anywhere else and the composite rocks also show the same cataclastic features along with foliation, banding and shistosity. The first explanation is one of straight load metamorphism accompanied by flattening of the recrystallizing mass.

It has been suggested by Daly (56) that the products of load metamorphism were conditioned mainly by depth, and that at places where schists reposed at high angle, it was due to movements after metamorphism. If this is the case in the area studied,we must assume that the estimate by Dunbar of 10,000 feet of sediments deposited in Grenville times is too low; since those sediments suffered plastic flow under their own load without the help of dynamometamorphism. Thus we have to infer that the thickness of the sediments was equalled to the depth to the zone of plastic flow, or some 11 miles (55,000 feet). Furthermore to accept such a theory one would have to explain the secondary structural features (foliation, schistosity, lineation) by the effect of flattening in a plane normal to the vertical. In other words the plastic mass had to flow outwards and thus the lineation would have to vary at random over a large area.

There are objections to the development of schistosity and lineation due to load metamorphism but the idea as a whole must not be rejected. The slow incoming of a granite mass or the proximity of a vast magma chamber rising upwards would cause metamorphism, schistosity and lineation, and would also diminish the theoretical depth of sediments necessary for those sediments to be metamorphosed and flow under their own weight. We have in the area north and west of Three Rivers two batholiths, one of anorthosite and the other of granite which could have sprung up from such an underlying magma chamber. Unfortunately such hypothesis fails, after some petrofabric work done by Osborne and Lowther (56) who showed that:

> " the schistosity is directly connected with the regional stresses that have produced the folding... and that the rocks bear the unmistakable imprint of strong deformation... most important of all, the tectonic axis b visibly expressed in the fabric by lineation parallel to b and by ac joints normal to b maintains a constant trend throughout the area. The lineation and schistosity are products of lateral flow in a single well defined direction."

To conclude, the writer is inclined to accept the influence of a magma chamber along with the influence of very high tensional stresses upon a Grenville belt whose rigidity was at one time different in many areas. In other words most probably that the cooling under high stresses of the whole Grenville Province was not done at the same rate everywhere. In the area N. and N.W. of Three Rivers, the tensional stresses that elsewhere caused tight folding because of more rigid formations, could do nothing more than to compress a plastic mass and develop into it, the normal effects of high pressures and strong metamorphism without tight folding.

Igneous Rocks Relationships with Surrounding Rocks.

It seems probable from the attitude of the linear and planar structures, that the whole rock assemblage exposed today by denudation was at one time in between a state of near rigidity and one of true plasticity, and that the schistose rocks show by their dips that they were either broken through by igneous masses or that they caved into the incoming magma. Dips at the contact of the intruded mass with the intruding body are now discussed.

In the Glamorgan stock area (2), rocks surrounding the stock show dips away from it suggesting that the rocks were rigid enough and yet plastic enough so that the slowly incoming mass could deform them without failure. Of course, the rocks could have been very rigid and yet fail through flowage if the time interval was sufficiently long. Conformable gradational contacts are usually the rule. Intrusions of pegmatite dykelets appears when the limit of plastic flow is attained and occasionnally a breccia is formed made of broken sheared basic bands cemented with lighter coloured granitic material. In some areas the granite intrusions are so numerous that the whole country is a giant breccia whose angular pieces are the patches of amphibolite and limestone bands.

In other areas, the igneous invasion was so slow and the temperature so high that formations were assimilated. It is assumed that when the rocks surrounding a stock or a batholith dip towards the igneous mass, those rocks were in process of caving-in.

Perhaps some relative ages between igneous rock intrusions could be worked out on a regional basis according to their degree of elongation and their degree of sharpness of contacts with the surrounding rocks. The more elongated a batholith is, and the less sharp the contact is with the surrounding rocks; the more chance there is that such an igneous mass is older than a more circular batholith with sharper contacts. Of course this rule would hold best on a regional rather than on a provincial basis. Maybe that, on such a criterion, relative ages between the Mont Tremblant gneiss and the Morin series, could be worked out and Faessler (29) in his age relationship studies of the problem utilizes the following observations: That the Mont Tremblant gneiss has a zone of contact with the Grenville sediments many miles wide while the Pine Hill granite has such a zone only a few hundred feet wide. The texture of both is also different. The Mont Tremblant has a texture typically gneissic while the Pine Hill shows an augen texture results of a thermodynamometamorphism preserved by an inferred quicker cooling after intrusion than had the

Mont Tremblant gneiss. If such texture may have existed in the Mont Tremblant gneiss at one time, all such traces of dynamometamorphism have disappeared due to a longer period of cooling which is a prerequisite for effective recrystallisation processes (31)

FAULTING AS TO FOLDING

In general

Most of the detectable faults in the Grenville may have been produced at one time by compression i.e. have been contemporaneous with folding but such a long time has elapsed since, that most of these faults today seem to have been reopened under tension.

However some dislocations were described by Adams and Barlow (2) and by Adams (1) which still bear the characteristics of faulting contemporaneous with folding. In the Haliburton Bancroft area two faults were spotted by an abrubt change in the gneisses direction. Adams and Barlow describe one of those:

> " This fault is not one which was produced by movement which took place after the intrusion of the batholith was completed and the rocks of the area had become cold and solid. It was developed about the time of the completion of the batholith intrusion, when the granite was so far cooled as to have completed the development of the foliation thus producing gneissic granite which in the latter stages of its development must have been a mass of ever increasing viscosity and at the time of faulting must have become nearly solid".

Pegmatite dykes are numerous along the fault thus indicating filled-in gashes which is another proof that the fault developed before the movements were stopped. The two faults found in that area are over most of their observed length parallel to the schistosity which is one of the reasons why, in an area of intense metamorphism, such faults are so hard to notice.

In the Laurentian area north of Montreal Adams (1) mentions two cases: 1o) One which involves the shearing of the basic elements of a gneissic series, 2o) The other which is an example of faulting similar to the one mentioned in the Haliburton Bancroft area.

1o) The shearing of the basic bands of a gneissic granite could be observed in many instances. When the shearing limit was attained, the bands broke and the clear granitic liquids still viscous or fluid at that particular temperature and pressure is seen to fill in the cracks. This was usually observed in very contorted areas or around an intruding mass.
2o) This faulting was detected by the abrupt change in direction of two masses of gneisses due to a "high state of compression" under which the gneisses were subjected

Osborne (49) mentions some shearing zones in his Labelle L'Annonciation map area but he is not sure if they are shear joints or fault zones.

Faessler (29) mentions many sharp scarps in his Lac Simon area but no real evidence for actual faulting.

N.E. Faults Marking the Grenville Front.

The Grenville front was studied by many distinguished geologists in five distinct areas:

A. Fabre township and Ville Marie area.

Henderson was the first man to undertake a detailed study of the area which is under some respects similar to the Lake Mistassini country. The presence of the Grenville type of rocks in contact with some Huronian sediments and some earlier sediments and lavas thought to be Keewatin and Temiskaming in age, is especially interesting.

The north side of the contact in between the Superior Province and the Grenville Province, at this place, is the loci of two sets of drag folds found in the earlier sediments and lavas. One set plunges at not more than 30^{o} to the east, and the top of the flows is towards the south inclined between 60^{o} and the vertical. Superposed over this set of drag folds is another set whose plunge is from steep to vertical towards the S.E. Determination of tops made by gradation in grain size favors the first set of drag folds as belonging to the original folding while the second set belongs to a subsequent movement

" probably caused by the thrusting action of the invading granite" (33)

B. <u>Vauquelin, Haig, Pershing area</u>.

The contact between the Grenville paragneisses and the Superior Province is said by Norman (46) to be a structural discontinuity. N.E. trends in the Grenville gneisses do contrast sharply with the E.W. trends of the flows and the sediments assumed to be Keewatin and Temiscaming. The fault itself is not seen, covered as it is by drift. It is rather a fault zone as advocated by Lowther (40) and this fault zone seems very wide. Linear valleys parallel to the contact show intense shearing and granulation of the gneisses and he adds that the escarpments bordering the valleys are nearly vertical thus suggesting high angle faults. Furthermore dips on opposite sides of the contact are rather steep, between 60° and 80°.

C. <u>Head of the Megiscane River area</u>.

Here the contact between the Grenville Province and the Superior Province is obscured by a batholith which is intrusive into both Provinces.

D. <u>Lake Mistassini area</u>.

This is the most important area mapped in the Grenville Province as much more precise clues were obtained on the relationship between the Huronian series, the Grenville series and a series called the Chibougamau. The Huronian series ~~could~~ be possibly be equivalent to the Grenville while the Chibougamau is assumed to be older than the two others, although the Chibougamau and the Huronian were never seen in contact. The Huronian series deposited in a basin and dipping gently towards the S.E. are highly folded and sheared in a narrow zone where the Grenville series and those rocks meet. One outcrop in particular was mapped by Norman (47)

> " where gneisses are brought up against the Mistassini strata... At one high hill capped by gneisses and schists near the north end of Lake Albanel dolomite strata dip S.E. at the base of the hill as if to underlie the gneisses and schists above. The contact is concealed there in a 900 foot interval of no exposures. Both the dip of the Mistassini strata and of the foliation and banding of the gneisses and schists near the faults are to the S.E. suggesting that the faults also probably dip in this direction".

The dip of the Mistassini strata nearest to the assumed fault ranges from 50° to 80° to the S.E. and that of the Grenville gneisses and schists from 25° to 65°. The presence of subsidiary faults and breccias on the north side of the contact and the presence of mylonitized gneisses on the south side further substantiates the idea of a major fault.

E. <u>Assup River area</u>.

A.M. Bell (11) reports that in the Assup River area the E.W. normal strike of the Keewatin belt changes abrubtly to a N.E. trend within half a mile of the gneisses to the south:

> "Near the contact both (trends) strike parallel to it. This direction of folding appears to have been superimposed on the earlier east-west folding which in places has been dragged sharply into the N.E. direction. The granite injections to which the gneiss owes its oritin followed the development of this northeasterly foliation in the schist... The close folding which resulted from these movements was probably accompanied by a certain amount of overthrust faulting in which the greenstones were shoved to the south over the sedimentary rocks in the synclinal areas. These early deformations occurred under conditions of deep burial in which shear zones rather than open breaks were produced and these shear zones parallel closely the direction of folding".

Most of the mineralization is of that deep seated type while none is found along a presumed later period of faulting parallel (N.E.) and transverse (N.N.E.) to the one now discussed. The later type of faulting is of a clean cut nature and diabase dykes do parallel it.

FAULTING

In General.

Faults are numerous in the Grenville Province but it is thought that very few of them can be detected adequately. Very recent faults such as those which have occurred after the Carboniferous are easily spotted because of the presence of down-faulted Paleozoic rocks. But most of these rocks, ideal as they are as horizon markers, have been eroded, almost entirely from the Grenville Province, and consequently other methods of attack have to be employed in detecting faults. Slickensides, due to shearing, lineation, granulation, gouge, mullion structures, breccias etc. are often obliterated by recrystallisation and erosion; changes in facies or in rock formation on opposite sides of presumed faults is very rarely seen as an intense metamorphism tends to erase any sharp contact between the different types of rocks. One tool which has never been used to that effect is structural petrology. Nevertheless some criteria can be used and the main ones are the physiographic and the topographic considerations, associated with known examples of faulting. This correlation of a typical feature such as actual faulting applied to a whole area is used extensively in the Grenville.

It is a very risky business to extend such meagre information to a great area but until better tools can be devised in the interpretation of faults, it will have to be done.

The interpretation of aerial photographs on that basis makes possible the use of a vast reservoir of information, but this accumulation of data has to be checked continuously against field work in order to be of true scientific use. Description of faults and zones of faulting, classified as much as possible with respect to relative ages, follows.

N.N.E. Set of Faults Cutting the Grenville Front.

This N.N.E. set of faults extends over a wide area from Lake Temiskaming as far east as an area mapped by Norman in the Mistassini Lake area. They usually intersect the general northern border of the Grenville Province at an acute angle but in some areas such as in Lake Victoria and in Lake Mistassini, they are the actual border. Sometimes as in between Lake Temiskaming and Lake Victoria they do not seem to cut the northern border of the Grenville at all, and they appear to be limited to the Superior Province only. They were studied in five different places, and from those studies, the author took the liberty to pick out linear valleys parallel to them and interpret them as faults of the same age.

A. Lac Caron Fault.

MacLaren (41) reports a fault along a linear valley occupied by Lac Caron and other water courses. Erosion had removed much evidence of a fault but some slickensides were still to be seen. The dip along the slickensides plane is more or less vertical, and the east side appears to have moved up. Between this linear valley and the next one to the east, diabase dykes are found which are parallel to the valleys. It is thought that diabase dykes may have occupied faults and as some dykes are easily eroded away, especially if they are high in iron, linear depressions resulted.

B. Victoria Lake Fault.

This fault is deduced by Lowther (40) on the topographic evidence and the deductions of M.E. Wilson (61) which concluded:

> " that the linear valleys in the Temiscaming country and the ways they intersect are remarkably similar to those, characteristic of fault planes, in regions which have been subjected to faulting of a block type".

Dawson (54) found a mylonitized zone on the shores of the lake. Every factor leads towards Wilson's conclusion although his principal objection is that very few fault planes are actually exposed. This could be explained by the presence of water or drift. The absence of rock heterogeneity on opposite sides of the fault may be explained by the following reasons: that usually in such a shattered area all the individual breaks have small displacements, and that in a region where strong dips prevail, not much change in rock composition may be noticed.

C. Head Waters of the Megiscane River area.

Carl Faessler (28) described two faults trending N.N.E. and N. which were spotted from topography and from the study of the rock features on opposite sides. No dips are given.

D. Lake Mistassini area.

This area was mapped by Norman(48) and consists of a series of Huronian rocks flat lying or gently dipping to the S.E. in most of the basin which is underlain unconformably by an older granite. In a zone forming the S.E. edge of the basin the Huronian strata are much crumpled, folded and faulted. In the S.E. part of Lake Mistassini a fault trending 10° E. of N. has been mapped which intersects the general northern border of the Grenville at an angle of 45°. No data is available except that the bedding planes of the Mistassini series dip between 80° and 60° to the S.E. near the faulted zone and the schistosity planes of the gneisses do dip between 35° and 50°. The fault according to Norman (48) is an upthrust and could be high angle.

E. Assup River area.

A.M. Bell (11) mentions the possibility that a N.E. and N.N.E. set of faults may be younger than the main Grenville front when part of the overlying weght was removed. Consequently a clean cut type of fracturing resulted and diabase dykes occupied some of the faults and were intruded parallel to the zone of dislocation.

F. Conclusions.

It seems reasonably certain that two periods of faulting occurred along the Grenville front. An earlier period which was of the type " Faulting contemporaneous with folding" and which is marked by an obscure boundary characterized by shear zones and intrusions by a common granite to the two Provinces. Even if the actual fault plane has never been seen such a fault is postulated because of this strange fact that south of it the Huronian formations and the Archeozoic series do disappear. As to the age of such a fault, the question is open. The best evidence so far favors a post-Cobalt and a pre-Keeweenawan age, but the upper limit is nebulous due to the fact that basic dykes are dated as being Keeweenawan without any serious foundation for such an affirmation. Cooke (47) considers that the Penokean revolution does not find its equivalent in the Grenville one, if any, and he dates the Grenville as having been mountain built in a post late Pre-Cambrian time. Norman (47) goes so far as to advance the theory, that because of a similarity in trends the Grenville revolution could have been an early stage of the Appalachian revolution, which is not impossible as the roots of the Appalachians should resemble closely the now exposed Grenville roots or some parts of the Alps. However Tuzo Wilson (65) on the basis of Lead-Uranium age determination assigns a definite pre-Appalachian and post-Superior age to the mountain belt, and considers both the Grenville and the Appalachians as having been formed by successive accretion to a nuclei namely the Superior Province. Then, according to the compilation of the writer and from the tectonic map of Canada, a second later period of faulting accurred. These late faults were emplaced some of them parallel to the Grenville front and some others at angle of 45° or less with it. These last ones are relative to the Grenville front, transverse, left-handed and of an "en echelon" type. Such a description from a plan view suggests that were produced at first, when tangential compression stresses were still active, but vertical slickensides on Lac Caron fault surface, for instance, may prove them to have been tensional afterwards due to the release of the compression stresses. M.E. Wilson gives a hint in saying:

" the ways they intersect are remarkably similar to faulting of a block type".

These tension movements may have occured repeatedly and even recently (i.e. in Pliocene time) MacClaren (41) suggested that maybe the absence of the Barlow-Ojibway varved clays approximately south of the Grenville northern border may have been due to faulting prior to the Pleistocene glaciation. Furthermore the height of land between the James Bay and the St-Lawrence basins follows approximately for a while the boundary between the two provinces thus suggesting that maybe it was established through recent down-faulting on the Superior province side of the contact. Glacial striaes also parallel the contact for a while, also suggesting that some kind of control prevented the flaciers from continuing their way towards the south. Any of these arguments are weak of course as not enough data has been accumulated on the subject.

Dyking.

Dykes generally assumed to be Keewenawan in age are encountered in great numbers in some localities of the Shield. In fact L'Esperance (39) who made a study of these diabase dykes throughout the Canadian Shield assigns four different ages to those intrusions: 1o) pre-Cobalt. 2o) post-Cobalt, pre-Killarney #1.

3o) post-Cobalt, pre Killarney #2. 4o) post-Killarney. No criteria exist that would be useful in determining the age of a particular dyke, in the Grenville sub-Province and they are all assumed to be Keewenawan in age. They most probably are post-Cobalt as they cut across fold axes of paragneiss and through all subsequent igneous boodies that are thought to have been thrusted and intruded at about that time. They are most probably pre-Brownsburg granite as some of those dykes are cut by it. We must assume concerning that statement, that all dykes in the Grenville, are of the same age; if not, they are simply pre-Paleozoic, (Postdam). In some places they occupy fault planes (L'Esperance (39) and joint planes (Cote (16). This would suggest that they were emplaced in shear zones or shear joints immediately after compression was released through failure. In some cases failure could have occurred through tension caused by cooling and denudation along potential shear zones developed during compression. Billings (14) calls release fractures, that type of failure. That would be one of the reasons why parallel trends do occur. Zones of post-Paleozoic faulting and jointing, parallel to a pre-Paleozoic dyke-set, is encountered in S.W. Quebec. One such zone is parallel to the Grenville escarpment, while the other is parallel to the Temiscaming and Ottawa-Bonnechere lineaments (L'Esperance (39). Such a fact could be an argument in favor of renewed activity of the post-Paleozoic period of dislocation along favored weakness belts established a long time earlier. All this would fit in the scheme developed by Hobbs (34) where he thinks that failure in the earth crust seems to occur along three main directions, namely E.W., N.E.-S.W. and N.W.-S.E. In the area considered, (S.W. Quebec), three main directions are represented but two of these mean tension features. They are along N.W.-S.E. and E.W. trending belts. Diabase dykes presumed to be of the same age as the ones under discussion occur in great number in the Temiscaming sub-Province (Superior Province) and seem to be related sith a period of faulting usually thought to be later than the revolution marking the end of the Temiscaming. These dykes are parallel to two sets of faults of which one seem to be at least contemporaneous with a possible post-Grenville revolution and the other possibly later. One of the sets strikes N.E. and marks the Grenville front, while the other one is N.N.E. and seems to offset the Grenville front.

Jointing.

A. Labelle - L'Annonciation area (Osborne (49).

In any typical area of the pre-Cambrian only very major faults are expressed by a change in lithology on both walls. Any marker like a key bed is very seldom encountered and usually serves the purpose of identifying only minor structures. Furthermore erosion has usually exposed any break in the crust and any trace of gouge or slickensides has disappeared or is easily mistaken for a finely foliated gneiss. So any valley resulting from a fault or from jointing will look exactly the same in most cases. The two kinds of joints occur in this area both shear and tension. Shear joints have a general direction parallel to the direction of the rock formations and for that reason are very difficult to distinguish from irregular features of the rock. They trend mainly N.S. Tension joints also occur in an E.W. direction. They are said by Osborne to be not simultaneous with the first set. They seem to indicate the persistance of an E.W. directed pressure which caused the lenghtening of some of the series in a N.S. to N.N.E.-S.S.W. direction.

B. Chertsey Map area.

In an area north of St-Theodore de Chertsey two main sets of joints are noticeable in the anorthosite body. N.W.-S.E. trending joints in one of which flows the Ouareau river and series of E.W. to N.E.-S.W. trending joints, some of them are occupied by tributaries of the Ouareau River. Both sets seem to be tension joints. At one place, in the N.W. trending Ouareau River, a diabase dyke occupied its bed.

C. Ottawa - Bonnechere area.

In this area the dominant trend of the joints is similar to that of the faults. That may imply that, 1o) the faults have developped along the trend of earlier faults, or that, 2o) the joints reflect the same stresses that produced the faults. It is seen that S.E.-N.W. trending joints are more prevalent in the faulted areas than in any other area where jointing is believed to be inconsequential. Along the cross-faults trending N.E. it is noticed that the S.E.-N.W. joints are not so numerous as elswhere. It is thought (Kay (38)

> " that the fault trends are a result rather than a cause of joints trends, but that joints have greater frequency in proximity of faults".

This is suggested in a tendency of the displacements to be offset linearly in a rhombic pattern as though the forces that produced the faulting were directed at an angle to preceding prevalent joint systems and adjustments took place principally along one joint system and partially on another. If this is correct, the stresses were tensional in a more N.S. direction than the direction normal to that of the principal faults. This conclusion is very important. It is thought that the joints in the pre-Cambrian rocks are the result of pre-Paleozoic movements.

D. Shawinigan area.

Osborne and Lowther (56) mentions that the prevalent joints in the Grenville metasediments are found to be N.E. and N.W., parallel and normal to the tectonic axis of the sediments.

Normal faulting.

Faulting interpreted as being normal was observed in the following areas:

A. Lake St-John and Saguenay River areas.

B. Southern border of the Grenville Province.

C. Ottawa Bonnechere Graben.

D. Lake Temiscaming area,

A. Lake St-John.

Paleozoic rocks as determined by their fossil contents are found in Lake St-John area. They were protected from erosion by a roughly circular scarp of Grenville rocks, thus indicating that they were either deposited in a hollow or later down-faulted into such a position. Examination of the contact between the Paleozoic and the Grenville rocks along a scarp trending N.W.-S.E. on the S.W. side of the basin shows at one place that the Trenton limestone is tilted to a high anlge, away from the scarp, and broken or crushed into a confused mass. Wherever such kind of dislocation can be seen, it appears to be of the gravity or the normal type of the dip slip variety. The displacement effected by single faults is possibly not great. According to Dresser, (21) one shows a maximum of 30 feet, another, 100 feet. The maximum displacement between the highest point underlain by the Trenton limestone and the lowest underlain by Richmond strata is approximately 280 feet. The bottom of the basin is thus inferred extensively faulted as the total maximum displacement measured on known faults does not exceed 100 feet. Cross-faulting of the same type has also been observed, but the resulting displacements are less than 100 feet. The fault already described by Dresser on the S.W. side of the Lake St-John basin is known to extend through Kenogami Lake to Ha Ha Bay and from there, down the Saguenay to the St-Lawrence. The inference of a fault along the Sâguenay river is based on the fact that the river was able to cut a deep channel keeping pace with the Pliocene uplift and maybe also with the Carboniferous one even though the Shield was tilted against the slope of the river. Fault gouge was easily dug out and carried away energetically (Cooke (17). The strike of the fault bordering the southern and western side of Lake St-John and extended via the Saguenay to the St-Lawrence river varies from N. 80 W. along the Saguenay to N. 10 W. west of Lake St-John and turns to N., N.W. of the lake. A fault along the Ste-Marguerite river scarp is assumed and has a strike N. 15 W. It is roughly perpendicular to the south border of the Shield.

<u>Age of faulting</u>: Dresser suggested that the faulting occurred at the end of the Carboniferous. Cooke dates that period of faulting as being middle to

late Pliocene because he concluded that the Shield at that time experienced a major uplift shich could have caused normal faulting. However he admits that many of the faults may have existed prior to the uplift and that movement along them may have been renewed at that time.

B. Southern Border of the Shield.

The Grenville Province southern limits due to their varied topographic expressions are divided in many type sections and they follow the North Shore of the St-Lawrence valley and basin as far up as Georgian Bay.

La Malbaie area: Blanchard (13) interprets the contact between the Paleozoic rocks and the Grenville as a graben type of faulting in the Malbaie river basin. The contact is linear and it appears to the writer that Blanchard based his interpretation on pretty meagre evidence. However the two inferred faults strike perpendicularly to the border of the Shield.

From Baie St-Paul down to La Malbaie: At Baie St-Paul, Mawdsley (44) records some normal faulted contacts of the dip slip type along some of the contact between the Paleozoic and the Grenville. The displacement may not have been very great, or else cross-faulting is present, because in many instances the contact has been described as being unconformable over an erosion surface. One of the faults at the contact is seen to cut into the Grenville gneisses. The basin is roughly circular and the faults have a general strike both parallel and perpendicular to the border of the Shield. The above mentioned faults are post Black River in age and pre Pleistocene.

<u>From Quebec City down to Baie St-Paul</u>: The Paleozoic rocks are rarely found in contact with the Grenville along the St-Lawrence shore except in the immediate vicinity of Quebec City. Near Quebec City a major post Lorraine fault forming the Montmorency fault occurs and has been described by Low (39 a) as being nearly vertical. This fault is not described as continuing into the Grenville although Derry (22) interprets it that way.

<u>From St-Jerome down to Quebec City</u>: From the town of St-Jerome eastward to Quebec City, no definite relationship between the two regions has been described. The contact is very irregular and overlain by a beavy mantle of drift. Some faults believed to be the continuation of post Paleozoic faults in the St-Lawrence Lowlands are shown extending into the Grenville on the Tectonic Map of Canada and have a N.N.E. trend. Fortunately however Rene Beland (10) covered part of the Rawdon map area and his conclusions as to the existence of a normal fault are the following:

1) The scarp is remarkably straight and must indicate a tectonic plane. An erosional scarp would be more sinuous according to the differential hardness of the different formations cut by it.

2) Some distance inland, valleys seem to indicate the existence of a network of great fractures. The best developed ones are parallel to the scarp.

3) At Kildare on the south side of the fault a mass of Grenville rocks is exposed 200 feet lower than the top of the scarp thus suggesting a down faulted block whose different formations do not coincide with those of the upthrown block.

4) Linear structures dip at 10^{o}-15^{o} to the south at Rawdon while at Kildare they dip north.

5) This fault could be a prolongation fo the Ste-Anne des Plaines - Ste-Julienne fault outlines by Dufresne (23 a). Thus the age would be pre Champlain (because of an undisturbed deposit of sand and gravel overlying it) and post Trenton. The Kildare rocky mass was no doubt covered discordantly with Paleozoic rocks or remnants of them just like at other places such as Kingston Mills and elsewhere on the Frontenac Axis.

Lower Ottawa Valley: (Eardley and Grenville escarpments). Two main hypotheses have been presented to explain the two escarpments:

1) Kindle and Burling (37).

   a) Formation of a post Grenville peneplain.

   b) Deposition of Paleozoic sediments on top.

   c) Major faulting along the whole actual southern border of the Grenville.

   d) One or more periods of successive uplifts and peneplanation which gave rise to a fault line scarp result of differential erosion on both sides of the fault accompanied by minor normal faulting along and across the contact (Eardley and Grenville scarps).

2) M.E. Wilson (63)

   a) Formation of a post Grenville peneplain.

   b) Major faulting along the whole actual southern border (Normal type ?)

   c) Deposition of Paleozoic sediments both in the tectonic valley and over the old land when they overlapped on the north side of the major fault.

   d) Differential erosion was accompanied by minor normal faulting along and across the contact.

The two theories are not opposed, but one may find an argument against the southern border having been faulted in post Paleozoic times. It is the fact that some of the actual post Paleozoic faults along the border have angular relations varying of as much as 42°. Thus making one wonder if they were through going or not, as a through going fault would be expected to be linear.

Of course this does not exclude the possibility that the through going fault has been produced in earlier times than the later divergent minor ones after the Paleozoic sediments were deposited. Minor faulting, parallel to the two escarpments occur in the Paleozoic plain to the south and outliers of Paleozoic rocks inside the Shield if projected outward in their approximate correct position over the Paleozoic plain if we take into account the local faulting. The two last statements suggest that the post Paleozoic faulting in the plain which also affected the Grenville was related to the faults at and across the contact, also that the strata were deposited in a valley, be it tectonic or not, and that they overlapped on its north shore.

Kingston area: All around and over the exposed parts of the Frontenac axis extending between Lake Nipissing and the Adirondacks no evidence of faulting has been recorded except for an arcuate fault on the S.E. side which probably is part of the Ottawa - Bonnechere Graben. The outliers of Paleozoic sediments all give evidence of having been deposited on an uneven old surface. A key bed of Trenton exposed on one of the high points of the Frontenac axis, and the some bed near Toronto, shows a difference in altitude of 1,800 feet. Faulting alone does not look to be the cause of such a descrepancy. Faulting and folding is one answer and Kindle and Burling (37) gives the age of that folding as being post Paleozoic. This is possible, but the Adirondacks and, in general, the Shield has always acted since the end of pre Cambrian times as a stable unit involving broad shallow flexures of great amplitudes, (hundreds of miles) accompanied by only some minor normal faulting. Alone, an uplift of post Paleozoic age affecting an area only 50 miles long, thus seems improbable. The writer suggests that maybe, differential compaction was part of the cause of such a flexure. Dunbar (23) interpreted the structure to the south of the Adirondacks as being an arch due to such differential compaction, when water during the Trenton times covered that part of the Shield. Maybe a similar event accurred to the north of the Adirondacks and similar results happened. Faulting and folding could have also occurred to complement the differential compaction action.

Conclusions: We have distinguished between two ages of faulting, one which was responsible for the through going linear southern border of the Grenville Province and one which was responsible for a series of normal faults of minor importance compared to the other but which were emplaced on the same southern border. It is strongly possible that no major through going fault occurred after the Paleozoic was deposited. If it occurred before, one must infer that such a clean cut fracture must have been made long after a possible Grenville orogeny and after the basic intrusives were in place. Otherwise, the fault plane itself would have been filled by a dyke. A tentative age would then be post Keeweenawan and pre Postdam, as most basic intrusives are assumed to be Keeweenawan. Maybe that such a fault was due to tensional stresses exerted on an especially weak belt, and in that case a graben was outlined. Why a weakness belt at such a place? It is thought that this zone of weakness could be an old continental shelf if we admit that the original Grenville sediments were off-shore equivalents of rocks at first deposited over a land area and that these sediments came from the N.W. Against this idea of a former continental shelf being a zone of weakness are those who believe that the bulk of the Grenville sediments came from the S.E. and those who take into account the fact that the Grenville rocks extend quite away south as the Adirondacks prove it. Today we have evidence that the relief between the high points of the tectonic valley and the lowest points around the southern border was at the time of the deposition of the Paleozoic sediments of the order of 600-1,200 feet. (Kindle and Burling) But we might think that in between the period following the formation of the fault and before the Paleozoic sediments were deposited that many successive peneplanations and uplifts may have occurred that could have reduced the height of the fault scarp, and even could have annihilated it at some time. So that today what we have is most probably a fault line scarp. We can be reasonably sure too that the Paleozoic seas have covered the greater part if not all of the Grenville Province at one time. The presence of an Ordovician outlier in Waswanipi area, found by Blake is a good support to that idea, along with the presence of the down-dropped Paleozoic blocks in Lake St-John and in Lake Temiscaming areas.

C. Ottawa-Bonnechere Graben.

From Ottawa westward over a distance of 120 miles and from Allumettes Islands (Coulonge scarp) over a distance of 60 miles south, occurs a zone of normal faulting commonly called the Ottawa-Bonnechere Graben. Faults are of the usual post Paleozoic type i.e. with the maximum throw in their middle part, thus involving most probably either some flexures or some transverse normal step faulting, whose effect is a maximum in the middle of the dislocation. The orientation of the Graben is N.W. and roughly perpendicular to the limit of the Shield and is expressed topographically by a series of scarps, each scarp having a maximum relief of about 1,000 feet. (kay (38). The principal scarps are: 3 of them north of the Bonnechere river and south facing: the Muskrat, the Dore and the Eganville, and 2 of them south of the river, the north facing Pakenham scarp and the south facing, Shamrock. The Paleozoic outliers along the bases of these respective scarps indicate that they have been downthrown along faults bordering the scarps. Cross-faults are also encountered. They trend N.E. and they carry westward the displacement of the N.W. trending fault. Kay (38) sites some conclusive evidence that the distribution of Paleozoic rocks in that part of Ontario is directly related to faulting and that the beds have been preserved in downthrown blocks:

a) Linear crystalline escarpments rise hundred of feet above the Paleozoic outliers.

b) The trend of the pre Cambrian rocks consistently deviates from that of the scarp which cannot be subsequent along more resistant rocks in the pre Cambrian suite.

c) Approaching the scarp the dip of the formations steepens. The directions of dips are towards the scarps and those two facts preclude the possibility that the sediments are in synclinal basin.

d) The sediments in the outliers retain consistent primary characters irrespective of their proximity to the scarps.

e) There is striking uniformity in the thin members of formations in separated outliers a condition strongly opposed to an interpretation that they were originally laid in separate elongate basins. By the way this similarity in the bed lithology goes as far as S.E. Ontario.

This fact is a pretty good evidence that the Shield may have been at one time extensively covered with Paleozoic sediments.

f) Slickensided silicified surfaces of the gneiss dip steeply toward near-by exposures of Rockland limestone. These slickensides show that nearly no eastward or westward components of the fault occurred, the lines pointing downward.

g) South of the Ottawa-Bonnechere Graben, Kay(38) describes the Lake Ontario homocline which consists of a series of cuestas of Paleozoic rocks, south dipping over a surface of pre Cambrian Grenville rocks. Those rocks are believed to be the northern limb of the Alleghany synclinorium and in that particular area they are merely remnants of what formerly covered all the Shield or most of it. In the southern part near Lake Ontario these east-west striking beds which were not otherwise particularly disturbed, have been affected by sub surface N.E. trending faults and their expressions on the Paleozoic surface is that of a series of monoclinal structures along parallel streams. The sedimentary beds form ideal planes with which to measure the deformation which would otherwise be not noticeable. They are identical with the cross-faults trending N.E. already described in other areas, like any post Paleozoic dislocation they are assumed to be either late Mesosoic or late Cenozoic in age.

Age of Faulting: The age is post Paleozoic maybe late Mesosoic ar late Cenozoic. Kay (38) is opposed to the idea of the faulting to have been renewed along pre Paleozoic faults of small throw. The evidence favors direct relation of the folding of the sediments with the faulting for the dip of the beds steepens nearer the faults.

D. Lake Temiscaming area.

Presence of different lineaments: The Lake Temiscaming area is characterized by three drainage systems that flow along three main and persistent directions across both the old land and some Paleozoic outliers present in the Graben outlined by the lake. The most pronounced is in the N.W.-S.E. direction including the western shore of the lake and the drainage line of Long and Kenogami lakes further north. M.E. Wilson (61) mentions a series of parallel linear N.E. trends valleys east of the Ottawa river and he thinks they may have been caused by faulting. The Montreal river follows that trend very persistently. The second system is in a N.E.-S.E. direction and is best represented by a line going through the north-eastward extension of Lake Temiscaming at its northern end. It passes along the longer axis of Cobalt lake and about 4 miles along the Montreal river where it turns abruptly from a N.W.-S.E. direction to a N.E. -S.W. one, between Latchford and Gillies. As to the N.-S. system it is best represented by parts of the shore of the lake being oriented that way. It is not a very prominent lineament however.

Local evidence for faulting: In regard with the N.W.-S.E. system of fracturing a study of the Paleozoic rocks has revealed the presence of a normal fault which is responsible for the straight western shore of Lake Temiscaming and a fault line scarp extending about 18 miles N.W. from the head of the lake. The displacement, according to Hume (35) is from 800 to 1,000 feet with the downthrow side to the east; much like the western limit of Lake St-John basin. In regard to the N.E.-S.W. fracture system which infludes the N.E. extension of Lake Temiscaming it is known that a fault exists at Cobalt. Furthermore two outliers west of Lake Temiscaming show varying dips and in places axis of downwarping trending in such a direction are suggested. It is possible that this lineament could be an expression of transvers-faulting similar to the one shown in Lake St-John area. The gentle warping could indicate minor faulting of the crust underneath while the overlying strata yielded incompetently. It is questioned whether the old land crystalline rocks could have been affected by such relatively capricious folding of such a recent age as the one inferred by those crust movements. Furthermore both in Lake St-John and in Lake Temiscaming areas it is shown by the major N.W.-S.E. fault contacts, that before the final break of the strata, they were downfolded first and in this particular case of N.E.-S.W. trends, they never went further. If we project this lineament further west towards Cobalt, it seems to be related with a similar one found in the oldland, stripped off its Paleozoic cover, and showing faulting rather than folding. In regard to the N.-S. lineament no definite relationship is available other than that suggested by their relationship to the two other systems.

Age of Faulting: Since the Silurian rocks have been broken by faulting, and glacial and post-glacial materials are undisturbed it is obvious that the age of faulting is post Silurian and pre Glacial. However, according to Hume (35) the age could have been nearer the Pleistocene than the Silurian, maybe Pliocene, because of the fact that the maximum throw being of 1,000 feet, the height of the scarp is still 400 feet; 150 feet exposed and 250 feet buried under glacial deposit. The relief between the two walls is still great enough to assume that age, but we must keep in mind that since the Paleozoic was deposited, at least two periods of peneplanation and uplifting occurred and that the fault scarp we are dealing with, could be the equivalent of a resequent fault line scarp representing a much older age for the fault. It is reasonable to believe that the fault plane is very old and that the actual fault has been renewed along it. It could be as old as the adjacent similar lineament to the west, at Cobalt, which was put in place after the intrusion of the Nipissing diabase.

SUMMARY and CONCLUSIONS.

The writer will try to give a short historical sketch of the Grenville Province with an aperçu of the work to be done in order to obtain a better understanding of its problem.

A. Sedimentation.

The sediments deposited in a sea bordering the Superior Province were quartzites, limestones, shales, greywacks, conglomerates and a certain amount of lavas. At least one unconformity has been recorded (in Ontario) and according to Adams and Barlow (2) it is a minor one, but according to Miller, Knight and Leith (64) it was a major one and was correlated with the Laurentian elswhere. These sediments are said, by different authors, to be offshore equivalents of the Keewatin, (Grenville series in Ontario); of the Temiscaming (Hastings series in Ontario); and of the Lower and Middle Huronian (Grenville series in parts of Ontario and in Quebec). If they are such offshore equivalents of any of these series, the sediments came from the mainland to the N.W. However, studies that would involve the directions from which the sediments came from could be useful; and the low dips area northwest of Three Rivers could be a favored country for such studies, provided the sediments (quartzites especially) have not been recrystallized to such an extent as to have been deprived of their primary structural features. If further studies proved that the bulk of the sediments did not come from the N.W., the alternative would be to think that they came from the S.E. from a landmass similar to Appalachia situated off-shore.

B. <u>Opinions as to the age of the sediments</u>.

Miller and Knight (64) thought that due to the presence of lavas in the Grenville series of part of Ontario that they are the equivalent of the Keewatin and that the Hastings series lying on top and separated by a deep unconformity is equivalent to the Temiscaming. The granite which does not intrude the Hastings series is the Laurentian over which this series rests and the other granite which does intrude both the Grenville and the Hastings series was correlated with the Algoman. Cooke (68) thinks that the Grenville sediments are equivalent in age to the Nemequish and that the Nemequish is Keewatin. Actually the age of the Nemequish is unknown. Mawdsley (68) believes the Grenville to be pre Huronian because he finds the Meach Lake conglomerate overlying the Grenville and correlates this sediment with the Huronian. Actually a sediment calssified as Huronian used to date the Grenville has no value since one of the critical ages of the Grenville could be post Middle Huronian. Collins near Lake Huron found some evidence of the equivalence of the Grenville series which are 2,000 feet thick there, disappear completely when cut off on the east and partly assimilated by the Killarney granite which is also intrusive into the Grenville series. One objection is that the Grenville series are mainly gneisses while the Huronian rocks are largely schists. One answer is that two formations of the same age can be metamorphosed to a different extent, and that a difference in metamorphism is not a sufficient criterion to date the age of a rock series. In the Alps Paleozoic and even Jurassic rocks show in some places the same metamorphism as found in the Grenville and yet their ages according to the majority of people are totally different. Stresses applied on a formation along with heat and time are the important factors in metamorphism but time alone is not sufficient. For these reason it is wise to think of the Grenville sediments to be as old as the Keewatin or as recent maybe as part of a Peleozoic series. Further studies will have to be made along those lines. The writer heard that at Queen's University they tried to determine the age of the different granite intrusions of the Grenville series according to their content in heavy minerals probably along a method developed by Tyler and Marsden The experiment however did not succeed in bringing conclusive evidence.

C. Folding and Flowage.

The sediments once accumulated to a thickness of approximately 10,000 feet (94,000 by Adams and Barlow but since reduced) began to suffer at their base from heat and weight so that when the tangential stresses came in, the upper parts of the Grenville series were still rigid enough to transmit part of the stress while the lower parts had to absorb the near totality of the stresses through flowage. Igneous intrusions accompanied the folding and the combined effects of heat, stresses and time changed all competent strata to a flowing or semi-flowing mass. The result was that it was metamorphosed and recrystallized, and the original folding was destroyed to such an extent that any linear features, resulting from the first assumed unidirectional stresses, were soon obliterated.

D. Faulting as to Folding.

At the precise moment when the maximum stresses were exerted, it is thought that the whole Grenville mass was shoved against the Superior Province. How was it done ? No proof of overthrusting has been recorded anywhere. The only indication that this may have occurred are the shear zones apparently at high angles which mark the Grenville front. These high angle shear zones could possibly be a deep zone equivalent of the high angle thrust faults found at the front end of certain overthrusts such as in the Highlands of Scotland and that the actual overthrust planes were eroded away as they were localized in an area higher up in the series where the rocks were competent enough to transmit stresses. During that inferred period of thrusting, igneous rocks were still being intruded as some of them suffered intense deformation, and all rocks were metamorphosed to a great extent.

E. Faulting.

When most of the rocks became colder , but while still under stress, shear joints resulted, and at the Grenville front a set of later faults developed parallel to the front (N.E.) and at an angle to it N.N.E. In some places the Grenville front is offset in an en echelon fashion and could have been of a hich angle thrust type. Dykes of diabase filled in some of the faults and most probably occupied shear joints when the pressure was released. Dykes of diabase also occur in S.W. Quebec near the southern border of the Grenville Province and they are parallel to it, and even one or two have been recorded as being N.E. in trend. Further west they are parallel to the Ottawa Bonnechere Graben. Strong similarity in the association of diabase dykes with such later faulting made the writer inclined to think that the southern border of the Grenville Province, the Ottawa Bonnechere Graben, the later faulting along the Grenville Front and the diabase dykes are related. How ? It is suggested that under continued compression of cooler less heavily loaded and thus more competent rocks, shear joints develo~~p~~ped first, than faulting, possibly under the form of high angle thrusts along some favored shear joints, and then the diabase dykes were intruded. Nowhere have such diabase dykes been cut by the later faulting. The Chatham Grenville and the Rigaud stocks were intruded after the diabase dykes. It is most probable that, soon after the diabase dykes were intruded, tension began to develop. It is suggested that possibly nearly all the faulted zones whether developed when the rocks were still plastic or afterwards, were affected by such tension faulting. A tectonic trough may have been down dropped at that time to receive the later Paleozoic sediments. At any rate the Paleozoic times came and afterwards more normal faulting occurred along the old fault planes at different periods and possibly even until recently.

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Legend.
Geologist responsible for area outlined
Faessler
Fold axis
assumed
Geological contact
assumed
defined
Fault, shear zone
assumed
Strike and dip of
bedding
shistosity
faults
Drift, alluvials, etc.
Paleozoic rocks
Chatham-Grenville, Rigaud stocks
Diabase dykes
Morin series (igneous)
Pine hill type
Buckingham type
Mont-Tremblant ortogneiss
Paragneisses
Limestone-Amphibolite bands non-differentiated
a
Limestone bands
Amphibolites
Keewatin-Temiskaming-Huronian rocks
KT H
TECTONIC MAP (No: 1)
OF PART OF
THE GRENVILLE PROVINCE
Scale
8 0 8 16 24 32 40
Miles

TECTONIC MAP (No 2) OF PART OF THE GRENVILLE PROVINCE