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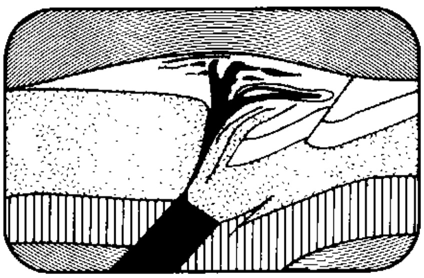
Conference Reports



Grenville Geology and Plate Tectonics

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A conference on the topic "Is Grenvillian Geology compatible with Plate Tectonics?" was held in the Department of Geology at the University of Ottawa, Ottawa, February 20 and 21, 1974. It was organized under the auspices of the Canadian Geodynamics Committee by A. J. Baer, R. F. Emslie, E. Irving and J. G. Tanner. It attracted some two hundred geoscientists from as far as British Columbia in the West, Newfoundland in the East, and Georgia in the South. This paper reports and comments on this conference.

Interest in the Grenville Province is out of all proportion to the amount of geological work done in it. An extremely complex and poorly known region, the Grenville Province symbolizes to many the unfathomable mysteries of the Canadian Shield. No other part of the Shield possesses such an aura of legend, accumulated over more than a hundred years of frustrated efforts at understanding its evolution. As a geological unit, the Grenville Province has suffered historically from over-exposure in the south and under-exposure elsewhere. For demographic and geographical reasons, detailed work has been largely concentrated in western Québec, Ontario and New York State whereas some eastern regions are still terra incognita. We have naturally tended therefore to apply to the whole Province knowledge acquired in the west and perhaps therefore to develop biased opinions about the evolution of the whole. Present status of work in the Province can be summarized in this way.

Ontario
In the area where the Grenville Group is well represented (southeast of the Pembroke-Bancroft line) most regions have been covered by detailed maps (1 in. = 1 mile or less) of the Ontario Government, supplemented by university work and some studies of the Geological Survey of Canada. In regions to the northwest, detailed work has been mainly concentrated along the Grenville Front. Elsewhere mapping varies from non-existent (parts of Algonquin Park) to excellent (Lumbers' work around Lake Nipissing and north of it).

Québec
For many years, the Québec Government has had a mapping programme (at 1 in. = 1 mile) for areas of particular interest or ready access. From 1965 to 1971 however, reconnaissance mapping (1 in. = 2 miles, 1 in. = 4 miles) progressed vigourously so that at least three quarters of the Québec sector has now been mapped. With the exception of joint federal-provincial aeromagnetic coverage, no systematic mapping has been undertaken by the Geological Survey of Canada since the 1964 mapping of Mt Laurier-Kempt Lake area by Wynne-Edwards *et al.*

New York State
The Adirondacks have been mapped at 1 in. = 1 mile or less for many years, and an excellent compilation by Isachsen was published in 1962, as part of the geologic map of New York. A new edition at the same scale as the first (1:250.000) has recently been made available. The Adirondacks are thus better known, geologically than most other parts of the Grenville Province.

Labrador
Most of the Grenville Province in Labrador is covered by reconnaissance maps (1 in. = 4 miles) of the Geological Survey of Canada, but detailed work is extremely limited. See also the summary given by Greene in this issue.

Evolution of Ideas
About 20 years ago early results of radiometric dating suggested that rocks of the Grenville Province were possibly not Archean, as believed previously. Results of K-Ar studies seemed for a while to suggest that the region could have been created by continental accretion about 1 billion years ago. A little over 10 years ago however, Walton and de Waard, Stockwell, and Wynne-Edwards suggested on geological grounds, that large parts of the Grenville Province were in fact a deeply eroded basement formed of remobilized older rocks. Better appreciation of K-Ar

ages and application of other dating methods have now proved this point many times over. Over the last five years, search for an acceptable model of evolution of the Grenville Province has intensified. Whereas some workers have developed a "classical" orogenic scheme (Wynne-Edwards), others (Martignole, Baer) looked to anorthosites as the major cause of upheaval. New and apparently divergent paleomagnetic data could be explained by long-distance drifting of the Grenville Province. (Palmer, Irving and Carmichael *et al.*) or by rotation of that Province (Fahrig *et al.*) relative to the rest of the Canadian Shield.

Evidence has now been accumulating for some time that plate tectonics mechanisms were active at least as far back as the Paleozoic. Recent discussions of Keweenawan volcanism as evidence of rifting have implied similar mechanisms in Grenvillian times. Burke has now proposed that the Grenvillian orogeny was a reactivation of older material alongside a subduction zone. Tibet is the type location of this suggested evolution. Starting from this idea, it is possible to construct a new Grenvillian model that could accommodate the available data (Baer).

The Conference

M. R. Dence presented a general view of the Grenville Province, where he reviewed the major rock types (Grenville Group, anorthosites and associated rocks, granulite facies rocks) typical of the Province. His introduction also served to focus attention on Grenvillian terminology. This brief recapitulation of Grenvillian geology was followed by a world-wide review of possibly related events of similar age. For instance it is difficult to dissociate from anorthosite emplacement the widespread metamorphism of apparently similar age in the south-central U.S.A. Later, between 1.35 and 1.15 b.y., while basic volcanism was concentrated in the mid-continent and while some granitic rocks intruded the southern Grenville Province, extensive epizonal granitic plutons and associated rhyolitic extrusives were emplaced

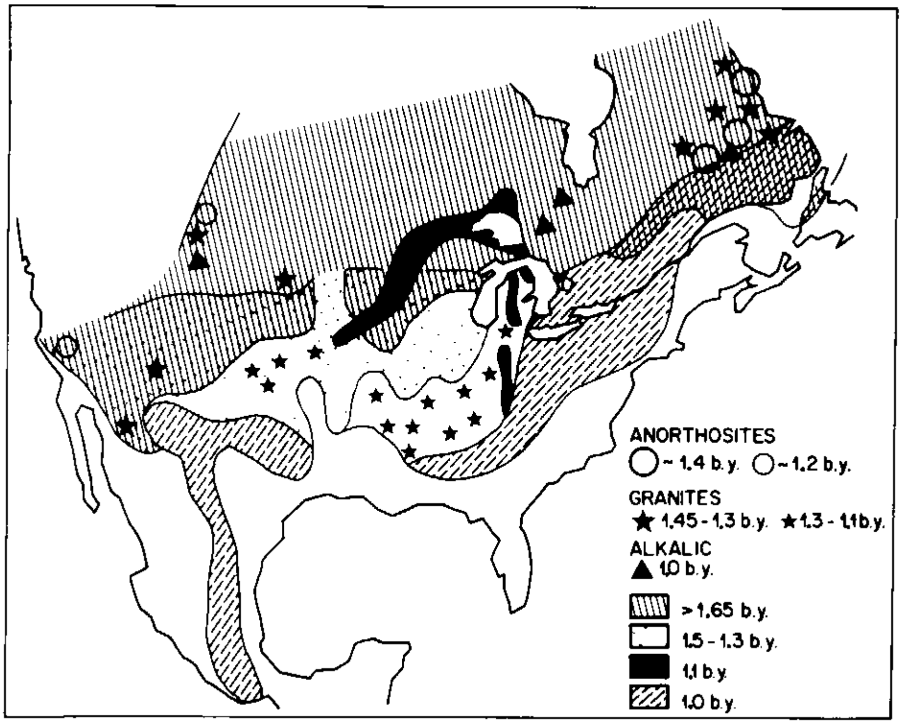

Figure 1
Basement map of part of North America showing radiometric sub-provinces and plutonic activity between 1.5 and 1.0 b.y. ago (M. R. Dence).

from Ohio to New Mexico.

Outside of North America, in Europe, in Africa, and in Australia, metamorphic belts about 0.9 b.y. to 1.6 b.y. old show features similar to those of the Grenville Province. Extensive high grade metamorphism with abundant granulites, and absence of typical eugeosynclinal sequences and of alpine-type peridotites are characteristic. There are suggestions in the rock-record that rifting and vertical movements were then more important than plate motions. These may well herald the break-up of Laurasia and the first opening of the proto-Atlantic.

Y. W. Isachsen was prevented from attending the conference as planned, but he contributed a summary of Adirondacks geology.

In this area, structural-stratigraphic trends are not parallel to the general northeast trend of the Province itself. They are generally east-west from the core of the Green Mountain anticlinorium to the western Adirondacks, where they gradually sweep in a southwesterly direction, some defining major nappes. Superimposed on this east-west isoclinal fold pattern is one of broad doming associated with the anorthosite bodies. In the southern Adirondacks, McLelland has recognized the following sequence of deformation: F_1, east-west isoclinal folds and nappes; F_2, large, fairly open, northwest-trending folds; F_3, broad open folds trending north-south. The anorthosite doming occurs late in this sequence.

Separating the northwest lowlands from the remainder of the Adirondacks is the Carthage-Colton zone of mylonitization which corresponds generally to the hypersthene isograd. The amount of displacement and the significance of this zone are not presently known.

Crustal thickness in the Grenville Province one billion years ago was probably about 60-65 km. This figure is the sum of the present 35 km depth to the Moho in the Adirondacks (Katz) and the required 25-30 km depth of burial for granulite facies equilibration. This fits the inferred

Proterozoic geothermal gradient of Ray (1970).

Isotope geochronology and contact relationships support the long-held view that the Adirondack anorthositic rocks are intrusive into the meta-stratified sequence rather than being part of an underlying basement. Where anorthosite is in contact with mangerite, the latter contains xenoliths of anorthosite in various stages of dismemberment into plagioclase xenocrysts. This relationship can be explained by contact anatexis of intruded quartzofeldspathic rocks, which subsequently intruded the earlier-congealing anorthosite.

The age of anorthosite intrusion in the Adirondacks is closely bracketed by U-Th-Pb dating at about 1100 million years (Silver). This cannot be tacitly assumed to be a reset age because zircons from quartzites in the area retain a 2.7 b.y. provenance age. This raises questions: do anorthosite bodies of the Grenville Province become successively younger from Nain southward (mantle plume control over a 300 m.y. period?) or do they represent two distinct periods of intrusion and orogenesis?

Baer's presentation of the Grenville Front emphasized that the Grenville Province has been "nailed" to the rest of the Canadian Shield at least since early Proterozoic times and in part since the Kenoran orogeny. If a suture is to be found, it is not along the Front. Various segments of the Front have evolved differently, over different periods of time. The Ontario segment existed at least as far back as 1550 m.y. ago (Krogh). It may also have represented a hinge zone during sedimentation of the Huronian Supergroup in the earlier Proterozoic. At the other extremity, in Labrador, the Seal Lake rift which represents the Front in that area, did not open before 1300 m.y. ago. Elsewhere (Labrador Trough for instance) evidence for a Front post-dates the Hudsonian orogeny. As it exists now, the Front northeast of Chibougamau differs by its structure, its gravity expression and its evolution from the segment extending southwest of that town. The northeastern segment appears to swing south into the Grenville Province near Chibougamau.

Emslie discussed at length the evolution of anorthosites, and the constraints that it places on possible models of evolution.

Major complexes are confined to the northeastern two-thirds of the Grenville Province and to Labrador north of the Grenville Front. Petrogenetic relationships of basic members to quartz-bearing members of the suite remain a problem. A simple comagmatic relationship with fractional crystallization is most unlikely. Magmas of composition ranging from olivine gabbro and norite to diorite and quartz monzonite have been present, and relative age relations support a general trend from basic to silicic. The concept of a parental magma is difficult to defend however, and instead the complexes seem more likely to be formed of successive injections of magmas evolving, or being generated somewhere below the level of emplacement.

Although the concept that anorthosite suites are closely associated with high-grade regional metamorphic terrains has been firmly entrenched, evidence from Labrador shows that envelope rocks as low as greenschist have been intruded, and low pressure contact metamorphic mineral assemblages produced.

Some rocks of the anorthosite suite in the Grenville Province have yielded ages of about 1130 m.y. by U-Pb on zircons and Rb-Sr whole rock methods and have been interpreted as primary ages. However, metamorphic rocks adjacent to some contacts have yielded 1450-1550 m.y. ages by the Rb-Sr whole rock method so that one is reluctant to reject the hypothesis that anorthosite suites with ages comparable to those in Labrador are present in the Grenville Province.

Baragar's presentation combined available data on basaltic plateau volcanism 1000 to 1300 m.y. old to suggest that it corresponded to widespread rifting in the Grenville Province. Under discussion are the Keweenawan, Seal Lake and Gardar magmatic provinces. According to Baragar, they testify to a pre-Grenville rift-zone which opened first in the northeast and extended slowly south-westward along the course of the present Grenville Province. Gardar, Harp Lake and Abitibi dykes, all with similar southwesterly trends, are assumed to have fringed the original dyke swarm associated with rifting and to have survived Grenvillian deformation because of their position north of the Grenville Front. Their direction is indicative of the direction of rifting. Alkalic intrusive complexes

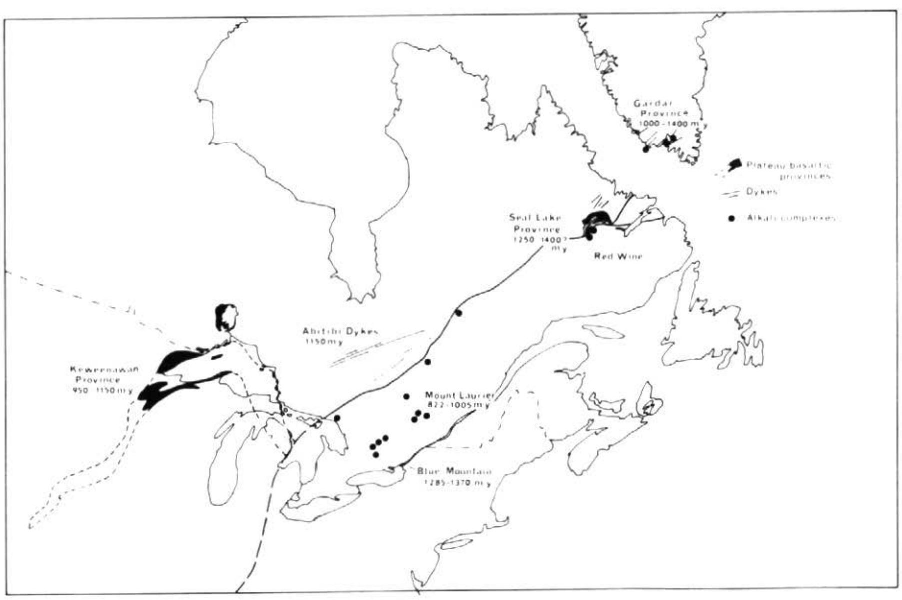

Figure 2
Eastern Canadian – Greenland Shield restored to pre-drift position showing various elements of Neohelikian, rift-related magmatism. Position of pre-Grenville rift zone shown here is highly speculative (W. R. A. Baragar).

(Gardar, Seal Lake, Blue Mountain) may be related to the same pre-Grenville rift-zone and very roughly mark out its course. According to Baragar, the evolution in Greenland and Labrador that culminated with the proposed rifting is as follows:

	Greenland	Labrador
1) geosynclinal stage	Ketilidian	Lower Croteau
2) orogenic stage	Ketilidian granitic rocks	Hudsonian granitic rocks
3) late orogenic stage	Sannerutian granites, appinitic suite	Upper Croteau pyroclastics
4) cratonic stage	Gardar magmatism	Seal Lake magmatism

Dallmeyer presented the two distinct tectonic settings of Grenvillian rocks in the Appalachians; overturned anticlinorial Highland massifs near the western margin of the orogen, and mobilized cores of gneiss domes in the high-grade Paleozoic terrane of the Piedmont Province. Many rock-types have counterparts in the Grenville Province. They include aluminous and calcareous metasediments similar to lithologies of the Grenville Group, hypersthene-bearing, potassium-poor quartz-plagioclase gneisses similar to the probable mobilized basement of the Group and abundant anatectic granitic rocks. A complex Grenvillian structural history is reflected in the basement rocks, and where detailed structural mapping has been carried out, at least three periods of coaxial folding about northeast-trending axes have been documented. Rb-Sr data imply that the range of whole-rock ages from 1320±100 to 1027±35 m.y. is a result of partial homogenization of an older terrane during Grenvillian metamorphism. No indication has been found of any addition of new material to the crust during the Grenvillian orogeny. Studies of K-Ar and $^{40}Ar/^{39}Ar$ ages and evidence of Grenvillian metamorphism around 4.5 to 5.5 kbars and 700° to 750°C allow construction of a model of the post-orogenic uplift of the Reading Prong. The uplift history reads as follows: 1060 to 900 m.y., average rate of 0.006 mm/yr; 900 to 790 m.y., average rate of 0.033 mm/yr; 790 to 650 m.y., average rate of 0.074 mm/yr. Uplift was probably more extensive to the west (near the Grenville Front) and to the north in the direction of the exposed part of the Grenville Province.

Presentations by geophysicists showed that if geological information is locally insufficient, geophysical data, with the notable exception of gravity and aeromagnetics, are even more confined to the study of specific areas or specific problems. Not enough is available, for instance about heat flow, seismics, remote sensing or even geochronology to help in geological interpretations of the whole Province. Radiometric data from the western part (Krogh) show that volcanic and igneous rocks associated with the Grenville Group in Ontario yield U-Pb and Rb-Sr ages younger than about 1300 m.y. whereas granitic gneisses to the north and northwest have ages between 1400 m.y. and 1800 m.y. In the French River area, about 50 km southeast of the Grenville Front, zircons in pegmatites pods associated with boudin structures, and overgrowth on zircons from paragneiss indicate that deformation and metamorphism occurred between 1070 and 1000 m.y. ago. Rb-Sr whole rock analyses from thick, homogeneous layers of felsic paragneiss in the same outcrops yield an age of 1845 m.y. In this region, the Grenvillian orogeny clearly represents reactivation of a Hudsonian basement. Elsewhere in the Province Archean metasediments yield zircons recording a 2600 m.y. (Kenoran) event. This is the case 10 miles south of the Front, near Lake Temagami, 25 miles south of it near Lac Cabonga and about 30 miles south of it near Gagnon. Most geochronological studies have been concentrated in Ontario and in western Québec, but areas north and northeast of Lac St Jean are badly lacking radiometric data. The other vexing problem in this field remains the determination of the age of anorthosites. Available ages are on rocks associated with them and may not necessarily date the anorthosites themselves (Emslie).

Dunlop described the state of the art in paleomagnetism. He showed, in particular how various recent possible interpretations (Irving, Fahrig) were related to each other and showed that only three models need be considered. These are: a) a "Grenville Loop" in the polar wander curve predating the Logan Loop, b) a Grenville Loop post-dating the Logan Loop, and c) an independent Grenville polar wander path converging with the younger end of the Logan Loop. Models (a) and (b) are geologically more attractive, but it is becoming possible to decide on magnetic evidence which model is best. To do this, it is crucial to determine the time of acquisition of stable magnetization (unrelated possibly to the age of the rock) and the relative ages of superimposed stable components reported by various groups of authors. For instance, model (a) requires magnetization to have occurred about 300 m.y. earlier than is needed for model (b). Relevant magnetic evidence includes fold-tests of the stable magnetization, relations between temperature of regional metamorphism and blocking temperatures of stable magnetization, and the presence or absense of superimposed stable magnetization components. Relative ages of superimposed components according to models (a) and (c) are opposite to the relative age required by model (b). Dunlop's presentation went a long way towards explaining to the professional sceptics among geologists what contributions to the Grenville problem can come from paleomagnetism.

Hood reviewed the existing aeromagnetic coverage (all of the Grenville Province except two areas in Labrador) and went on to demonstrate, with examples, correlation between geology and magnetic signature. Anorthositic rocks stand out typically as "lows" and associated gabbros as "highs". In specific cases (Bancroft area for instance) high grade of metamorphism corresponds to magnetic "highs" and low grade to magnetic "lows". Results of sea-magnetometer surveys off Eastern Labrador were presented by Van der

Linden. It appears possible to follow the eastern extension of the Grenville Front under the continental shelf and slope. A basement high south of Kap Farvel, in Greenland may represent the pre-Tertiary extension of part of the Grenville Province, and a further extension of the Grenville Front through Rockall Bank can be postulated.

A major negative gravity anomaly extends along the Grenville Front from Chibougamau to Labrador and has puzzled geophysicists for some time. Both Tanner and Berry discussed it, the first in his review of available gravimetric data, the other in presenting a deep seismic refraction experiment mounted in 1968 and centred about the eastern half of the Grenville Front. In a shorter communication, Mereu recalled results of the seismic profiling run across the Front from Chibougamau to Lac St. Jean. Berry reported that the crust under the Superior Province is thinner on average than under the Grenville Province (respectively 34 km and 39 km) and thickens to 45 km under the Front zone. The Conrad discontinuity lies at an average depth of about 24 km along the Front. The preferred seismic model has a thicker upper crust along the Front as well as a thicker and deeper low-velocity channel at a depth of approximately 10 km. The pronounced gravity anomaly along the Front has horizontal gradients that require lateral variations of density in the upper crust. To explain the anomaly, Berry suggested that these lateral variations may coincide with the low velocity channel, but that under the Superior and Grenville Provinces the channel more probably represents a suddent rise of pore pressure with consequent decrease in effective pressure and reduction of seismic velocity.

In his presentation, Tanner suggested that the gravity low centred over the eastern half of the Grenville Front is due to an "edge effect" between a thinner lower density Superior crust and a thicker higher density Grenville crust together with a slightly thickened (i.e., non-isostatic) crust in the vicinity of the Grenville Front. This model also accounts for the regionally higher gravity anomalies over the Grenville Province. This interpretation is similar in many respects to that presented by Berry, but differs in that a vertical discontinuity or strctural break is implied at the Grenville Front. Tanner also discussed the gravity expression of anorthositic masses and possible models to explain the anomalies. As a rule, most major anorthosite complexes in the northeastern Grenville Province are overlain by gravity highs, whereas those in the southwest are normally associated with gravity lows. This implies that the former have mafic roots, but not the latter, and gives to the northeastern Grenville Province a unique character. Tanner also compiled an updated computer-contoured gravity map of the Grenville Province which was the object of considerable interest. Judge, and also Hamza, discussed heat flow and distribution of radioactive heat. Judge reported on 46 published measurements on heat flow in borehole made either in the exposed Shield rocks of the Grenville Province or in thin sediments overlying a Grenvillian basement. Values range from 0.7 to 1.4 µcal $cm^{-2}sec^{-1}$ with a mean of 1.0±0.2. This mean is similar to that for the Superior Province. Near-surface measurements of uranium, thorium and potassium contents of a variety of basement rocks have been made at 11 sites within the region. Heat productions range from zero in the anorthosites to as high as 0.61 µcal $cm^{-3}sec^{-1}$ in some basement gneisses. Since the shield areas are old and, with the exception of climatic disturbances to the top 3 km, close to thermal equilibrium, the observed heat flow is primarily due to radioactive heat production in the crust and upper mantle. The 5 sites for which heat flow and heat production have been measured scatter around Roy's curve for the Central Stable Region of the continent. Estimated present temperatures at the base of the crust range from 300 to 600°C. These estimates are considerably lower than the 700°C average temperature of metamorphism of the present surface rock and very much less than the 900°C estimated for the Central Granulite Terrain. Thus at the time of metamorphism, the crust must have been thicker, the heat productions much higher or the thermal regime similar to that in the Cordillera today.

Kurtz and Niblett reported that magneto-telluric variation studies across Logan's Line (Appalachian Front) indicate some anomaly to the southeast of the Line; however, no anomaly was detected in a pilot study across the Superior-Grenville boundary.

Earthquake data and their significance were reviewed by Leblanc. The period covered is too short to shed any light on the emplacement of the Grenville Province. Seismicity maps for the last four centuries, the last forty years and the last decade indicate the presence of a broad belt of activity extending from Temiscaming through the Ottawa Valley (including the Bonnechère region), Montreal, Eastern Townships and down to Boston. A cluster of important activity also centres near La Malbaie, Québec. Leblanc favors this NW-SE trending belt against a proposed NE.-SW. alignment, but does not rule out the latter entirely. The presence of strong horizontal stresses associated with local crustal weakness due to unhealed faults or other causes could explain the current distribution of epicentres.

ERTS images of parts of the Grenville Province were presented by Slaney in a discussion of the uses and advantages of various type of remote sensing techniques. Remote sensing imagery appears more useful in some areas than in others, as it basically supplies the user with structural information. An advantage of ERTS pictures is also that the same area can be compared under various weather conditions (Summer, Winter; snow, no snow) for maximum information. With the help of a great variety of imagery, the author took us above the Grenville Province, from stratospheric heights to low passes that permit cows to be counted in the fields.

Through what they said as much as through what was left out, authors of the review papers succeeded in presenting the Grenville Province "as it is", and it was left to model-makers

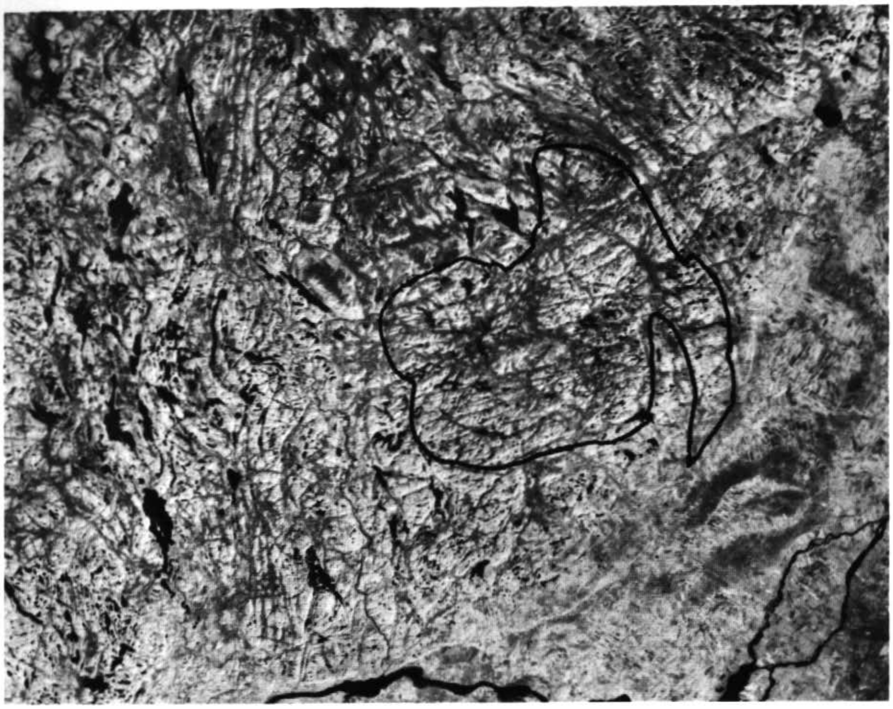

Figure 3
Part of the Grenville Province north of Montreal. Metropolitan Montreal is in the extreme lower right. The Ottawa River appears along the lower margin. St. Lawrence Lowlands mark the edge of the Precambrian Shield below and to the right. The Morin anorthositic massif is outlined in black. Note the distinctive east-west joint pattern within anorthosite. North-south structural trends appear to the west of the Morin body whereas on the eastern margin structures wrap around it. The black arrow indicates north. ERTS image courtesy of the Canada Centre for Remote Sensing (R. F. Emslie).

to suggest suitable answers. Interestingly, all three have come to the Grenville Province through widely different paths. H. R. Wynne-Edwards, the first speaker, has been steeped in Grenvillian lore since his student days and has made major geological contributions to the Grenville Province over the last fifteen years. E. Irving, a paleomagnetician came to the Grenvillian problem a few years ago. Kevin Burke, with geotectonics experience in Africa and Asia has developed a model of evolution of the Tibetan Plateau which he is cheerfully suggesting could be most useful in the Grenville Province . . . if the experts want to listen.

Everybody was listening when Wynne-Edwards presented his "millipede" model. He had been dubbed "fixist" in the programme, mainly because in the past he has advocated models that did not require plate tectonics. It became clear, from his presentation, that, as a geologist, he is most concerned with accommodating structural and petrological data. Structural evidence from the Mt Laurier area and systematic reconnaissance mapping by the Quebec Ministry of Natural Resources indicate superposed deformations on a regional scale. These have been interpreted as ghost fabrics of Kenoran and Hudsonian orogenies visible through the Grenvillian structural overprint. Petrological barometers and thermometers of various kinds all indicate that some rocks presently at the surface were formed under temperatures of 700° to 750°C at depths of about 20 km. Any valid model should be able to explain or at least accommodate these data, and, of course, to take into account the particular role played by anorthosites. The major concept in the millipede model is that of a continental plate slowly drifting over a hot zone or a chain of hot spots. At any given time, domains above a hot spot are in extension whereas those farther off to the side are under compression and tend to fold along axes parallel with that of the hot zone. As the plate moves, each point in it passes successively through extension and contraction domains. The present geographical distribution of anorthosite massifs, in three north-trending rows could represent the orientation of a hot zone over which North America was drifting.

Irving has been described as a "rafter" because of that recent paper in which he and colleagues suggested that, on paleomagnetic evidence, part of the Grenville Province could have been rafted over thousands of miles to join the rest of the Canadian Shield at the time of the Grenvillian orogeny.

Three possible models are available, and using Dunlop's nomenclature they require the age of the "Grenville Track" (a linear array of poles that are available) to be as follows:

In Model 1: greater than about 1250 m.y.

In Model 2: around 1000 to 1150 m.y.

In Model 3: less than 1000 m.y.

Irving favors the second model, and his argument goes like this: Recent work on the Morin and Lac Croche complexes (Barton and Doig, Rb-Sr isochrons) shows that they underwent granulite facies metamorphism around 1125 m.y. ago. These complexes contain two magnetizations and corresponding poles that define the limits of the Grenville Track. One magnetization is due to hematite and has blocking temperatures of about 600°C. The second is probably due to magnetite and has blocking temperatures of 200°-500°C. Extrapolating this to regional cooling following metamorphism over time-scales of 10^6 years and using Neel's single domain theory, the "hematite" and "magnetite" magnetizations were acquired at temperatures of about 300° and 200°C respectively. Accepting 200°C as a reasonable temperature below which radiogenic argon is retained in micas, then the age of the "magnetite" component can be equated with the K-A ages (~1000 m.y.). The age of the "hematite" component then probably lies between the Rb-Sr and K-A ages, that is about 1100 m.y. This would mean an age of the Grenville Track from about 1100 m.y. to 1000 m.y., which favours Model 2.

If (and only if) we accept these arguments, a formal plate tectonics reconstruction can be calculated for the convergent phase. There is some paleomagnetic evidence to support the idea that this was preceded by a divergent phase during which the southern part of the Grenville Province was rifted from the rest of the Shield at about 1300 m.y. This rifting was marked geologically by the Seal Lake Volcanics and Abitibi dyke swarm. The later Proterozoic history of the Grenville Province may simply be an example of the Wilson cycle – an opening and closing ocean. This model requires that there be a suture within the Grenville Province. The suture must lie southeast of these rocks that can indubitably be traced across the Front. Presently available paleomagnetic results indicate that the suture should lay northwest of a line joining Parry Sound, Bancroft, Ottawa, Lac St Jean and Allard Lake.

Vigorous discussion followed this presentation, centered as much on the use of paleomagnetic evidence as on the geological consequences of the model. Geologists (particularly field geologists) object to it on the basis that no suture line has been identified. Although this only represents negative evidence, it is true that structural trends run in part at high angles to the proposed suture with which the known geometry can hardly be reconciled.

Paleomagneticians are divided about the relative ages of magnetization (see Dunlop), or the assumptions needed to "date" them. Some go as far as suggesting that truly reliable data cluster around a fixed point, and deny the existence of a Grenville Track (Symons).

Kevin Burke presented his Tibetan model, or, as he also describes it, the basement-reactivation model. He proposes that the Tibetan Plateau is a modern analogue of, for instance, the Grenville Province, and that it represents crustal thickening

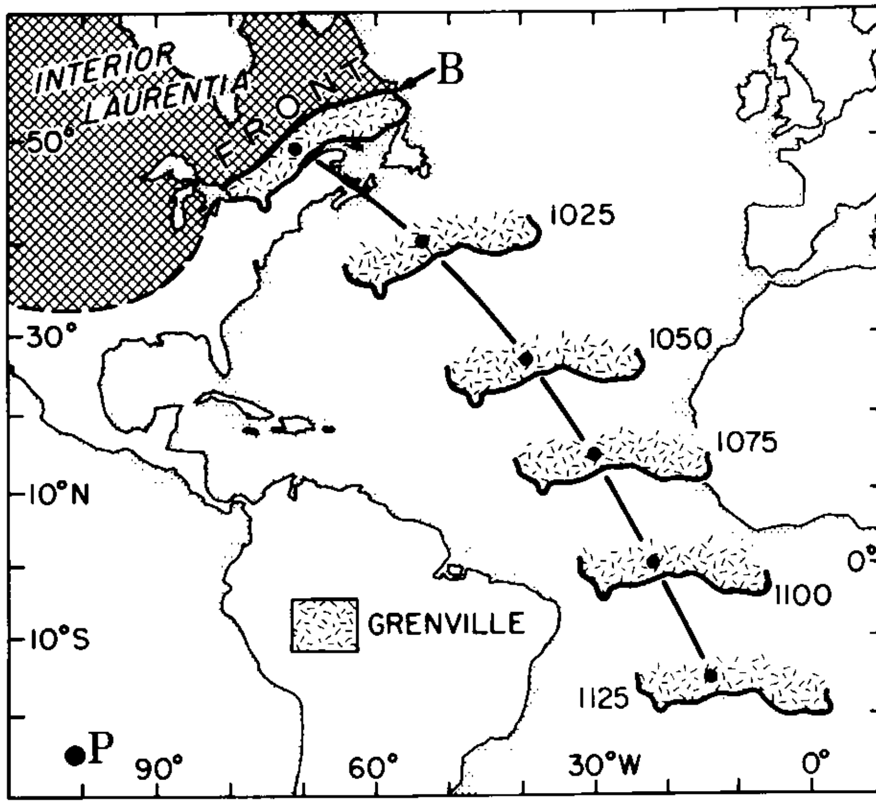

Figure 4
Reconstruction of movement of southern part of the Grenville Province relative to the remainder of Laurentia between about 1125 and 1000 m.y. based on option 2 in the text. P is the pivot point about which the Grenville rotates. B is the zone immediately south of the Grenville Front that remained attached to Interior Laurentia (E. Irving).

following continental collision. Reactivated terranes comprise a two-layer crust between collisional sutures and Grenville-type fronts. The suture in this case would have been where the Appalachians now stand. The lower crust, consisting of pyroxene granulites and anorthosites would be generated in the process. Anorthosites with associated gabbros and titanium-rich fractions would represent residues of the melting of calc-alkaline rocks (quartz diorite) in the lower crust. More potassic/silicic liquids would rise as diapirs to intrude at higher levels (now eroded away). Progressive dehydration of the lower crust would generate pyroxene granulites, charnockites and mangerites.

It became clear during the general discussion that none of these three models completely satisfies everyone. Major objections can be made to all of them. For instance, the ages of anorthositic rocks is not explained by Burke, the lack of any vestigial geological evidence for a suture line hampers the Irving model, and no hard evidence is available to disprove or to prove the suggestion of Wynne-Edwards. During the discussion, Baer suggested that the Tibetan model could be modified to better accommodate the known geology. One could argue that deposition of the Grenville Group filled an aulacogene occupying approximately the region where the Group occurs now. Basement reactivation followed old lines of weakness, in particular the Grenville Front from the Labrador Trough to Chibougamau and an extension of it from there to the south along the edge of the earlier aulacogene. In first approximation, successively deeper structural levels are encountered from the Grenville Front to the southeast, but also from northeast to southwest from Labrador to Lac St Jean and Morin area. Regions west of the

Grenvillian "marble belt" would have been spared the brunt of the deformation.

From the presentations as well as from the discussion, one gets the impression that most experts would agree on the following:

a) The Grenvillian orogeny may be explained in terms of plate tectonics
b) It reactivated a pre-existing complex of plutonic and metamorphic rocks
c) It is not the result of evolution of a miogeocline-eugeocline couplet
d) Archean rocks may well occur farther southeast than a 30 or 50 km fringe inside the Grenville Front
e) The Grenville Front is not a suture line
f) The evolution and history of anorthositic suites is one key to the Grenville problem
g) The Grenville Province may not be unique, but only better known than others of similar age or evolution
h) More field information is urgently needed.

Besides reviews of existing data that brought every one up to date on the state of the art, glimpses of new approaches were given by some speakers. Dallmeyer for instance has successfully worked out the late and post-orogenic uplift history of some Grenvillian terrain in the U.S. Similar work in large areas of continuous Precambrian rocks would be extremely useful to petrographers, tectonicians, and to geophysicists for their crustal studies.

Baragar implied that pre-Grenvillian rift zones in the Grenville Province may be traced by studying the distribution of (metamorphosed) rift-type igneous rocks. In terms of models, the Tibetan is possibly the most intriguing. It may be that the "Grenville problem" will not be one very much longer.

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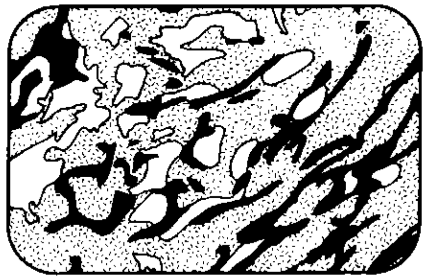

Canadian Shield Volcanic Belts with Emphasis on the Abitibi Volcanic Pile

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Summary

The Quebec part of the Abitibi volcanic belt is the subject of an intensive research project oriented towards providing detailed petrological and geochemical data integrated with stratigraphy and tectonics. In establishing the changing composition of the volcanic pile in the region north and south of Rouyn (from monotonous tholeiite basalt in the lower sections to intermingled calc-alkaline and tholeiitic series in the higher sections) such diverse subjects as the role of immiscibility in the formation of variolites, and the nature of quench-texture in Archean tholeiites have been investigated. A conference series designed to provide a means of exchange of information between project personnel and researchers investigating related topics elsewhere in Canada was convened. The feedback obtained during the conference series resulted in new directions being initiated within the confines of the project, and a complete traverse of the Abitibi volcanic pile from south of Rouyn to Matagami is planned.

Introduction

Commencing in mid 1972, the Minister of Education of the Government of Quebec started funding a research project entitled the "Geochemistry of Volcanic Piles of the Noranda Region". This project formed a part of the Ministry's programme encouraging concerted team research on topics within Quebec. This project, which has been funded for two years and has just been renewed for the period of 1974-1975, is led by L. Gélinas and C. Brooks and involves as other principal researchers and associates, colleagues from the École Polytechnique, the Université de Montréal, the Quebec Department of Natural Resources and the Geological Survey of Canada.

The first two years of the project resulted in the accumulation of a considerable amount of data within the realms of field relationships, petrology and geochemistry. In order to maximize the usefulness of this data and expose our students to relevant research in other parts of Canada, a conference series on Canadian Shield Volcanic Belts was organized. This conference series which convened on the campus of the Université de Montréal and the École Polytechnique, during the interval November 1973 to April 1974, involved 18 presentations of ongoing research in diverse topics related to ancient volcanic rocks. The following section gives a progress report on the research project, and this is followed by a brief outline of the topics presented and discussed during the conference series.

Project Report

The research project has involved the establishment of a sampling traverse oriented roughly north-south in the vicinity of Rouyn and running from the southern limit of volcanics south of Rouyn, north towards Lake Abitibi (Fig. 1). This traverse provides a reference zone which intersects all of the main lithological entities of the area. It is essentially a petrological and geochemical traverse but its establishment has been closely integrated with regional mapping (in collaboration with E. Dimroth, Q.D.N.R.). We have used as a base for geochemistry, the detailed