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Résumé de l'article

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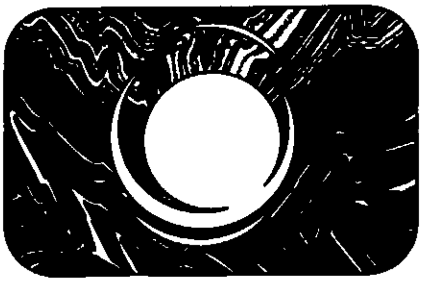

Magmatism in the Grenville Province Since the Grenville Orogeny

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Summary
Post-Grenville orogeny igneous rocks that are unrelated to later orogenics (i.e., anorogenic rocks) make up an important component of the Grenville Province. They commonly consist of small intrusions, but also include the largest mafic pluton in eastern Canada (the Sept Iles complex). Most of the extrusive post-orogenic rocks have now been reworked by the Appalachian orogeny, but a widespread diabase dyke swarm in the western part of the province suggests that a vast area of flood basalts may have been removed by erosion. Most of the post-orogenic rocks are associated with the St. Lawrence rift system which appears to have been active for most of the last 1000 Ma. Post-orogenic rocks may be discovered elsewhere in the province when detailed study is extended beyond the area adjacent to the rift.

Introduction
Although there are several good syntheses of the geology of the Grenville structural Province of the Canadian shield (e.g., Wynne-Edwards, 1972; Douglas, 1970) most do not describe rocks formed since the Grenville orogeny, approximately 1100 Ma ago. In fact many geologists mistakenly feel that only rocks which underwent metamorphism during the Grenville orogeny can be included in the province of the same name. The purpose of this paper is to remedy that error. The Grenville Province has a long history of post-Grenville orogeny, anorogenic magmatism (termed post-orogenic elsewhere in this paper) and large-scale fault movement. This paper describes the post-orogenic magmatic rocks of the Grenville Province and adjacent St. Lawrence lowlands and shows how they may be related to brittle failure of the crust induced by regional stress fields (Fig. 1).

Geochronological data on the post-orogenic magmatic rocks is somewhat limited, but most of the central complexes have at least one K-Ar date. Work on alkaline complexes in the U.S.A. (summarized by Zartman, 1977) and elsewhere has shown that similar rocks within the same complex may cover a large age range. Despite these shortcomings the rocks will be described in chronological order.

More detailed information and original references on many of the complexes considered to be "alkaline" in nature may be obtained from Currie (1976). Estimates of the surficial area of each complex have been included to show their relative importance.

Precambrian
Rb-Sr studies (e.g., Doig, 1977) show that the peak of the Grenville orogeny occurred approximately 1100 Ma ago. The rocks exposed today in the Grenville Province cooled slowly to give K-Ar ages that range from 850 to 1050 Ma. However, dating by Rb-Sr and zircon methods has shown that many magmatic rocks intruded during this cooling period may be distinguished from the main phase of magmatism.

Rb-Sr studies of uraniferous pegmatities in the Bancroft area yield an age of 959 Ma, 120 Ma younger than similar non-uraniferous granites in the area. Uraniferous granites and pegmatites from the Mt. Laurier and Johan Beetz areas give ages of about 930 Ma, again considerably younger than other granites from the same area (Fowler, 1980). Other uraniferous rocks may also belong to this category, but further Rb-Sr or zircon work must be completed before their magmatic age can be determined.

Nepheline-bearing alkaline rocks of Monmouth and Glamorgan townships (Haliburton county) are closely associated with nepheline gneisses but have igneous textures. It is possible that these rocks were formed in the immediate post-Grenville period.

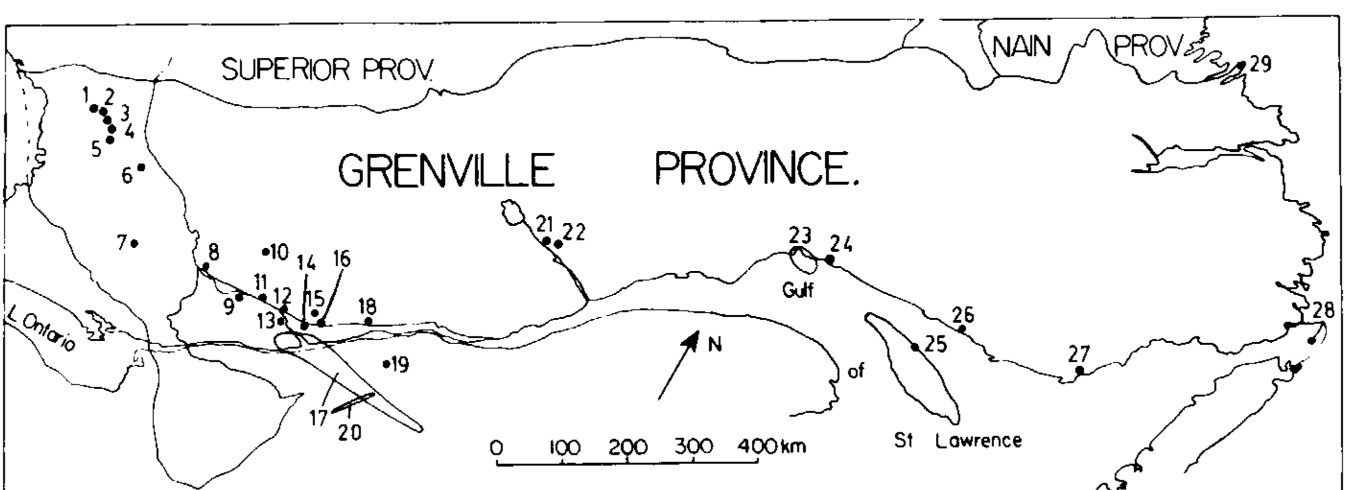

Figure 1 *Location of post-orogenic igneous rocks in the Grenville province and adjacent regions. 1) Iron Island; 2) Burritt Island; 3) Manitou Islands; 4) Callander Bay; 5) Powassan; 6) Brent; 7) Bancroft region; 8) Onslow; 9) Eastview; 10) Mt. Laurier area; 11) Buckingham; 12) Chatham-Grenville; 13) Rigaud; 14) Oka; 15) Ste. Sophie; 16) Ile Blizard; 17) Monteregian hills petrographic province; 18) Lac Noire; 19) Bon Conseil; 20) Tibbit hill formation; 21) Chicoutimi; 22) Ste. Honoré; 23) Sept Iles; 24) Moise; 25) Anticosti Island; 26) Johan Beetz; 27) Baie des Moutons; 28) Strait of Belle Isle; 29) Allik Bay.*

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Cambrian

Anorogenic rocks of Cambrian age are particularly prolific and extend throughout the entire length of the Grenville Province. The Nipissing alkaline province (approx. 12 km^2 in area) consists of at least seven distinct circular plutonic complexes distributed for 100 km along an extension of the Ottawa graben. Callander Bay, Manitou Islands and Iron Island are relatively well exposed, especially at their rims. Burritt Island, Springer township, Powassan and Brent crater are poorly exposed or inferred from the presence of fenitisation, the characteristic country-rock alteration of alkaline complexes. The cores of the complexes appear to be nepheline syenites and pyroxenites; however, they are cut by numerous cone sheets of lamprophyre, carbonatite and syenite. Some of the complexes show economic or subeconomic concentrations of Nb, U, rare-earth elements (REE) and Fe. K-Ar ages on whole-rock and biotite samples have a narrow range of values close to 560 Ma (Currie, 1976). Unroofing of these rocks must have occurred relatively soon after their emplacement as Ordovician sediments were deposited on many of the complexes.

The Onslow complex (5 km^2 in area) is situated near the Ottawa graben fault (Sabourin, 1965). Syenite and granite intrude the Precambrian shield as a central complex and as dykes. K-Ar measurements yielded confusing results; a wide dyke gave a whole rock age of 620 Ma whereas the central complex gave a biotite age of 883 Ma (Doig and Barton, 1968). Further measurements must be made before this intrusion can be placed in its proper context.

A circular alkaline complex at Ste. Honoré (30 km^2) on the edge of the Saguenay graben is almost completely concealed by Ordovician limestone. The complex consists of nepheline syenite, ferrodiorite and carbonatite, the latter of considerable economic importance. The carbonatite has a massive core enriched in REE and Th, surrounded by a foliated rim enriched in Nb (Vallée and Dubuc, 1970). The K-Ar age of the complex is 650 Ma, slightly older than other rocks described in this section. A second phase of carbonatite intrusion may be represented by nearby dykes dating at 560 Ma (Doig and Barton, 1968).

The Sept Iles complex is situated on the north shore of the St. Lawrence estuary at the junction of two graben faults. It is by far the largest post-orogenic intrusion in the Grenville Province (2,500 km^2 in area, based on the assumption that its boundaries are those of its magnetic and gravity anomalies). Anorthosite, gabbro, diorite, syenite, granite and Fe-Ti oxide rich rocks are exposed on the islands and the mainland as plutons and dykes, but most of the complex is concealed beneath the Gulf of the St. Lawrence. A large positive gravity anomaly suggests an overall mafic composition for the igneous complex. Detailed Rb-Sr studies have shown that both acidic and basic portions of the complex are co-temporal and have originated from isotopically similar sources in the lower crust or upper mantle (Higgins and Doig, 1981). Sept Iles is the only post-orogenic occurrence of anorthosite in the Grenville Province so far discovered, but the rock-types identified there are similar to those of other anorthosite bearing complexes.

A circular complex is located at Baie des Moutons (Mutton Bay) on the north shore of the Gulf of the St. Lawrence, some 500 km east of Sept Iles (450 km^2). It consists of multiple intrusions of differentiated pink and green syenite, cut by lamprophyre, trachyte, carbonatite and diabase dykes which extend into the country rocks (Davies, 1968; Lalonde and Martin, 1980). Biotites from the syenite and carbonatite yield K-Ar ages of 568 Ma. A wide anorthositic-gabbro dyke exposed nearby is of particular interest. Patches of syenite within the dyke appear to be residual liquids formed by differentiation, possibly combined with liquid immiscibility of the parent magma. Similar structures at Sept Iles have been used to obtain a Rb-Sr age from the anorthosite, and could be used in a similar way on other mafic plutonic rocks.

Dykes exposed on the shore of the Saguenay river at Chicoutimi have been dated at 564 Ma (Doig and Barton, 1968). Gittins *et al.* (1975) have shown that these rocks are transitional between kimberlite and carbonatite. Lamprophyre dykes exposed at Allik Bay in Labrador gave ages of 570 Ma (Leech *et al.*, 1963).

Diabase dykes at Lac Noire and Ste. Sophie give K-Ar ages of 560 and 520 Ma (Doig and Barton, 1968). Trachyandesite flows (K-Ar whole-rock age 573 Ma) and diabase dykes (K-Ar whole-rock age 503 Ma) are preserved in a small north-east trending graben near Buckingham (Lafleur and Hogarth, 1981).

Extensive Cambrian flood basalts and feeder dykes are exposed on each side of the Strait of Belle Isle. Cambrian basalts are now exposed in the Appalachian fold belt in Quebec (Tibbit Hill formation).

Ordovician-Silurian

The most important post-orogenic rocks of this age are the two sub-circular Chatham-Grenville (90 km^2) and Rigaud (30 km^2) stocks. They are situated on opposite sides of the Ottawa graben and consist of multiple intrusions of syenite and granite (Osborne, 1934; Higgins, 1981).

A few lamprophyre dykes are associated with the Chatham-Grenville stock, which is intruded into the Precambrian shield. The Rigaud is much less well exposed and intrudes the St. Lawrence lowlands. K-Ar measurements on whole-rocks and mineral separates gave ages of 450 Ma for both intrusions (Doig and Barton, 1968).

The Bon Conseil intrusion is located on the southeast side of the St. Lawrence lowlands, near Logan's line. It is a small, poorly exposed body of mica peridotite and pyroxenite. The latter contains irregular patches of syenite that differ from their host only in their modal abundances, not their mineralogy. Philpotts (1978) suggested that these rocks may have once been immiscible liquids. Rb-Sr data indicate that small alkali-granite dykes were intruded into the Sept Iles complex 485 Ma ago (Higgins and Doig, 1981).

Diabase dykes form an extensive swarm from Sudbury to Québec City. K-Ar and Rb-Sr data from these dykes commonly give Ordovician-Silurian ages, but some may be as old as 1400 Ma (Dankers and Lapointe, 1981). These dykes may have been feeders for a vast region of flood basalts, now removed by erosion.

Carboniferous

Carboniferous rocks are of very limited extent in the Grenville Province. Carbonatite dykes that cut limestone at Eastview, near Ottawa have been dated at 320 Ma, whereas mica peridotite dykes at Buckingham give K-Ar ages of 275 Ma (Doig, 1970).

Cretaceous

The Monteregian alkaline province forms the second post-orogenic surge of magmatism in the Grenville Province (total area 140 km^2). There are several good reviews of these rocks (e.g., Philpotts, 1974; Gold, 1967). Ten major plutons and many minor stocks, dykes, sills and diatremes have been intruded in a linear belt that extends from the Shield, through the St. Lawrence lowlands into the edge of the Appalachian region. Magnetic anomalies suggest that as many as seven plutons remain buried in the lowlands. A broad positive gravity anomaly underlies the belt, which is co-linear with the Ottawa graben.

All the major plutons appear to be cylindrical in shape. With the exception of Oka, they all contain at least 50% of a melanocratic component (mafic or ultramafic) that commonly shows concentric layering parallel to the margins of the intrusion. Most of the complexes contain a leucocratic component that is commonly intrusive into the melanocratic rocks. However, at Mt. Johnson this contact is gradational over a few metres. In the eastern part of the province the mafic rocks tend to be SiO_2-saturated, as are the associated syenites and granites. Further west SiO_2-undersaturated mafic rocks, such as essexites are associated with nepheline syenites. These relationships imply that the leucocratic and melanocratic components be derived from a common source at depth.

A number of unusual rock types are confined to the western end of the province. The Oka hills are one of the largest sources of niobium (Nb) in the world. The Oka complex consists of concentric shells that appear to have been emplaced from the outside inward. Rock-types include okaite (Ti-augite, melilite, magnetite), nepheline carbonatite and nepheline-Na-pyroxene rocks. The complex and the surrounding country rocks have been metasomatised and cut by lamprophyre dykes and diatremes (breccia pipes).

Diatremes are important elsewhere in the western part of the Monteregian province. The best known and one of the largest is exposed on Ile Ste. Hélène, near Montréal. Excavation for the Montréal subway showed that this diatreme passes downward into an igneous breccia with a gabbroic-lamprophyre matrix. At Ile Bizard, 20 km to the west, an eclogite bearing kimberlite pipe occurs within a large diatreme. Milling tests produced some small diamonds but these may have been from contamination by the crushing plant.

K-Ar data indicate a range of ages from 95 to 120 Ma. Limited Rb-Sr data indicate a similar range, but agreement between the two systems is poor. Initial Sr ratios are low and indicate an origin for the magmas in the lower crust or upper mantle (Gold, 1967). Eby (1980) has examined the trace-element abundances in a number of the Monteregian intrusions and concludes that although the basic rocks are mantle derived, the acidic rocks must contain a component of crustal origin.

Diabase dykes on Anticosti Island, dated at 178 Ma by K-Ar methods, are the only anorogenic Mesozoic rocks in the Grenville Province and adjacent St. Lawrence lowlands, away from the Monteregian region (Wanless *et al.*, 1971).

Undated Post-Orogenic Rocks

The Moise mica diorite is a circular intrusion east of Sept Iles (15 km²). Little is known of this body but its shape suggests that it is anorogenic (Greig, 1940).

Correlation with Magmatism Elsewhere

Doig (1970) has correlated Cambrian anorogenic rocks within the Grenville Province with alkaline rocks in Greenland and Scandinavia. Recent research has revealed further carbonatites and lamprophyres in west Greenland at Holsteinburg (K-Ar age 587 Ma, Smith, quoted in Scott, 1981), Sarfartoq and Qaqarssuk (fission-track age 500 Ma, Gleadow quoted in Secher and Larsen, 1980). Further isotopic work on the Alnö complex has confirmed its lower Cambrian age (Rb-Sr age 553 Ma, Brueckner and Rex, 1980). Several anorogenic plutons in Newfoundland may also be of this age, but ages obtained so far are unreliable (Bell *et al.*, 1977). Anorogenic granites on the east coast of Brazil are also contemporaneous, but may not be related to the same tectonic event (Sial *et al.*, 1981).

Middle Palaeozoic anorogenic rocks of eastern North America outside the Grenville Province are mostly confined to the northern Appalachian region and consist dominantly of peralkaline granites. They include: The Topsails complex (Newfoundland) which gives an Rb-Sr age of 419 Ma, the Quincy, Cape Ann and Peabody intrusions (Massachusetts) which gives ages by various methods in the range 450 ± 25 Ma, and granites from the Gulf of Maine (422 Ma, all references in Taylor, 1979). Taylor (1979) has also correlated these rocks with peralkaline rocks of similar age in Niger and Nigeria. Bell *et al.*, (1979) have reported a Rb-Sr scatterchron of Middle Palaeozoic age for the Heckla-Kilmer alkalic suite in northern Ontario.

Two peralkaline granites from Newfoundland, the Seal Island Bight and St. Lawrence intrusions, are both 315 Ma old, and are contemporaneous with the Eastview carbonatite dyke. Taylor (1979) has also correlated these rocks with granitic complexes in Niger.

The northward extension of the Monteregian Province into the Superior Province is represented by dykes at Coral Rapids that give a K-Ar age of 128 Ma (Wanless, 1973). Small alkaline ultrabasic intrusions and associated lamprophyre dykes in central Newfoundland give K-Ar ages that range from 115 to 144 Ma (Strong and Harris, 1974; Helwig *et al.*, 1974). To the south, contemporaneous magmatism occurs extensively in New Hampshire and Maine (White Mountains Province), the western Appalachian region (New York and Virginia), the 38th parallel lineament and the Gulf coast region (Zartman, 1977). Lamprophyre and carbonatite dykes from southwest Greenland are slightly older than the Monteregian rocks (151 to 116 Ma) but may be part of the same province (Hansen, 1980).

Tectonic Significance of Anorogenic Magmatism

Three main theories have been proposed, either explicitly or implicitly, to account for the production of anorogenic magmas.

1) Anorogenic magmas are produced in some unknown way during the waning of the preceding orogenic cycle, following about 100 to 150 Ma after the peak of orogeny.

2) A stationary hot-spot in the mantle beneath a continent causes doming and faulting. Magmas produced by the higher geothermal gradient are channelled up these faults.

3) Large-scale stresses in the crust, produced by distant tectonic forces, reopen lines of weakness. Magmas produced in the mantle by reduction of pressure are channelled up these lines of weakness.

There is evidence in the Grenville Province to support all three theories.

The first theory may be illustrated by the Precambrian anorogenic rocks of the Grenville Province. These rocks were formed about 100 to 150 Ma after the peak of the Grenville orogeny and are considered by many authors to be a late phase of that orogeny. However, Fowler (1980) has attributed these rocks to an early precursor of the St. Lawrence rift system on the basis of the close association between late Grenville uraniferous granites, alkaline rocks and the rift faults. Early movement of some of these faults is suggested by the occurrence of a pseudo-tachylite (glassy rock produced by fault movement), dated by K-Ar at 975 ± 45 Ma (Philpotts and Miller, 1963).

The earliest descriptions of the St. Lawrence rift system considered it to be the result of crustal doming in late Precambrian time that has now subsided (Kumarapeli and Saull, 1966). Similarly Taylor (1979) suggested that the spate of anorogenic activity in the Middle Palaeozoic represented a time when plate motion was minimal and hot-spots had time to punch through the continental plate. However, it seems unlikely that hot spot activity would occur in the same areas repeatedly over Phanaerozoic time, as indicated by the wide age range of anorogenic rocks in this area. In addition the St. Lawrence valley does not resemble a typical rift as it is bounded by faults only to the north for much of its length. Perhaps this fault becomes less steep with depth, analogous to the listric faults with rotational motion that are thought to occur in more recent continental margins. Perhaps a composite of theories two and three best explains the data. In this scheme the Ottawa and Saguenay grabens would result from doming over hot spots while the St. Lawrence valley would result from the opening of the lapetus (Proto-Atlantic) ocean. Stresses induced by this tectonic event could have induced the widespread anorogenic magmatism in Greenland, Scandinavia and possibly elsewhere in the world by tapping magmas already present at depth. Similarly regional stress fields set up by the closure of the lapetus ocean may have reactivated rift faults and led to the widespread Middle Palaeozoic magmatism.

Mesozoic dykes from southwest Greenland are believed to be associated with the opening of the Labrador sea (Hansen, 1980). Although the Monteregian activity just post-dates these rocks, the first ocean floor was not generated in the Labrador sea area until 75 Ma ago, after the end of the Monteregian activity. Hence it is possible that distant tectonic forces may have opened up a line of crustal weakness through which the Monteregian magmas flowed.

Conclusions

The Grenville Province shows abundant evidence of magmatic activity since the end of the Grenville orogeny. Some Precambrian anorogenic magmatism may be related to the preceding orogeny, as has been suggested by Zartman (1977) for areas further south. However, it is also possible that this activity represents the earliest phase of rifting in this area. The ancestral St. Lawrence rift system may have formed in the early Cambrian by crustal doming over mantle hot-spots. However, most Phanerozoic activity appears to be related to large-scale stresses set up during the opening and closing of the lapetus (proto-Atlantic) ocean and opening of the Atlantic ocean and Labrador sea. The distribution of magmatic activity along faults and the lack of magmatism on many post-orogenic faults reflects the depth of faulting and weakening, and the availability of magma in the source region. The latter is controlled by the temperature and composition of the upper mantle, whereas the former reflects the orientation and duration of tectonic stresses.

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