MONTEREGIAN ALKALIC MAGMATISM AND THE ST. LAWRENCE RIFT SYSTEM IN SPACE AND TIME

P.S. KUMARAPELI

Department of Geological Sciences
McGill University, Montreal, Quebec

ABSTRACT

Monteregian igneous bodies are largely concentrated in an approximately east-southeast trending zone that extends across the southern part of the St. Lawrence valley. The St. Lawrence valley is essentially a graben, and forms part of the St. Lawrence rift system. The Beauharnois axis that marks the south end of the St. Lawrence valley is a transverse "arch", which may have formed as a direct result of structural subsidence along the St. Lawrence valley. On the north flank of the Beauharnois axis are a number of normal faults along which the axis has apparently undergone relative uplift. Intersections of these faults with meridional faults of the graben structure may have produced openings for the ascent of Monteregian magmas. The Monteregian alkalic magmatism is probably synchronous with the latest phase of major tectonic movements along the St. Lawrence rift system.

INTRODUCTION

The products of Monteregian magmatism are what some workers refer to as alkalic rocks of the platform type (Borodin 1957; Zhabin 1959). This type of alkalic rock commonly occurs in readily definable petrographic provinces and these alkalic provinces are commonly closely associated in space with zones of major faulting (McCall 1959; King & Sutherland 1960; Ginzburg 1962; Bailey 1961, 1964), especially those related to large grabens in continents. Such a close association is quite evident in East Africa (Kent 1944; McCall 1959; King & Sutherland 1960; Bailey 1961, 1964). In the East African rift system large sections of the chains of grabens are free from products of alkalic magmatism, but with few exceptions most of the alkalic centers and lava fields are spatially related to graben structures. Notable concentrations of magmatic activity characterise bifurcations of grabens. Often, chains of intrusive centers occur roughly perpendicular to grabens. Similar spatial relations occur on a worldwide scale (Heinrich 1966, p. 25). In addition to the spatial association there also seems to be a broad temporal relationship between phases of activity of faults and episodes of alkalic magmatism. Some of the igneous activity may be related to the initial fault formation and others to phases of rejuvenation of fractures.

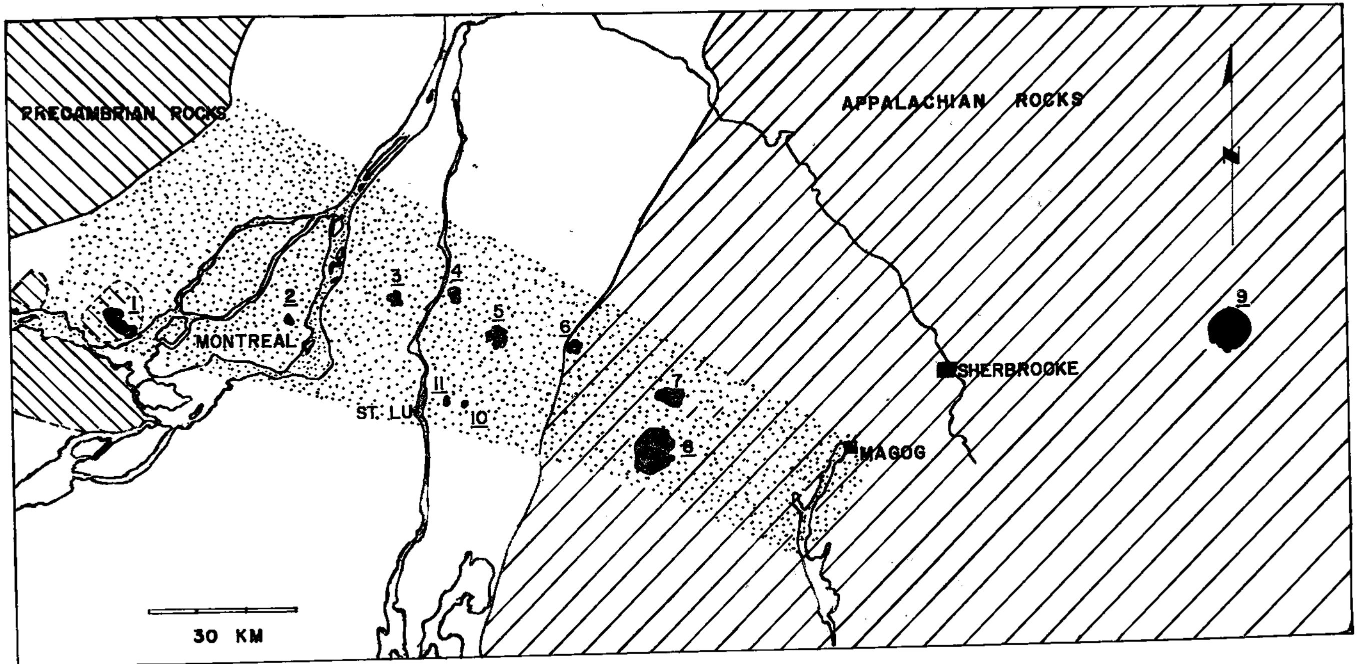

FIG. 1. Map showing the area (stippled) of the largest concentration of Monteregian igneous bodies. The main intrusive centers are (1) Oka, (2) Mount Royal, (3) St-Bruno, (4) St-Hilaire, (5) Rougemont, (6) Yamaska, (7) Shefford, (8) Brome, (9) Mount Megantic, (10) Mount Johnson, (11) Grand Bois.

MONTEREGIAN ALKALIC MAGMATISM

The products of Monteregian alkalic magmatism occur mainly in an approximately east-southeast trending zone that extends across the south end of the St. Lawrence valley and some distance into the Appalachian fold belt (Fig. 1). This zone may be regarded as the Monteregian province "proper" (Hodgson 1968, p. 3), although some probable co-magmatic rocks occur outside it (Gold 1968, p. 290).

Nine main centers of intrusion are exposed. A tenth is only slightly exposed (Kumarapeli *et al* 1968, p. 552) at the present level of erosion. These centers are represented by small stocks and ring complexes. Related dikes, sills and small plugs intrude the zone intensively.

Monteregian rocks vary widely chemically as well as mineralogically. In the main plutons, for instance, the initial phase is ultrabasic or basic and later phases are more silicic. At one extreme are peridotites, pyroxenites and titanaugite gabbros and at the other extreme are strongly alkaline syenitic rocks, the two being linked through normal gabbro and essexite, monzonite and syenodiorite (Gold 1968, p. 290). The above variations seem to reflect trends of magmatic differentiation, probably in local magma chambers.

Monteregian rocks also show variations of a regional character. For instance, westward along the province there is a progressive decrease in SiO_2 and a progressive increase in K_2O/Na_2O. The westernmost pluton, the Oka complex, is largely made up of carbonatite and other extremely undesaturated rock types. The part of the province west of Montreal Island contains ultrabasic potassic rocks such as alnöite and kimberlite. This part of the province is also characterised by numerous diatreme breccia pipes, probably representing a gas-rich pipe drilling phase. A probable explanation of the westward variations of Monteregian rocks is that, in this direction, magmas were derived from increasingly greater depths within the upper mantle (Hodgson 1968, p. 131).

The isotopic ages of Monteregian rocks vary from about 90 m.y. to about 150 m.y. (Gold 1968) indicating that the magmatic event took place in the Mesozoic.

ST. LAWRENCE RIFT SYSTEM

Figure 2 shows the grabens of the St. Lawrence rift system (Kumarapeli & Saull 1966). Fault zones that outline individual grabens of the system are well documented except those along the St. Lawrence Trough, which for the most part is under water. The geomorphic expression of

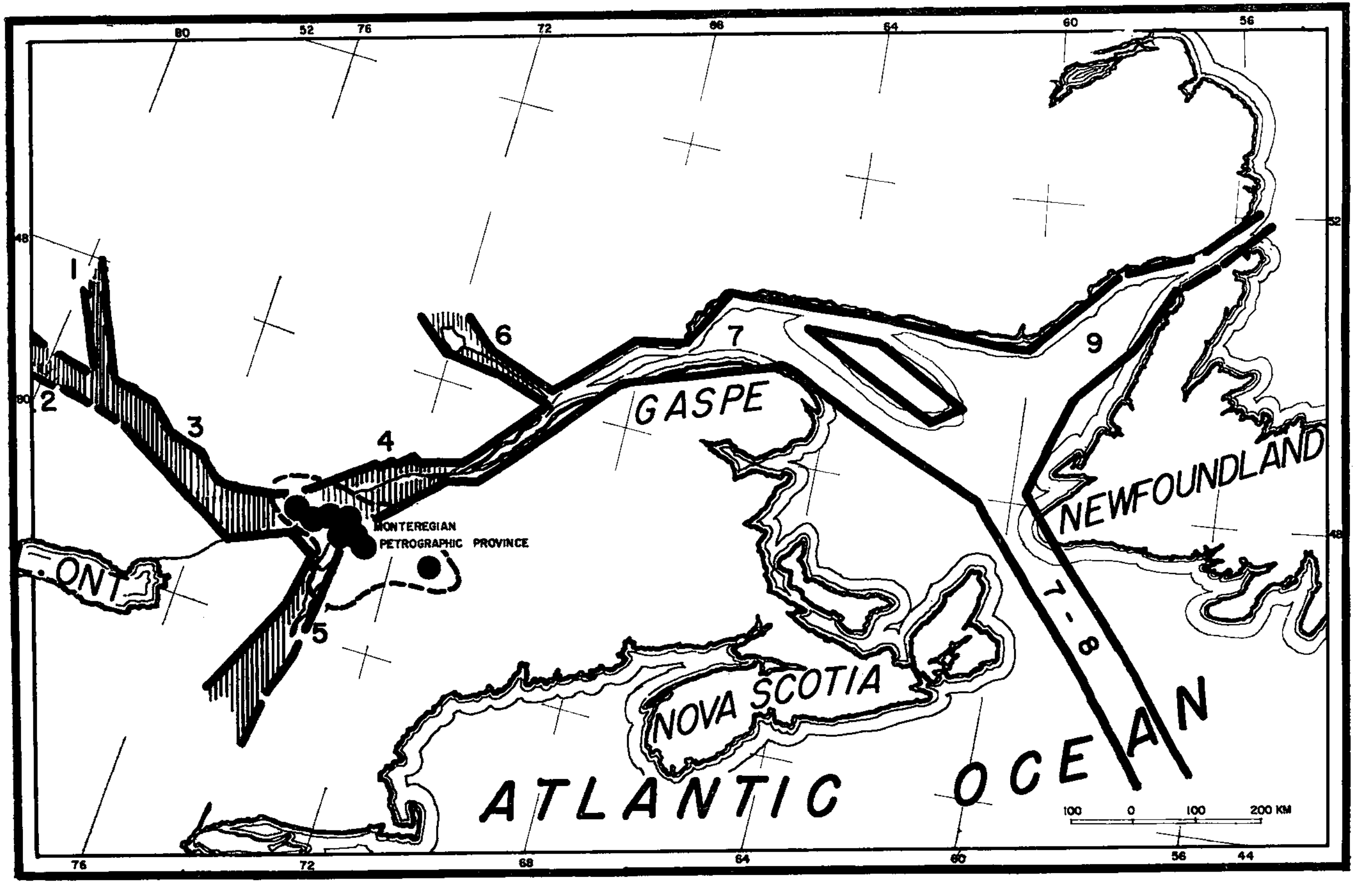

FIG. 2. Sketch map showing the St. Lawrence Rift System. (1) Timiskaming graben, (2) Nipissing graben, (3) Ottawa graben, (4) St. Lawrence graben, (5) Champlain graben, (6) Saguenay graben, (7) St. Lawrence Trough, (8) Laurentian Channel, (9) Belle Isle Trough.

these grabens consist of a group of linear depressions. They are the Temiskaming and Nipissing depressions, the St. Lawrence and Champlain valley, the Saguenay-Lac St. Jean depression, the St. Lawrence and Belle Isle Troughs. The grabens that extend along the Champlain valley and through the St. Lawrence valley, the St. Lawrence Trough (excluding the Laurentian Channel) and the Belle Isle Trough lie along the boundary between the Canadian shield and the Appalachian fold belt, as though these graben structures had something to do with the transition from the shield to the fold belt. The tectonic setting of this part of the rift system is similar to that of the Baikal rift system which extends along the boundary between the Siberian platform and the Caledonide belts of Transbaikalian folding. Two branches of the St. Lawrence rift system, however, transgress structural elements of the Canadian shield, and in this respect, display the cross-structure habit of the East African rifts. The Saguenay graben, for instance, extends for about 250 km across the Grenville structural province. The Ottawa graben also extends across the Grenville Province for about 400 km and then it branches into Nipissing and Temiskaming grabens. The Temiskaming graben extends across the Grenville-Superior boundary and continues for some distance into the Superior Province. The branch of the rift system that is believed to underlie the Laurentian Channel extends across the Appalachian fold belt.

In many respects, the geological and geophysical characteristics of the St. Lawrence rift system are similar to those of the East African rift system, but there are some notable differences. The fault troughs of the St. Lawrence rift system are shallow compared with those of the East African rifts which are supposed to be as much as 6 km deep (Dixey 1956) ; consequently the morphology of the former is less pronounced. Volcanic activity is not known to be associated with the grabens of the St. Lawrence rift system nor do the fault troughs contain large quantities of Tertiary and Quaternary sediments. Furthermore, the present activity of the St. Lawrence rift system appears to be restricted to mild seismicity.

The St. Lawrence rift system seems to have originated sometime in the Precambrian. Glassy pseudotachylite from one of the marginal faults of the rift system has given a K/Ar age of about 900 m.y. (Philpotts & Miller 1963, p. 337). The products of the earliest known alkalic magmatism associated with the rift system date around 600 m.y. (Doig & Barton, Jr. 1968, p. 1401). The youngest known igneous event associated with it took place in the Mesozoic. The products of the latest igneous event include the Monteregian alkalic rocks (including Monteregian rocks in the eastward extension of the province to Mt. Megantic, and alkalic dikes and sills of the Champlain valley region), kimberlite dikes at the

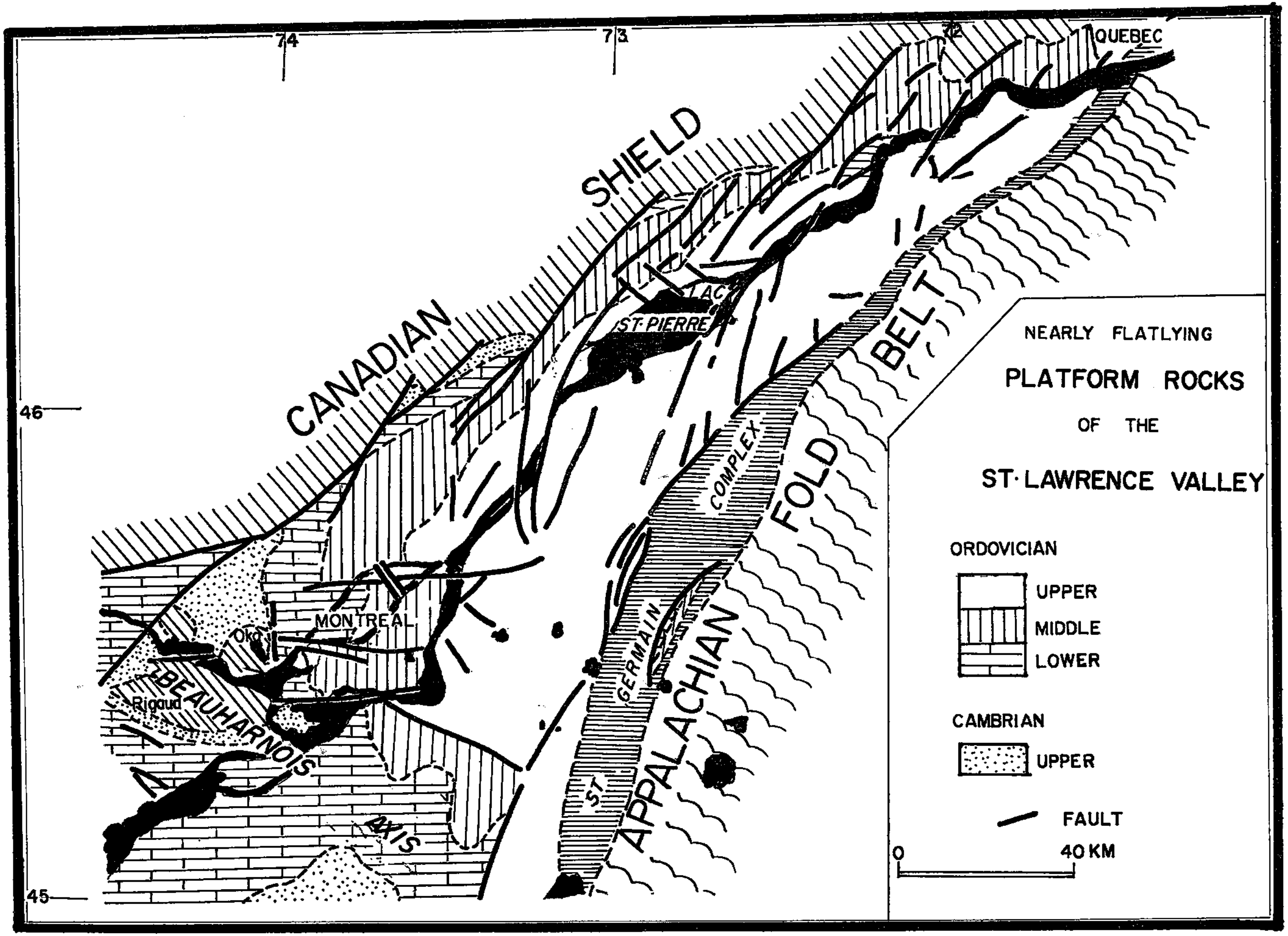

FIG. 3. Generalized geological map of the St. Lawrence valley (slightly modified after Roliff 1967).

north end of the Temiskaming graben (Lee & Lawrence 1968, p. 1), lamprophyre dikes in northeastern Newfoundland (Heyl 1936; Wanless *et al* 1967, p. 114), and probably also alkaline dikes along the west margin of the Belle Isle Trough (Gerencher & Gold 1968, p. 28). The Pb (Zn)—Ag—barite (fluorite, calcite) veins in the marble belt of southern Grenville Province seem to be related to Mesozoic movementts along the Ottawa graben (Sangster 1969, p. 45; also see Kuellmer *et al.* 1966). Near Madoc area, Ontario, some of the fluorite—calcite—barite veins cut Lower Paleozoic rocks and are definitely post-Middle Ordovician in age (Hewitt 1964, p. 12).

Space Relations

Although some of the Monteregian rocks intrude parts of the Appalachian fold belt and the Champlain valley region, the greatest concentration of these rocks occur in the southern part of the St. Lawrence valley. The main intrusive centers are aligned more or less perpendicular to the valley.

The St. Lawrence valley is a tectonic depression related to the St. Lawrence rift system (Fig. 2). Structural subsidence along this depression has largely been achieved by movements along a system of normal faults that is approximately parallel to the valley (Fig. 3). Subsidence has not taken place *en bloc*, but rather in strips. From the south end of the valley, at least as far as Lac St. Pierre, the subsided block is outlined on both sides by inward dipping normal faults and the structure of this part is that of a graben. North east of Lac St. Pierre the structure seems to be essentially the same, except that faults are not known to outline the subsided block on the east side. On this side, structural subsidence has been achieved presumably by down-flexing. The overall structure along the valley can be referred to as the St. Lawrence graben.

Structural subsidence along the St. Lawrence graben is not uniform, the greatest sinking being in the area just southwest of Lac St. Pierre. North eastward as well as southwestward from the area of greatest subsidence, the basement of the graben block rises progressively. The southwestward rise of the basement culminates in an arch-like structure — the Beauharnois axis — that extends across the south end of the St. Lawrence graben. The northeastward rise of basement also seems to culminate in a transverse "arch" in the vicinity of Quebec City (see Osborne 1956, p. 168).

Thus in a longitudinal direction the subsided block seems to have a curved cross-section. This shape has been achieved, at least in part, by

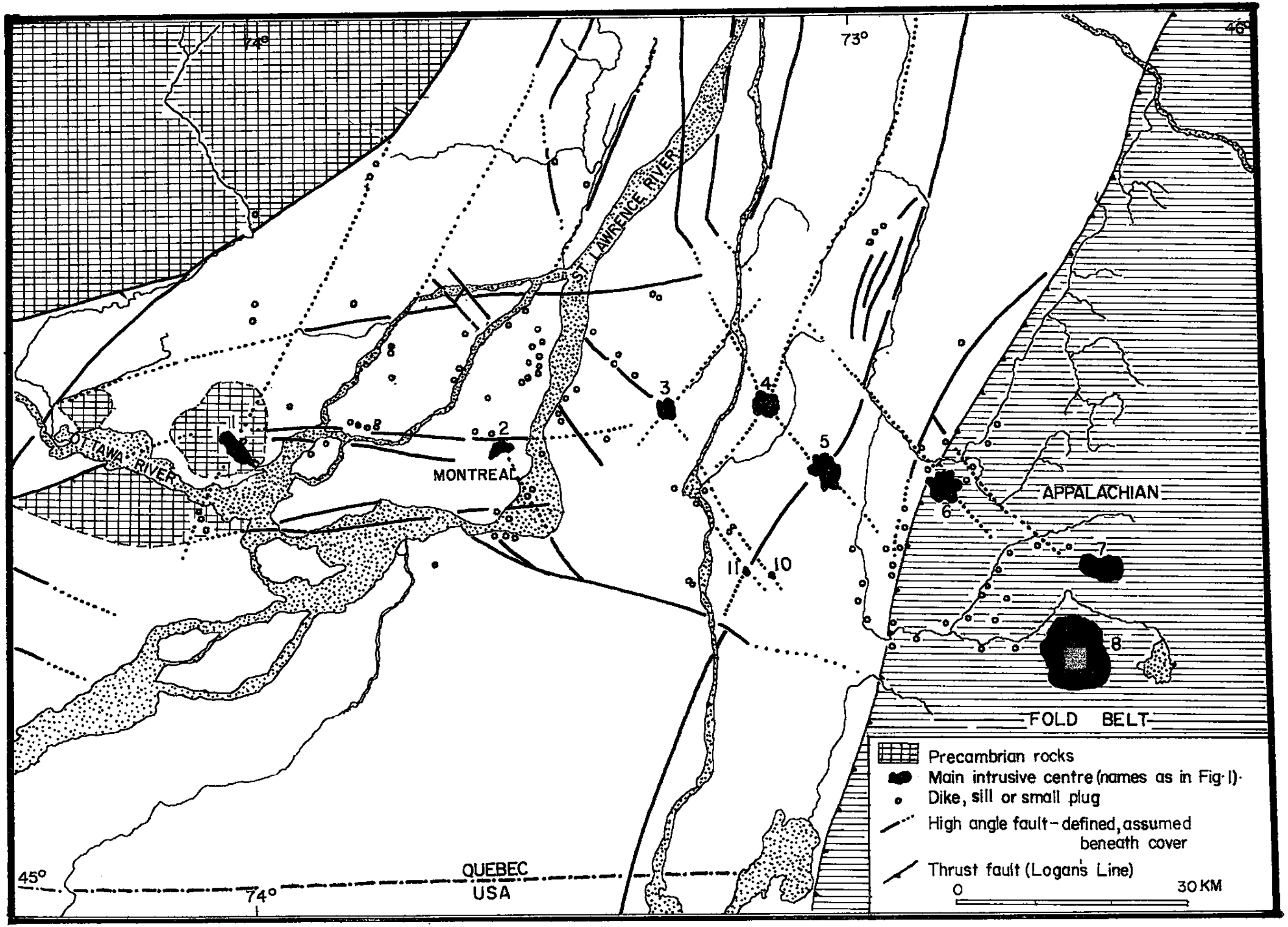

FIG. 4. Map of the southern part of the St. Lawrence valley, showing probable fault pattern and the distribution of Monteregian rocks.

movements along transverse faults. Such faults are known to occur on the north flank of the Beauharnois axis and in the vicinity of Lac St. Pierre. In the East African rift zones too, transverse "arches", separating down-warped blocks seem to characterise long stretches of down-faulting (Holmes 1964, p. 1065). This is probably why a long rift valley such as the Western Rift Valley in East Africa, is occupied by a chain of lakes (lakes Albert, Edward, Kivu and Tanganyika) instead of one long lake.

Holmes (1964, p. 1065) has pointed out that the formation of transverse "arches", in long zones of down-faulting is dictated by the spherical shape of the earth. The top of a long narrow strip of the earth's crust represented by a chain of graben blocks has the shape of an arc of a circle prior to structural subsidence. With subsidence, such a strip would settle towards the corresponding chord. But as the chord is shorter than the arc, the strip may buckle into a wave-like form, the wave-crests forming the transverse arches. It is likely that the Beauharnois axis is a transverse "arch" of similar origin, related to structural subsidence along the St. Lawrence valley. Along the axis, blocks of the basement rise as block mountains (Rigaud, Oka) and stand over 100 m above the general level of the valley, The structure and tectonic setting of these blocks are very similar to those of a horst block such as Ruwenzori. The mountains, along the Beauharnois axis, however, are dwarfed by the immensity of the Ruwenzori massif.

The faults on the north flank of the Beauharnois axis are broadly parallel to the axis. Their downthrow is almost always to the north indicating that along these faults the Beauharnois axis has undergone relative uplift. These transverse faults and the meridional faults of the St. Lawrence graben constitute two sets of intersecting normal faults and thus the north flank of the Beauharnois axis is intensely block-faulted. This area of block-faulting has been the site of much of the Monteregian igneous activity. The main intrusive centers are probably located at the locii of intersections of major faults (Fig. 4). The transverse fault system associated with the Beauharnois axis seems to continue for some distance into the Appalachian fold belt, as evidenced by the presence of some of the main intrusive centers there.

As stated earlier, the regional variations of Monteregian rocks, may be the result of derivation of magmas from progressively deeper levels in the upper mantle westward. If this hypothesis is correct, then the related tectonic movements also may have been more intense westward, involving progressively deeper levels of the upper mantle. This may, in fact, be the actual case, for horst-blocks that have undergone large vertical movements are restricted to the westernmost part of the province.

Time Relations

As mentioned earlier, the initial fault formation along the St. Lawrence rift system began sometime in the Precambrian. The tectonic movements responsible for most of the features of the rift system as we see them today, seem to have taken place in post-Ordovician time. Unfortunately, it has not been possible to bracket the age of these movements more closely by direct methods. A reasonable conclusion is that the post-Ordovician tectonic activity along the St. Lawrence rift system and the Monteregian alkalic magmatism are broadly synchronous.

Conclusions

The products of the Monteregian alkalic magmatism are closely associated in space with the St. Lawrence rift system. By far, the greatest concentration of igneous activity seems to be related to block faulting attendant with the uplift of a transverse arch at the south end of the St. Lawrence graben. Temporally, the Monteregian magmatic event is probably synchronous with the latest phase of major tectonic movements along the rift system.

References

Bailey, D.K. (1961) : The mid-Zambesi-Luangwa rift and related carbonatite activity. *Geol. Mag.*, **98**, 277-284.

——— (1964) : Crustal warping — a possible tectonic control of alkaline, magmatism. *J. Geophys. Res.* **69**, 1103-1111.

Borodin, L.D. (1957) : Types of carbonatite deposits and their connection with ultrabasic-alkalic rock complexes. *Izv. Akad. Nauk SSSR, Ser. Geol.*, **(5)**, 3-16.

Dixey, R. (1956) : The East African rift system. *Colonial Geol. Mineral Res. Bull. suppl.* **1**.

Doig, R. & Barton, J.M., Jr (1968) : Ages of carbonatites and other alkaline rocks in Quebec. *Can. J. Earth Sci.* **5**, 1401-1407.

Gerencher, J.J. & Gold, D.P. (1968) : The significance of some dike swarms along the north shore of the Gulf of St. Lawrence in Eastern Quebec (Abstr.) *Geol. Soc. Amer. Progr. annual meeting* 1968.

Ginzburg, A.I. ed. (1962) : *Geology of rare element deposits*, 17. Geological structure and mineralogical characteristics of rare-metal carbonatites. Gosgeoltalhizat, Moscow.

Gold, D.P. (1968) : Alkaline ultrabasic rocks in the Montreal area, Quebec. In *Ultramafic and related rocks* (P.J. Wyllie, Editor). Wiley and Sons, New York, pp. 288-302.

Heinrich, E. Wm. (1966) : *The geology of carbonatites*, Rand McNally, Chicago.

Hewitt, D.F. (1964) : Precambrian-Paleozoic contact relationships in Eastern Ontario. In *APPG and Soc. Econ. Paleontologists and mineralogists guide book on the geology of Central Ontario.*

Heyl, G.R. (1936) : Geology and mineral deposits of the Bay of Exploits area. *Princeton Univ. contributions to the geology of Newfoundland*, No. 12.

HODGSON, C.J. (1968) : Monteregian dike rocks. *Unpub. Ph.D. thesis, McGill University, Montreal, Que.*

HOLMES, A. (1964) : *Principles of physical geology,* Nelson, London.

KENT, B.C. & SUTHERLAND, D.S. (1969) : Alkaline rocks of eastern and southern Africa, Part I. Distribution, ages and structures. *Sci. Progr.,* **44**, 298-321.

KUELLMER, F.J., VISOCKY, A.P. & TUTTLE, O.F. (1966) : Preliminary survey of the system barite-calcite — fluorite at 500 bars. In *Carbonatites* (editors O.F. Tuttle and J. Gittins), Interscience Publishers, 353-364.

KUMARAPELI, P.S. & SAULL, V.A. (1966) : The St. Lawrence Valley System : A North American equivalent of the East African rift valley system. *Can. J. Earth Sci.,* **3**, 639-658.

KUMARAPELI, P.S., COATES, M.E. & GRAY, N.H. (1968) : The Grand Bois anomaly : the magnetic expression of another Monteregian pluton. *Can. J. Earth Sci.,* **5**, 550-553.

LEE, H.A. & LAWRENCE, D.E. (1968) : A new occurrence of kimberlite in Gauthier township, Ontario. *Geol. Surv. Can., paper* **68-22**.

MCCALL, G.J.H. (1959) : Alkaline and carbonatite ring complexes in Kavirondo rift valley, Kenya. *Intern. Geol. Cong. 20th sess. Assoc. Serv. Geol. Africanos,* 328-334.

OSBORNE, F. FITZ. (1956) : Geology near Quebec city. *Naturaliste Canadien* **83**, 157-224.

PHILPOTTS, A.R. & MILLER, J.A. (1963) : A Precambrian glass from St-Alexis-des-Monts, Quebec. *Geol. Mag.* **100**, 337-344.

ROLIFF, W.A. (1967) : A stratigraphic analysis of the subsurface data relating to the Chazy Group in the St. Lawrence Lowland of Eastern Canada. *Can. J. Earth Sci.,* **4**, 579-595.

SANGSTER, D.F. (1969) : Metallogenesis of some Canadian lead-zinc deposits in carbonate rocks. (Abstr.) *Joint annual meeting Geol. Assoc. Canada, Mineral Assoc. Canada. Gen. progr. and Abstr.*

WANLESS, R.K., STEVENS, R.D., LACHANCE, G.R. & EDMONDS, C.M. (1967) : *Geol. Surv. Can. Paper* **66-17**.

ZHABIN, A.G. (1959) : On a new type of carbonatite manifestations associated with alkalic complex of Vishnevy-Ilmen Mountains in the Urals. *Dokl. Adad. Nauk SSSR, Earth Sci. Sect.,* **128**, 932-933.