ABSTRACT

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OR APPLATION EVOLUTION

EELTED METATOCA AND PLATE TECTONIC MODELS

THE ST. LAWRENCE RIFT SYSTEM.
d'âge Mésozoïque Moyen, résultant des forces de tension associées à l'ouverture de l'océan Atlantique actuel.

Le système de fractures du Saint-Laurent semble avoir agi comme métallotecte pour certains dépôts minéralisés du cortège des carbonalites. On peut distinguer deux périodes de déposition de minéraux, l'une au Cambrien Inférieur et l'autre au Mésozoïque Moyen. Les dépôts de minerais connus sont ceux de niobium, se présentant sous forme de disseminations de pyrochlore dans les roches-hôtes de carbonatite.

INTRODUCTION

The concept of a St. Lawrence rift system extending along the Ottawa and Champlain Valleys and thence through the St. Lawrence Valley and the Laurentian and Esquiman Channels was first proposed by Kumarapeli and Saull in 1966 (Fig. 1). For convenience, that part of the rift system west of the confluence of the Saguenay and St. Lawrence Rivers will hereafter be referred to as the western half and the remainder as the eastern half. The general area in which the St. Lawrence rift system is located, will be referred to as the St. Lawrence Region.

Although earlier workers have postulated graben structures along parts of the rift system (Wilson, 1903; Kindel and Burling, 1915; Kay, 1942), the key to Kumarapeli and Saull’s synthesis (1966) was the recognition of the fact that the normal fault systems along the Champlain and Ottawa Valleys combine to form a single fault system extending along the St. Lawrence Valley (Fig. 2). Accordingly, it was possible to group the Ottawa and Saguenay grabens and the graben-like structures along the Champlain and St. Lawrence Valleys into a branching rift system which, together with rifts postulated through Lake Nipissing (Nipissing graben) and Lake Timiskaming (Timiskaming graben), made up the western half of the St. Lawrence rift system.

There are four considerations which favoured the hypothesis that the rift system continued downrider beyond the confluence of the Saguenay and St. Lawrence Rivers: i) the Saguenay graben faults and the St. Lawrence Valley faults appear to meet at an acute angle, pointing in the direction of the Laurentian Channel, indicating that these two structures of regional extent continue downrider; ii) the topographic low which overlies the rift zone along the St. Lawrence Valley continues downrider as the Laurentian Channel; iii) the branching pattern of the rift system at the southern end of the St. Lawrence Valley resembles the branching pattern at the end of the Rhine or the Eritrean grabens. In these latter grabens, however, a bifurcation occurs at each end. Just downrider from Anticosti Island the Laurentian Channel does divide into two branches which are the outer part of the Laurentian Channel and the Esquiman Channel. If branch rifts are assumed along the two branch channels, the symmetry considerations of a large rift system are satisfied, i.e. it will have a trunk rift with a bifurcation at each end; iv) a rift along the outer part of the Laurentian Channel, first proposed by Gregory in 1929, has subsequently been corroborated by Press and Beckman (1954) based on interpretation of the results of a seismic refraction survey. In view of the above considerations, the hypothetical rift system was extended downrider along the inner part of the Laurentian Channel and branches were postulated along the outer part of the Laurentian Channel and along the Esquiman Channel. The main aim of this paper is to consider the relationships between tectonic activity along the St. Lawrence rift.
system and the formation of certain mineral deposits which are closely associated in space with the rifts. Before going on to this, the writer considers it necessary to present to the reader an updated view of the rift concept by discussing: (a) how the rift concept has fared during the last eight years, (b) the age of the St. Lawrence rift system, and (c) whether the St. Lawrence system and the Appalachian fold belt are in any way related, and if they are, to develop a model for the origin of the St. Lawrence rift system within the framework of models of Appalachian evolution.

AN APPRAISAL OF THE RIFT CONCEPT

During the past eight years, the concept of a St. Lawrence rift system as proposed by Kumarapeli and Saull (1966) has received some support. It also has been the target of severe criticism. In view of some of the criticisms, certain modifications of the original concept appear necessary.

Criticisms of the rift concept

One aspect of the rift concept that has come under criticism is the idea of a presently active St. Lawrence rift system (Voight, 1969). Based on results of in situ stress measurements, Voight concluded that the St. Lawrence region is not, today, an active extensional feature as suggested by Kumarapeli and Saull (1966); instead he proposed that it is an area of high horizontal compressive stress. Voight's criticism appears to be valid; in fact, the concept of an inactive St. Lawrence rift system is more in keeping with the relatively subdued morphotectonic expression of the rifts and the lack of recent volcanism in the St. Lawrence Region. The mild seismicity in the St. Lawrence Region can be interpreted as a result of the release of compressional stresses on some of the faults of the rift system.

The other aspect of the rift concept that has come under criticism is the postulation of branch rifts along the Esquiman Channel and along the outer part of the Laurentian Channel (Sheridan and Drake, 1968; King and MacLean, 1970; Keen, 1969, 1970; Hobson and Overton, 1973; Shearer, 1973). The criticisms are based on interpretations of geophysical (seismic refraction and reflection, gravity and magnetic) data. In the results of geophysical work published to date, however, there is nothing to contradict the idea of a rift structure (such as the one that underlies Champlain-St. Lawrence Valleys) extending along the Esquiman Channel and through the Strait of Belle Isle, nor is it clear whether there is anything in the geophysical evidence that is incompatible with the hypothesis of an ancient fracture zone (e.g. a pre-Appalachian rift structure preserved in a relic form) along the outer part of the Laurentian Channel (Kumarapeli, 1974). In fact, the results of gravity surveys over the outer part of the Laurentian Channel support the concept of a deep structure along the Channel (Stephens et al., 1971). Moreover such a concept is attractive in the context of the regional tectonic picture: an ancient fracture zone along the outer part of the Laurentian Channel may have been the determinant of the continental margin offset in the Grand Banks area and the Newfoundland Fracture Zone (Auzende et al., 1970; Le Pichon and Fox, 1971).

Perhaps a great deal of confusion regarding the existence of the eastern half of the rift system has arisen from the analogy that Kumarapeli and Saull (1966)

Figure 2. Fracture pattern experimentally produced by swelling an oval-shaped hot water bottle coated with moist clay (upper diagram) compared with the fault pattern in the western part of the St. Lawrence Rift system.

Source: Cloos, 1939.
Support for the rift concept

The presence of western half of the rift system, parts of which were relatively well-known at the time the rift concept was advanced, has received additional support from the work of Lovell and Caine (1970) in the Lake Timiskaming area, and of Lunmers (1971) in the Lake Nipissing area. Their work indicates the existence of rifts in these areas as hypothesized by Kumarapeli and Saull (1966). The eastern half of the rift system, the existence of which was originally inferred mainly on circumstantial evidence, has also received more geological support. For instance, when Twenhofel (1928) mapped Anticosti Island in the 1920s, he noted only a few faults of minor displacement on the island. But seismic reflection work on the island in 1960s (Roliff, 1968), has revealed the presence of high-angle faults of a magnitude previously quite unsuspected. Furthermore, the work of Cumming (1967, 1972) in the Strait of Belle Isle area, gives additional support to the concept of a rift through the Esquiman Channel as suggested by Kumarapeli and Saull (1966).

The possible use of the St. Lawrence rift system as a regional guide in exploration for niobium-bearing carbonatites and diamond-bearing kimberlite pipes was suggested by Kumarapeli and Saull (1966). The subsequent discovery of two economic deposits of Nb-bearing carbonatite (Vallée and Dubuc, 1970; Gleeson and Cormier, 1971) in widely separated parts of the rift system, adds weight to the rift concept. This concept has been used successfully to explain the recurrent alkaline-carbonatite magmatism (Currie, 1970; Doig, 1970) and the presence of certain explosion craters (Currie, 1971, 1972) in the St. Lawrence region. An alkali magmatic event dated (K-Ar) around 565 m.y. has its products in widely separated areas (Lake Nipissing, Lac St. Jean and Baie-des-Monts on the northwest margin of the rift zone through the Esquiman Channel) of the rift system (Doig, 1970) suggesting the tectonic unity of the rift system. Furthermore, the rift concept has been used to rationalize the distribution of certain mineral deposits (Sangster, 1970; Kuitunen, 1972) in the St. Lawrence region. In view of the above considerations the writer contends that the concept of a St. Lawrence rift system, modified as suggested earlier, merits further consideration as a working hypothesis. Better known western half alone is about 1100 km long, i.e. about three times the length of the Rhine Graben.

AGE OF THE ST. LAWRENCE RIFT SYSTEM

In many parts of the rift system, the rift faults clearly cut and displace Paleozoic strata, but in no part of the system has it been possible to bracket closely the ages of the fault movements by direct methods. Magmatic events, however, (including the Montaregian magmatic event, Gold, 1968), whose products range in age from 90 to 150 m.y. occurred in widely separated parts of the rift system (Currie, 1970; Doig, 1970). It is entirely likely that the emplacement of these igneous rocks and the greater part of the faulting that displaces the Paleozoic strata may have been mutually connected events (Kumarapeli, 1970). A mid-Mesozoic phase of movements, therefore, may have been largely responsible for the present form of the rift system.

In places, there are indications that the faults cutting the Paleozoic strata have been superimposed on older faults, also of tensional origin. The following are the main lines of evidence for the earlier rifting: i) the occurrence of a regional dyke swarm — the Grenville dyke swarm — of possible Hadrynian age (Fahrig, 1970; Murthy, 1971), in close association with a 650 km segment of the rift system (Fig. 3); ii) the occurrence of a dyke swarm and flood basalts of early Cambrian or Hadrynian age (Williams and Stevens, 1969; Strong and Williams, 1972), along the rift system, in the Belle Isle area; iii) the occurrence, in widely separated parts of the rift system, of alkaline-carbonatite complexes giving K-Ar ages of about 255 m.y. (Doig, 1970); iv) the lithological and sedimentological characteristics of the basal arenites of the platformal sequences (Lewis, 1971, p. 59; Wiesnet, 1961, p. 76; Clifford, 1969, p. 92; Wilson, 1964, p. 112) within the rift zones indicating that the arenites accumulated in fault-bounded graben-like depressions. The upper parts of the arenite sequences are commonly Cambrian, but the lower parts in some areas may be Hadrynian (e.g. see Hofmann, 1972, p. 4).

The earliest (but post-Grenville) and the most pervasive igneous activity along the St. Lawrence rift system has been the emplacement of diabase dyke swarms along the Ottawa-Nipissing grabens (Fig. 3) and in the Belle Isle area. The flood basalts in the latter area may be the remnants of once extensive plateau basalt fields (Strong and Williams, 1972). The emplacement of these dyke swarms, possibly accompanied by large-scale flood basin eruptions, is probably mutually connected in time and cause with early rifting along the St. Lawrence rift system. The Tibb Hill volcanics (late Precambrian and/or early Cambrian) of the Pinnacle formation in northwestern Vermont and adjacent Quebec (Cady, 1969, p. 148) may also be deformed remnants of the early rift volcanics. The precise ages of the above dyke rocks and volcanics are uncertain. Dykes in the northern part of the Long Range Mountains have been radiometrically dated (Ar 40/K-Ar) at 600 ± 6 m.y. (Stukas and Reynolds, 1974) and these dykes may be concomagmatic with the Belle Isle dykes and flood basalts (Pringle et al., 1971). K-Ar age determinations by the Geological Survey of Canada have given ages ranging from 450 m.y. to 974 m.y. (Wanless et al., 1967) for the Grenville dyke swarm, and Murphy (1971) suggested 700 m.y. as the most probable age of the dyke swarm. All the dykes in the swarm need not be of the same age, however, for as Sutton (1972, p. 366) has pointed out, diabase dyke swarms along rift systems may develop over periods of 200-300 m.y.

In summary, it can be said that a mid-Mesozoic phase of rifting may have led to the development of the St. Lawrence rift system, essentially to its present form. The mid-Mesozoic movements, however, appear to have been superimposed on older faults, also of tensional origin. These older faults probably originated in the Hadrynian, about 600 to 700 m.y. ago.
ORIGIN OF THE ST. LAWRENCE RIFT SYSTEM

Any genetic model for the origin and evolution of the St. Lawrence rift system must provide a coherent rationale for the following features of the rift system: i) the part of the rift system that extends along the Champlain-St. Lawrence Valleys, the inner part of the Laurentian Channel and thence through the Esquiman Channel, which will hereafter be referred to as the Marginal Rift Zone, follows closely the northwestern edge of the Appalachian fold-belt; ii) the Ottawa graben extends into the continental interior from the axis of a Salient — the New England Salient (Cady, 1969, p. 35) — of the fold belt. The New England Salient is coincident with a transverse geosynclinal trough that first appeared late in the Precambrian and persisted as a transverse trough throughout the evolution of the fold belt; iii) the postulated branch of the rift system along the outer part of the Laurentian Channel extends from a re-entrant of the fold belt; iv) the first appearance of the rift system and the beginning of the Appalachian stratigraphic sequences are nearly contemporaneous (note that the Belle Isle volcanics and the Tibbit Hill volcanics occur at or near the bases of the Appalachian stratigraphic sequences of the respective areas); v) the greater part of the rifting that involves Paleozoic rocks may have occurred in the mid-Mesozoic after the Appalachian geosyncline ceased to be a mobile belt.

From the above, it can be seen that the rift system and the Appalachian fold belt are intimately related in space. Furthermore, the greater part of the evolution of the rift system appears to overlap in time with that of the geosyncline. These space and time relationships suggest a causal relationship, indicating that not only the fold belt but also the rift system are products of geosynclinal evolution. If this is so, it should be possible to explain the origin of the rift system within the framework of models of Appalachian evolution. The present volume, however, is primarily concerned with plate tectonics, so the writer proposes to discuss the origin of the rift system in terms of plate models of Appalachian evolution.

Plate models of Appalachian evolution and the Origin of the St. Lawrence Rift System

Recent plate tectonic syntheses of the Northern Appalachians (Dewey, 1969; Stevens, 1970; Bird and Dewey, 1970; Schenk, 1971) are basically similar. Of these, the one by Bird and Dewey (1970) is the most pertinent for the segment of the Appalachians with which the rift system is associated. The Bird-Dewey model envisages that the geosynclinal activity began late in the Precambrian when distension, along a narrow zone, of a then continuous North American/African protocontinent led to the formation of a rift system. This rift system will hereafter be referred to as the eo-Appalachian rift system. According to this model the rift system expanded from late Precambrian to Ordovician to form a proto-Atlantic ocean (Wilson, 1916) and from the Ordovician to the end of the Devonian the proto-Atlantic ocean contracted and finally closed. The stratigraphic zones and deformation sequences of the Appalachian foldbelt are related to the opening and closing of the proto-Atlantic ocean. The St. Lawrence rift system can be understood as a feature inherited from the eo-Appalachian rift system.

Figure 3. Map showing the space relation between the Grenville dyke swarm and the Ottawa-Nipissing grabens.

### TABLE I

<table>
<thead>
<tr>
<th>Name of the alkaline-carbonatite complex</th>
<th>Location</th>
<th>Isotopic age data</th>
<th>Minerals of economic interest</th>
<th>Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Island</td>
<td>I in Fig. 4</td>
<td>—</td>
<td>Iron-titanium oxide minerals, uraninite-pyrochlore, apatite, chalcopyrite</td>
<td>The complex has been explored by drilling</td>
<td>Lumbers, 1971</td>
</tr>
<tr>
<td>Burritt Island</td>
<td>BI in Fig. 4</td>
<td>—</td>
<td>Pyrochlore</td>
<td>No subsurface exploration has been carried out up until 1971</td>
<td>Lumbers, 1971</td>
</tr>
<tr>
<td>Manitou Island</td>
<td>MI in Fig. 4</td>
<td>565 m.y. K-Ar on biotite</td>
<td>Pyrochlore</td>
<td>Five uraninite pyrochlore deposits are known. These are the first large pyrochlore deposits to be discovered in North America. No mining has been carried out.</td>
<td>Lumbers, 1971; Gittins et al., 1967</td>
</tr>
<tr>
<td>Callander Bay</td>
<td>CB in Fig. 4</td>
<td>—</td>
<td>Niobium mineralization, possibly as pyrochlore</td>
<td>Has been explored by diamond drilling</td>
<td>Lumbers, 1971</td>
</tr>
<tr>
<td>St. Honoré</td>
<td>Fig. 5</td>
<td>564 m.y. K-Ar on biotite and whole rock</td>
<td>Pyrochlore, rare earth minerals</td>
<td>Potentially economic deposit of Nb incompletely explored by 1971</td>
<td>Vallée and Dubuc, 1970; Doig, 1970</td>
</tr>
</tbody>
</table>

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The ST. LAWRENCE RIFT SYSTEM AS A METALLOGENETIC SYSTEM

The critical upwarping and extensional faulting related to the formation of the St. Lawrence rift system and the significant shift of the plate margin in either side of the rift is related to the metallogenetic system of this region. The St. Lawrence rift system is considered to be a major tectonic feature that has had a significant influence on the distribution of metallogenic provinces in the area. The rift system is characterized by a series of transverse faults that have led to the formation of metallogenic provinces along the rift axis. These provinces are characterized by the presence of significant mineral deposits, including Ni, Cu, and Au. The metallogenic province associated with the St. Lawrence rift system is thought to be one of the most important in the world, with significant deposits of Ni, Cu, and Au. The metallogenic province is thought to be related to the upwarping and extensional faulting that occurred along the rift axis. The metallogenic province is thought to be related to the formation of the rift system and the significant shift of the plate margin in either side of the rift. The metallogenic province is thought to be related to the formation of the rift system and the significant shift of the plate margin in either side of the rift.
intersections of these faults provided the loci for the emplacement of the complexes (Lumbers, 1971, p. 66). The easternmost complex — the Callander Bay complex — is located approximately where the graben begins spaying out westwards. The spaying out of the graben structure seems to have provided a favourable tensional environment for the emplacement of the complexes.

The St. Honoré complex (Vallée and Dubuc, 1970) was discovered in 1967 and is the only known alkaline complex in the Saugeen graben. It intrudes Grenville plutonic rocks and is overlain by a thin (0-75 m) blanket of Trenton (middle Ordovician) limestone. The complex is located in an area where the graben structure rapidly widens, indicating that like the complexes in the Nipissing graben, the St. Honoré complex may be localized in an area where the graben structure spays out.

An important feature of the early Cambrian carbonatites discussed above is that they appear to be of identical petrological character, age (about 565 m.y.) and tectonic setting. If, as discussed above, the St. Lawrence rift system did originate...
about 600 to 700 m.y. ago, then the carbonatite activity and accompanying metallogeny occurred about 50 to 150 m.y. later. This time interval may reflect, at least in part, the duration of the late Precambrian-early Paleozoic cycle of tensional plate margin evolution. The Hadrynian and/or early Cambrian igneous rocks of tholeitic and transitional character (represented by the Grenville dyke swarm, the Belle Isle dykes, and flood basalts, Tibbit Hill volcanics) and the early Cambrian alkaline-carbonatite intrusions may be the products of magmatism related to the above cycle of plate margin evolution.

Mid-Mesozoic Deposits

Niobium

The two westernmost central complexes of the Monteregian line of intrusions are Nb-bearing alkaline-carbonatite complexes (Fig. 6). The Oka deposits, averaging 0.44 per cent Nb_2O_5 (Gold et al., 1967) have been the chief source of Nb in Canada since 1961. The Nb-bearing zones of the recently discovered St. André complex appear to be similar in mineralogy and tenor to those of Oka (Gleeson and Cormier, 1971).

The Oka and St. André complexes intrude Grenville plutonic rocks of two relatively small basement highs which are probably fault-block uplifts. There are two principal sets of high-angle faults in the general area, a northeast trending set and an east trending set. The latter set appears to outline the eastward continuation of the Ottawa graben trend. Intersections of the faults may have determined the loci of the intrusions (Kumarapeli, 1970).

Lead-Zinc veins

In the so-called “marble belt” of the southern Grenville Province are numerous Pb-Zn (calcite-barite-fluorite) veins (Fig. 7) which are almost entirely restricted to the carbonate units of the marble belt (Sangster, 1970). The veins are parallel to the longitudinal fault system of the Ottawa graben. In places, the veins cut Lower Ordovician rocks, but the actual age of the veins is not known (Sangster, 1970), and they are not obviously related to any known intrusions. Sangster suggested that they may represent Grenville Group sedimentary material remobilized during the mid-Mesozoic reactivation of the rift faults. Alternatively, they may represent an aspect of alkaline magmatism (see Kuilmar et al., 1966) in the area, the marble host-rocks providing the necessary chemical control for the vein deposition.

Figure 6. Map showing the tectonic setting of niobium-bearing alkaline-carbonatite complexes in the western part of the Monteregian line of intrusions: (1) St. André; (2) Oka. Also shown are the locations of: (3) Isle Bizard Kimberlite pipe; (4) Mt. Royal intrusion. Sources: Fault patterns after Clark, 1972, among others.

Figure 7. Locations (filled circles) and strike directions of lead-zinc (barite-fluorite) veins in the southern part of the Grenville Province.

Source: Sangster, 1970.
Notes: Stippling — Paleozoic platformal rocks; clear — Grenville rocks; thick broken lines — high-angle faults; thin lines — prominent air photo lineaments.
Kimberlites

Several kimberlite occurrences are known along the St. Lawrence rift system (see Satterly, 1948; Lee and Lawrence, 1968; Clark et al., 1967; Marchand, 1970; Gold, 1972). Of these, the Ile Bizard kimberlite (about 10 km east of the Oka carbonatite complex, see Fig. 6) has been prospected for diamonds by De Beers Consolidated Mines in 1969.

As already stated, the mid-Mesozoic alkaline-carbonatite magmatism, and hence the related metallogeny, may be mutually connected with the latest phase of major reactivation of the St. Lawrence rift system. The stresses that caused the reactivation are thought to be a part of the same general extensional forces that led to the formation of tensional plate margins of the present day Atlantic Ocean.

REGULARITIES IN THE DISTRIBUTION OF CERTAIN MINERAL DEPOSITS AND THE ST. LAWRENCE RIFT SYSTEM

Kutina (1972) after studying the regularities in the distribution of hypogean mineralization along several rift structures including the St. Lawrence rift system concluded: i) hypogean mineralization tends to concentrate in belts along rift structures even if the mineralization is older than rifting; ii) mineralization sometimes concentrates along extensions of straight segments of rift zones; iii) areas of intersection of rifts with deep-seated fractures of other trends appear to be favourable loci for the emplacement of ores; and iv) important concentrations of ores sometimes occur along extensions of smaller rifts which extend from the main rifts, especially where they intersect with fractures of other trends. He proposed that both the rifting and hypogean mineralization were related to the same pattern of deep-seated fractures of the crust and that the correlation of the ore occurrence distribution with the pattern of rifting sometimes enables one to derive a prospecting net of intersecting fractures and predict areas favourable for ore deposition. Using the St. Lawrence rift system, Kutina constructed a prospecting grid consisting of three east-west oriented lines and seven north-south oriented lines, for a part of the Superior structural province.

In the St. Lawrence region, the surface of the shield is characterized by numerous lineaments, commonly in the form of narrow rectilinear or zig-zag valleys ranging in length from a few kilometres to several tens of kilometres. Only a small portion of these lineaments can be considered to reflect bedding and/or foliation directions, for many of them cut across these trends, and therefore seem to be fracture (fault and/or joint) controlled. The lineaments fall into two principal sets, a northwest trending and northeast trending set. The rift faults commonly conform to one or the other of these two directions (Kumarapeli, 1974). This might imply that the faults have developed along trends of earlier fractures or that the fracture pattern is a product of the same stresses that produced the faults. It is thought that the fault trends are a result rather than a cause of the fracture pattern; because the rift faults are restricted to relatively narrow zones whereas the lineament pattern is widespread, and the lineaments do not appear to have a greater frequency in proximity to the faults. The pattern of the rift system itself appears to be controlled by this fracture pattern: it consists mainly of northeast and northwest oriented segments with strongly developed longitudinal faults, linked by east-west oriented segments with weakly-developed longitudinal faults.

Kutina's prospecting grid (Kutina, 1972, Fig. 3), consisting of east-west and north-south lines, does fit the distribution pattern of many important ore fields of the Superior Province, but the distribution pattern can be equally well accommodated in a northeast and northwest grid which would be consistent with the writer's findings.

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