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THE LABRADOR GEOSYNCLINE REVISITED*

ERICH DIMROTH

Department of Natural Resources, Québec

ABSTRACT. The Labrador trough is one of several erosional remnants of a Precambrian geosyncline that separates the Superior and Churchill Provinces of the Canadian Shield. It is similar in many respects to Phanerozoic geosynclines but has several distinguishing properties. These are: (1) ophiolitic rocks and shallow water sediments are stratigraphically superposed in the Labrador trough, not juxtaposed as in recent geosynclines; (2) ophiolites are at least locally based on continental crust; (3) sandstones are derived from granitic rocks and from older, unmetamorphosed sediments; (4) calc-alkaline volcanic rocks, granites, or volcaniclastic rocks typical of island arcs are virtually absent; (5) melange zones and continuous thrust belts are absent. The Labrador trough is not a Precambrian suture, and evidence for active plate margins is absent in or around the Labrador trough.

The main part of the Churchill Province forms the hinterland of the Labrador trough and the other remnants of the Circum-Ungava geosyncline. The terrain adjoining the geosyncline is mainly underlain by granitoid gneisses, of which some at least are Archean. Rock associations of island-arc type are known only from Manitoba but do not occur elsewhere in the hinterland of the geosyncline; at least some of them are Archean. Basins situated 200 to 600 km behind the geosyncline have a filling of sial-derived sediments deposited in shallow water. At least some of them are underlain by a sialic basement. These features place rigorous restraints on plate-tectonic interpretations of the Circum-Ungava Geosyncline.

INTRODUCTION

Whether Precambrian orogens formed by plate-tectonic processes, as did those of the Phanerozoic, is one of the most important questions of Precambrian geology. Gill (1949), Wilson (1949), Stockwell (1961, 1963, 1964, 1969), and King (1970) subdivided the Canadian Shield in structural provinces or orogens; Dietz (1963), Dickinson (1970a, 1971), and Dewey and Bird (1970) outlined the principles of plate-tectonic interpretations of recent orogenic belts. The following pages will attempt to assess this problem from the point of view of the Labrador trough.

The general construction of the Canadian Shield (Stockwell, 1969; King, 1970) and the principles of plate tectonics are well known and need not be discussed here. Fossil plates and plate margins can be identified by key lithic associations (Dickinson, 1971) and by key structures. Certain ophiolite complexes are remnants of oceanic plates and have been generated at accretive plate margins (spreading centers). Intrusive-extrusive complexes of the calc-alkaline magma suite occur behind consuming plate margins. Zones of overthrusting, melange zones, and blue-schist zones directly identify consuming plate margins.

Ophiolite complexes generated at fossil spreading centers have an internal construction (Dewey and Bird, 1971) that agrees well with pres-

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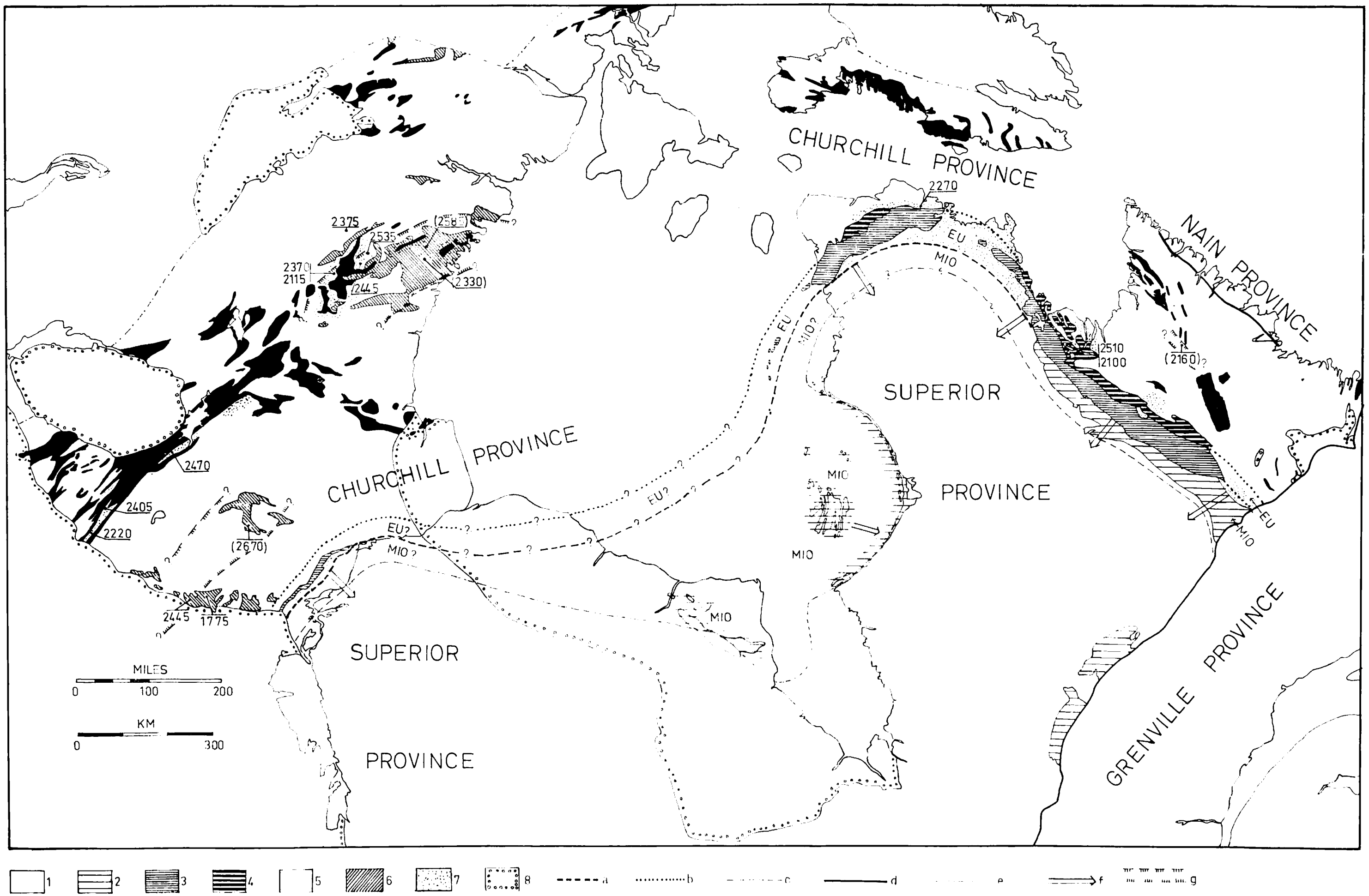
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ent petrologic-tectonic models of ocean-floor spreading (Kay, 1969; Miyashiro, Shido, and Ewing, 1969, 1970a, 1970b). They consist of an upper unit of basalt flows, underlain by sheeted gabbroic dike complexes. These dike complexes bear evidence of strong dilation during basalt volcanism and therefore suggest crustal spreading. Peridotites and serpentinites occur below the sheeted gabbro complex. Such ophiolite complexes are of course allochthonous.

Zones of overthrusting, melange zones, and blueschist zones identify fossil subduction zones (Ernst, 1970). They are continuous over the whole length of the consuming plate margin. Calc-alkaline intrusive-extrusive complexes and their envelope of volcaniclastic rocks accompany the consuming plate margin. Their chemistry should vary across the trend of the volcanic belt in the way outlined by Rittmann (1953), Kuno (1967), Sugimura (1968), and Dickinson (1970b).

All these features are absent from the Labrador trough and its hinterland. Consequently the hypothesis that the Labrador trough formed at a Precambrian plate junction is rejected.

Geosynclinal terminology used here is descriptive and is based on the tectonic setting as recognized from the rock record. There is of course no assurance that previous authors would apply terms like "eugeosyncline" or "parageosyncline" to the units so-called in the following pages, because the Labrador trough is not identical to the classical geosynclines of North America (Kay, 1951) or Europe (Aubouin, 1965). Descriptions of each zone are detailed enough to permit comparison. Therefore, the terminology of this paper should be "convertible" into the terminology of others, which is important (compare, Kay, 1967).

THE LABRADOR TROUGH

The Labrador trough has been described by Harrison (1952), Gastil and others (1960), Bergeron (1957b, 1965), Baragar (1967), Gross (1968), and Donaldson (1970). Recently the writer discussed its tectonic and paleotectonic evolution in more detail (Dimroth, 1968, 1970, 1971a,

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Fig. 1. Geotectonic sketch of part of the Churchill Province: 1 = Superior Province, greenstone belts and "granitoid" rocks. 2 to 4 = geosynclinal facies; 2 = platform and miogeosynclinal deposits; 3 = eugeosynclinal deposits; 4 = metamorphosed metasediments of the immediate hinterland. 5 to 7 = hinterland; 5 = "granitoid" rocks (mainly Archean?); 6 = greenstone belts (mainly Archean?); 7 = Archean basement of Proterozoic basins (age certain). 8 = Post-Aphebian deposits; black = deposits of parageosynclinal basins characterized by meta-arkose, quartzite, marble. Boundaries of geotectonic domains: a = mio-eugeosynclinal boundary (= Superior Churchill Province boundary); b = distal limit of eugeosyncline; c = proximal limit of miogeosyncline; d = other province boundaries; e = limit of compilation; f = facing direction of the geosyncline; g = possible limits of domains that escaped strong Hudsonian deformation and metamorphism. K-Ar ages in brackets. After Stockwell (1969), modified after Taylor (1969, 1970), Emsley (1963, 1964), Bell (1970), Money and others (1970). Ages after Wanless (1970) and various sources. Only Archean ages are plotted.

1971b; Dimroth and others, 1970[1]). Therefore, only the barest skeleton of the general geology of this unit will be outlined, except for the features that are essential from the point of view of this discussion.

General outline.—The Labrador trough is an erosional remnant of a north-northwest trending geosyncline in northeastern Quebec (fig. 1). It is composed of Early Proterozoic (Aphebian) rocks deposited in the interval between 2150 and 1600 m.y. (diabase dikes of basement: 2150 m.y., Fahrig and Wanless, 1963; metamorphism: 1700 to 1600 m.y., Beall and others, 1963; Wanless, 1970; rock ages: 1900 m.y., Fryer, 1971). The filling of the trough has been folded and metamorphosed during the Hudsonian orogeny.

The Labrador trough is subdivided in three longitudinal facies zones (fig. 1): predominantly sedimentary rocks in west and east, predominantly mafic igneous rocks in the center. These represent erosional remnants of the miogeosyncline (west), eugeosyncline (center), and the immediate hinterland (east) of Aubouin's (1965) geosynclinal model. It should be noted that the eastern zone (the immediate hinterland) is not part of the Labrador trough as defined by tradition (compare Fahrig, 1957).

Domes of the granitoid basement complex exist in all three zones and a continuous zone of granitoid gneisses frames the trough in the east (Wynne-Edwards, 1960, 1961; Fahrig, 1956; Taylor and Skinner, 1964; Gélinas, ms; Baragar, 1967; Taylor, 1969, 1970). The Archaean age of the granitoid complex east of the Labrador trough has been proved independently in four areas (Wynne-Edwards, 1960, 1961; Gélinas, ms; Hardy, ms, 1969; Dimroth, 1964 and unpub.).

The oldest Proterozoic rocks of the trough are continental red beds (arkose, conglomerate) deposited in a complex fault basin south of 57°N. Trachybasaltic and andesitic volcanic rocks (Baragar, 1967, 1970) are associated with the red beds.

The fault-basin deposits grade upward into the geosynclinal sequence. It shows well developed cyclicity defined by alternation of tectonically stable and unstable periods. Cycles began with deposition of orthoquartzites and chemical sediments (dolomites, iron formation) in a shallow marine environment under relatively stable tectonic conditions. Stromatolitic beds, oölitic beds, coarse current crossbedding occur across the whole width of the Labrador trough and prove that shallow marine conditions prevailed even in the eugeosyncline. Cycles culminate with deposition of thick shale-quartz wacke suites and with eruption of voluminous basalt and intrusion of gabbro sills in the eugeosyncline. Intermediate and acidic volcanic rocks are virtually absent. The two phases of the depositional cycle are called "pre-ophiolitic" and "ophiolitic" in the following pages.

Tectonic movement during the orogeny was toward the west. The miogeosynclinal rocks have been intensely folded and overthrust, whereas

[1] These papers are not referred to in the following pages; individual contributions to Dimroth and others are quoted as Baragar, 1970; Bergeron, 1970; Jackson, 1970.

their basement remained essentially undeformed. A decollement separates basement and cover. The rocks of the eugeosyncline and of the immediate hinterland have been folded with the basement. Very few thrust faults intersect the basement-cover contact.

Rocks of the eastern zone of the Labrador trough have been overprinted by a synkinematic to post-kinematic metamorphism of an intermediate pressure series (Gélinas, ms; Baragar, 1967). A few pegmatitic and granitic dikes and stocks are present, but their volume is exceedingly small (Fahrig, 1956; Taylor and Skinner, 1964; Taylor, 1969, 1970; Gélinas, ms). The amount of intrusive granite in the area underlain by granitoid gneisses east of the trough is unknown.

Source areas and source rocks.—Clastic rocks of the Labrador trough are derived from source areas west and east of the trough. Internal uplifts, probably chains of islands, were additional source areas during certain periods. Bergeron (1954, 1957b) repeatedly stressed that sialic source areas existed east of the trough. This has been confirmed by data on the facies distribution outlined in the writer's previous publications and in particular by the discovery of arkoses and conglomerates with gneiss pebbles in the easternmost part of the Labrador trough (Taylor, 1969; Dimroth, 1964 and unpub.).

Orthoquartzites are the characteristic clastic rocks of the pre-ophiolitic phases. Quartz wackes of an unusual type are the typical arenites of the ophiolitic phases. They generally contain a high percentage of clay matrix (> 15 percent[2]) and some shale chips. Therefore they belong to the graywacke class of Pettijohn (1957, p. 290-292). Well rounded quartz grains are the dominant fragmental fraction; some percent of feldspar (< 15 percent[2]) and fragments of sedimentary rocks (chert, dolomitic siltstone, dolomitic sandstone) are locally subordinate components. The rocks fall into an unnamed field of Pettijohn's sandstone tetrahedron (Pettijohn, 1957, fig. 75); quartz wacke should be an appropriate term.

Subordinate mafic volcanic components have been described in clastic rocks by Baragar (1967). Fragments of unmetamorphosed volcanic rocks are rare and, where present, can be related to extrusive rocks close by. The writer has never seen a fragment of a metamorphosed sedimentary or volcanic rock (other than the granitoid basement gneiss) in any clastic rock of the Labrador trough.

These compositional features are unusual for geosynclinal arenites. They demand derivation of the clastic material from a granitoid basement complex that was partly covered by unmetamorphosed mature sediments. Clastic rocks derived from a metamorphic and volcanic welt, like typical graywackes or volcaniclastic rocks, are entirely absent. Source areas were not the site of appreciable volcanic activity.

Paleotectonics.—Faulting took place repeatedly within the geosyncline and at its margins. Uplifts that emerged from time to time within the geosyncline and local depositional basins were at least locally bounded by faults. Faulting was particularly intense at the beginning of the ophio-

[2] Visual estimates of composition in thin section.

litic phases. It appears that the syn-sedimentary faults had essentially vertical movement components. Evidence of folding, thrusting, or metamorphism during deposition of the Labrador trough sequence is absent.

The ophiolites.—Basaltic rocks (flows of pillowed and massive basalt, subordinate mafic pyroclastic rocks, hyaloclastic rocks, very thick and widespread gabbro sheets) make up some 70 or 80 percent of the filling of the eugeosyncline. Sills of serpentinized peridotite are present (Fahrig, 1962; Sauvé and Bergeron, 1965; Baragar, 1967; Frarey, 1967). Aggregate thickness of the ophiolites is perhaps 15 km at lat 55°30′N (Baragar, 1967).

The ophiolites form a very regular concordant sequence as is well shown on maps of Sauvé and Bergeron (1965), Baragar (1967), and Frarey (1967). They are essentially autochthonous, despite minor telescoping at the western margin. They overlie a sequence of orthoquartzites and iron formation at the northern termination of the Labrador trough (fig. 2) and a sequence of red beds, stromatolitic dolomites and shales in the center (fig. 3); iron formation and stromatolitic dolomite also subdivide the ophiolitic suite in the center of the Labrador trough (Baragar, 1967; Donaldson, 1966). The situation of these shallow-water deposits is anomalous. In the Labrador trough ophiolite sequences are stratigraphically superposed upon shallow-water marine associations; the two rock associations are not simply juxtaposed, as in Phanerozoic geosynclines. Needless to say sheeted gabbro complexes are entirely absent.

The rocks of the ophiolitic suite are closely related to oceanic tholeiites (Baragar, 1970). Intermediate and acidic volcanic rocks are virtually absent, and granitic rocks are very rare (Baragar, 1970). Basalts show moderate iron enrichment during differentiation (Baragar, 1970), and gabbros show strong iron-magnesia fractionation (Baragar, 1960, 1967, 1970; Sauvé and Bergeron, 1965; Hardy, ms). They share these features with oceanic tholeiites (Miyashiro, Shido, and Ewing, 1970b).

Structure and metamorphism.—A schematic section across the Labrador trough is shown as fig. 4 (from Dimroth, 1970). Synclinoria in the west and east parts of the trough, anticlinoria in its center and east of the trough are the large scale units. A decollement separates the folded and faulted Proterozoic rocks from their basement in the western synclinorium. The basement gneisses below the western synclinorium therefore have not been involved in Hudsonian deformation, except in some small slices that were sheared off at pre-orogenic faults. Basement and cover are folded jointly farther east.

Great thrust faults carry the metamorphosed sediments of the eastern anticlinorium over the ophiolites in the area between lat 56°45′N and 58°00′N (Fahrig, 1956) and again south of 56°00′N (Donaldson, 1966; Baragar, 1967). These faults are not continuous. They do not extend north of lat 58°N (Gélinas, ms) and are also absent between lat 56°45′ and 56°N (Dimroth, 1964 and unpub.). The contact between the eastern synclinorium and anticlinorium is unfaulted north of lat 60°N (Hardy, ms; Laurin, 1969), between lat 58° and 59°N (Sauvé, 1959; Sauvé and

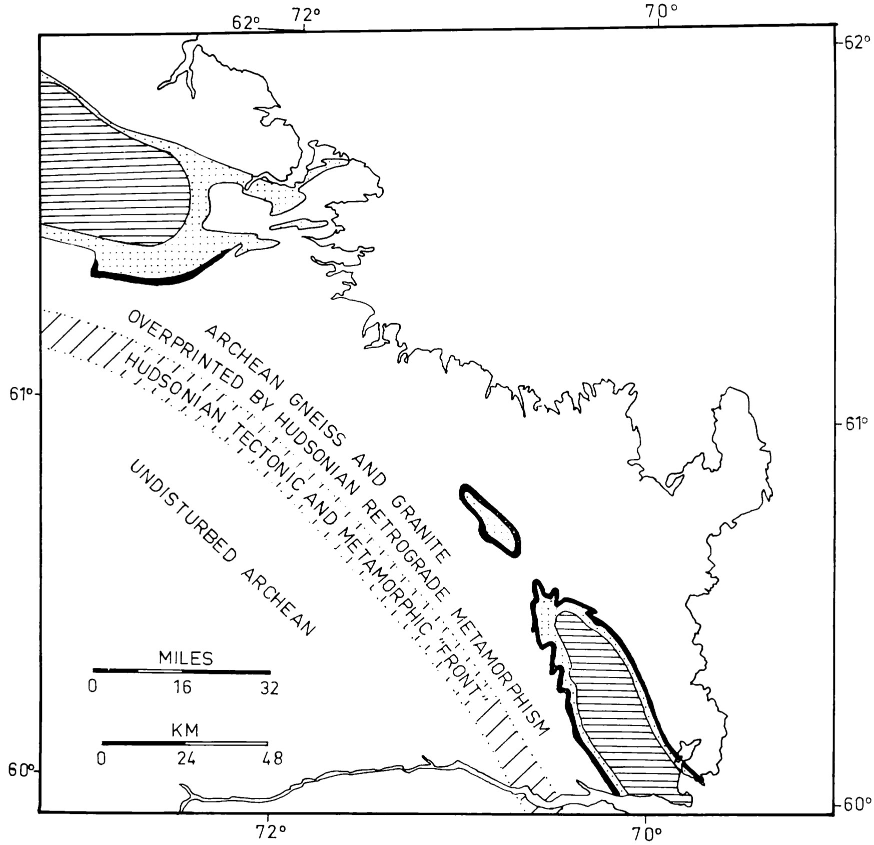

Fig. 2. Junction between the Cape Smith belt and the Labrador trough. After Laurin (1969) and Schimann (in press). Quartzite and iron formation: black; metapelitic sediments: stippled; mafic and ultramafic igneous rocks: ruled. Two additional basins of Proterozoic rocks between both belts, discovered by Schimann (1972), are not plotted.

Bergeron, 1965; Gélinas, ms), between lat 56°30′ and 56°00′ (Dimroth, 1964 and unpub.). It is consequently not possible to interpret these faults as a "suture" between different Precambrian blocks. The relations in the center of the trough (fig. 3) and in the area between the Labrador trough and the Cape Smith belt (fig. 2) are sufficiently illustrative and prove that the Archean blocks of the immediate hinterland are welded to the Archean of the foreland.

The movement picture during orogeny, shown in figure 4, is defined by upwelling and westward migration of the hinterland, by subsidence and contraction of the geosyncline. A subduction zone does not exist.

The rocks of the easternmost zone of the Labrador trough have been overprinted by a synkinematic to postkinematic metamorphism of an intermediate-pressure series. Low-grade rocks (of the pumpellyite-prehnite

Fig. 3. Sketch map of the central segment of the Labrador trough. 1 = Archean; 2 = Archean with Hudsonian overprint; 3 = continental red beds; 4 = marginal arkose and conglomerate, equivalent of 5; 5 = orthoquartzite and dolomite of the first cycle; 6 = orthoquartzite, dolomite, iron formation of the second cycle; 7 = shale, graywacke; 8 = mafic volcanic rocks; 9 = gabbro; 10 = gabbroic sheets alternating with shale and graywacke (in part extrusive); 11 = metamorphosed pelite, semi-pelite, orthoquartzite. a = biotite isograd; b = garnet isograd; c = sillimanite isograd; scale: 1 cm = approx 4 km. After Fahrig (1956), Baragar (1967), Taylor (1969), Dimroth (1968 and unpub.).

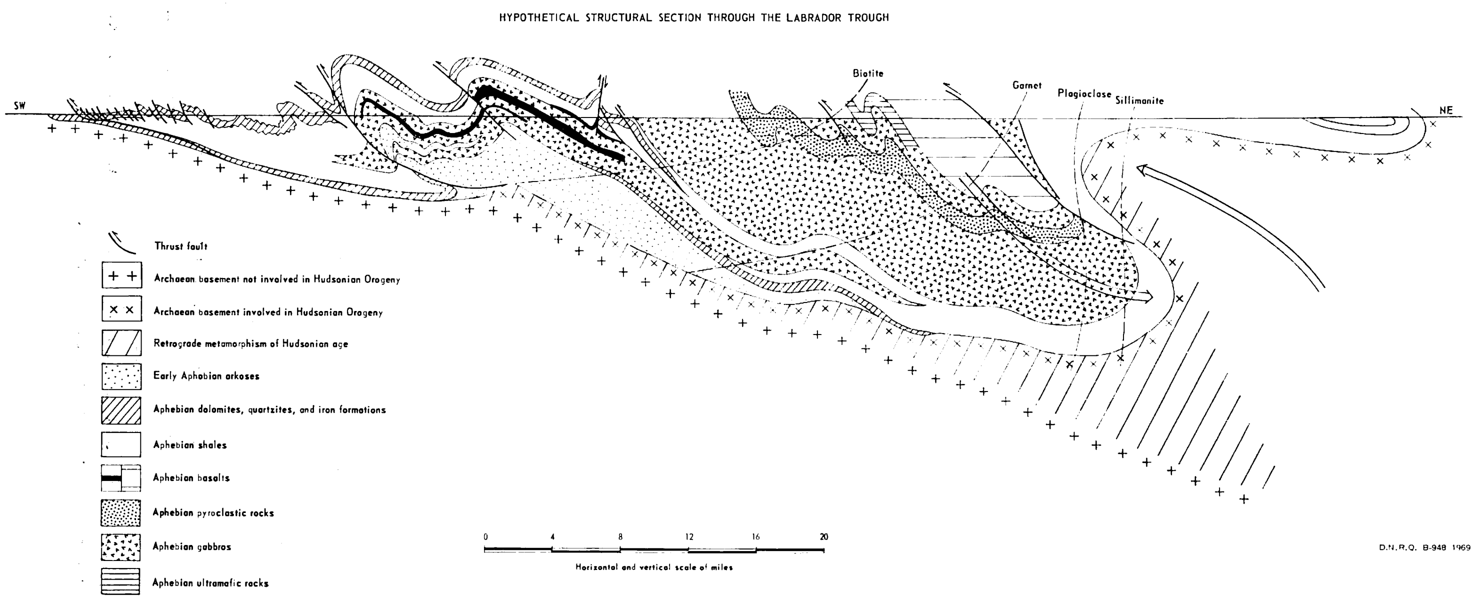

Fig. 4. Section across the Labrador trough. Surface section from Baragar (1967). Arrows: main transport direction. From Dimroth, 1970.

facies—Baragar, 1967) underlie wide areas. Boundaries between facies zones in the greenschist and pumpellyite-prehnite facies are rather vague and cut across the Labrador trough in function of the exposed tectonic level. This suggests that the isograds of low-grade metamorphism are nearly horizontal, dipping slightly westward. Isograds of amphibolite-facies metamorphism are closely spaced and are reasonably straight (Gélinas, ms; Baragar, 1967; Dimroth, unpub.). These features suggest that isograds of high-grade metamorphism are steeply inclined. The relations are shown in figure 4 and suggest that heat flow during the late stage of the orogeny increased from the geosyncline toward the hinterland.

Discussion.—It is evident that the ophiolites of the Labrador trough do not represent remnants of an oceanic plate. Features that would prove the presence of a consuming plate margin are also absent; the Labrador trough is not a Precambrian suture.

Very strong evidence proves that the Labrador geosyncline formed by subsidence of a continental area. Subsidence was not continuous in time; periods of rapid subsidence alternated with periods of slow subsidence. Shallow-water deposits formed during periods of slow subsidence; their facies is akin to the facies of platform sediments, but the formations are far thicker than platform deposits. Shales and wackes were deposited during periods of rapid subsidence. Oceanic basalts erupted during periods of rapid subsidence in zones of greatest subsidence. Sediments are in part derived from a zone extending east of the geosyncline, underlain by granitic gneisses and by unmetamorphosed sediments.

THE SETTING OF THE LABRADOR TROUGH

The arguments advanced so far leave open the option that the evolution of the Labrador trough was caused by processes related to plate interaction deeper in the Churchill Province. It is not possible to reject such a hypothesis at the present time; however, what is known about the setting of the Labrador trough and of the other Proterozoic belts of the same geosynclinal system appears to contradict it. McGlynn (1970) and Donaldson (1970) presented a clear account of the geology of the Churchill Province, to which the reader is referred for a more general background.

The Labrador trough is one of several erosional remnants of the Circum-Ungava geosyncline. The Circum-Ungava belt surrounds the Superior Province and forms a marginal zone of the Churchill Province of the Canadian Shield (fig. 1). The Cape Smith-Wakeham Bay belt (Bergeron, 1957a,b, 1970), Belcher fold belt and Sutton Inlier (Jackson, 1960, 1970; Bostock, 1969), and perhaps some supracrustal rocks of the Nelson River zone (C. K. Bell, 1966; McGlynn, 1970) are other remnants of the geosyncline. The main part of the Churchill Province is a hinterland to the geosyncline. Its geological relations to the geosyncline cannot be understood without discussion of the relations of the geosynclinal strata to their basement and without description of the facies changes that take place at the distal margin of the geosyncline.

The basement complex.—It has been known for many years that the Proterozoic strata of the Labrador trough, Cape Smith belt, and Belcher fold belt rest unconformably upon an Archean basement complex of the Superior Province. This complex has been described by Eade (1966), Bérard (1965), Baragar (1967), Hardy (ms) west of the Labrador trough, and by Bergeron (1957a, 1958) and Beall (1959, 1960) south of the Cape Smith belt. The writer has visited the basement complex west of the Labrador trough between lat 55°30′ and 56°30′N, at Payne Bay (lat 60°N), and the basement south of the Cape Smith belt at several localities west of Wakeham Bay (between long 72° and 73°W).

The basement complex is extraordinarily monotonous, being composed mainly of anatectic and diatectic biotite-amphibole gneisses and pyroxene gneisses. Interbeds and mappable zones of amphibolite are very common. The gneisses are well layered in some areas, but more generally the layering has been largely destroyed by intense anatexis, and virtually homogeneous diatexites underlie large areas. Well preserved biotite paragneisses, garnet gneisses of granodioritic composition, and massive granites, possibly of intrusive origin, underlie smaller areas.

The Archean gneisses west of the northernmost Labrador trough and south of the Cape Smith belt give Hudsonian K-Ar ages (Beall and others, 1963; Wanless, 1970). Beall and others (1963) were the first to relate the Hudsonian up-dating of the Archean in this district to Hudsonian metamorphism and showed that the Hudsonian biotite isograd of the Labrador trough crosses the western contact of the Labrador trough at Leaf Bay (Beall and others, 1963, fig. 2). The contact between the Archean basement and its Proterozoic cover is folded north of that latitude (Gold, 1962a; Hardy, ms), suggesting that the Archean basement in this region suffered not only Hudsonian metamorphism but also Hudsonian deformation. South of the Cape Smith belt the writer observed basement gneisses that contain a schistosity defined by sericite and chlorite films. This schistosity is present in Early Proterozoic diabase dikes (older than the Labrador trough) as well as in the Archean rocks and indicates probable Hudsonian dynamic metamorphism of low grade. It is inferred from these observations that a tectonic, metamorphic, and K-Ar age front extends between the northernmost Labrador trough and the Cape Smith belt. This front also recognized by Wanless (1970), has been used to define the boundaries of the Superior and Churchill Provinces in figures 1 and 2.

The basement complex west of the Labrador trough and south of the Cape Smith belt has been followed around the synclinal terminations of both belts and is materially continuous with granitoid gneisses extending east of the northernmost Labrador trough and north of the Cape Smith belt (Bergeron, 1957a, 1958, 1965; Hardy, ms; Laurin, 1969; Schimann, in press).

South of Payne Bay the basement gneisses east of the northernmost Labrador trough trend into Ungava Bay. Similar gneisses re-enter the mainland at Leaf Bay whence they have been followed continuously to the Grenville front (Sauvé, 1959; Gélinas, ms; Fahrig, 1957; Taylor, 1969, 1970; Dimroth, unpub.; Baragar, 1967; Wynne-Edwards, 1960, 1961). Domes of granitoid gneisses are present farther west. The basement nature of these granitoid gneisses has been proved independently in three areas: in the Fort Chimo area (lat 58°N) by Gélinas (ms), in the Romanet-Duhamel Lakes area between lat 56°00′ and 56°30′ N by Dimroth (1964, and unpub.), and in the Michikamau and Ossokmanuan Lakes areas (south of lat 55°N) by Wynne-Edwards (1960, 1961).

The granitoid complex is stratigraphically below the lowermost Proterozoic strata in all three areas. Arkoses and conglomerates with gneiss pebbles indistinguishable from the basement gneiss form a basal formation in parts of two areas (Dimroth, 1964 and unpub.; Wynne-Edwards, 1960, 1961). The granitoid gneisses suffered retrograde metamorphism that correlates with a prograde metamorphism of the Proterozoic rocks (Dimroth, 1964 and unpub.; Wynne-Edwards, oral commun., 1967). This retrograde metamorphism is superposed upon an anatexis that is absent from the Labrador trough rocks. Retrograde metamorphism affects the mineralogy and the texture of the gneisses as shown in table 1. Rb-Sr data (Beall and others, 1963) finally prove that the granitoid complex has a crustal history dating back to at least 2400 m.y. The areas where the basement nature of the granitoid gneisses has been proved by these arguments are shown by stippling in figure 1.

Facies changes in the hinterland.—Facies changes east of the Labrador trough are known in the Fort Chimo region (Gélinas, ms) and between lat 56°00′ and 56°30′N (Dimroth, unpub.). The proportion of volcanic material abruptly decreases at the eastern margin of the eugeosyncline. Metamorphosed pelites and semi-pelites (siltstones) form the bulk of the sequence. Intercalations of metamorphosed dolomite (marble) and of aluminous pelites (kyanite and sillimanite gneiss) are relatively rare. Metamorphosed marls (calc-silicate amphibolite) and dolomitic sandstone (calc-silicate quartzite) are widespread subordinate components. Metamorphosed orthoquartzites are a widespread major component composing perhaps 15 percent of the sequence. Taylor (1969, 1970) mapped arkoses and conglomerates in several areas within the Proterozoic sequence and at its contact to the granitoid gneisses, and Dimroth (unpub.) discovered conglomerates with pebbles of granitoid gneiss that are indistinguishable from the basement. A facies change from a predominantly volcanic sequence into a predominantly sedimentary sequence with a high proportion of mature orthoquartzites is therefore indicated in the extreme east of the Labrador trough.

The distant hinterland of the Labrador trough.—The distant hinterland of the Labrador trough is poorly known. Map on scales of 2.5 or 5 km to the centimeter are the only available data (Christie, 1951, 1952; Fahrig, 1952; Christie, Roscoe, and Fahrig, 1953; Douglas, 1953; Kranck, 1953; Emsley, 1963, 1964; Taylor and Skinner, 1964; Stevenson, 1967, 1969a, 1969b; Taylor, 1969, 1970, 1971). Detailed work is limited

TABLE 1
Retrograde metamorphism of Archean basement gneisses

	Greenschist Facies		Amphibolite Facies
	quartz–albite–epidote–biotite subfacies	quartz–albite–epidote–almandine subfacies	Sillimanite–almandine–muscovite subfacies
			Basement gneisses not present in lower subfacies of amphibolite facies
Mineral reactions	plagioclase ⟶ albite + epidote	calcic plagioclase ⟶ sodic plagioclase + epidote	
	amphibole ⟶ chlorite } related to feldspar ⟶ sericite } shearing	feldspar ⟶ muscovite	feldspar ⟶ muscovite
	feldspar with sericite filling	epidote in cores of plagioclase	muscovite tables in feldspar
Typical textures	mylonitization of quartz and feldspar	muscovite tables in plagioclase	granulation of quartz and feldspar, followed by complete recrystallization of strongly deformed rocks
	sericite and chlorite flasers	granulation of quartz and feldspar	
Rocks: original	coarsely	granoblastic	biotite-amphibole gneiss
↓ increasing intensity of deformation	↓ phyllonitic albite–sericite–biotite–(actinolite) gneiss	↓ blastomylonitic biotite–amphibole–epidote–(muscovite) gneiss	↓ blastomylonitic biotite–amphibole–(muscovite) gneiss
	↓ albite–sericite–biotite phyllonite or albite–epidote–chlorite–actinolite phyllonite		↓
annealing of extremely deformed rocks	annealing recrystallization absent	?	finely granoblastic biotite–amphibole–muscovite gneiss with deformed metapegmatoids

Note: Gradations exist between all rock types listed.
Retrogression of amphibolites not shown

to a small area at the Labrador Coast (Gandhi, Grasty, and Grieve, 1969; Clark, 1971; Sutton, Marten, and Clark, 1971).

Pre-Hudsonian rocks of the distant hinterland fall essentially in the following two units: (1) infracrustal granitoid gneisses, migmatites, and granulites, and (2) supracrustal rocks, notably paragneisses, orthoquartzite, marble and calc-silicate rocks, and arkose and conglomerate. It is most likely that the supracrustal rocks are Proterozoic, but the age of the infracrustal gneisses is in dispute. Taylor (1969, 1970) inferred that all infracrustal rocks east of the Labrador trough were Proterozoic. This opinion may be doubted for the reasons outlined on the preceding pages. Furthermore a K-Ar age of 2160 m.y. has been determined at lat 57°19′N long 65°03′W (Taylor, 1969; Wanless, 1970): it could be interpreted as a slightly up-dated Archean age, or it could be due to a Pre-Hudsonian disturbance at that date. In either case gneisses giving an age older than 2100 m.y. are basement to the Labrador-trough rocks. It is clear that part of the infracrustal complex is Archean. But it is also clear that part of it is Proterozoic; the volume of Proterozoic metasediment and of Proterozoic intrusive rocks is unknown.

Proterozoic supracrustal rocks of the distant hinterland have properties characteristic of the filling of ensialic basins: They contain sections of orthoquartzite and marble thick enough to be mapped on a scale of 5 km equals 1 cm. (Taylor, 1969, 1970). Thick sections of arkose and conglomerate are known from Makkovik Bay (Gandhi, Grasty, and Grieve, 1969; Clark, 1971). Volcanic rocks are subordinate (Taylor, 1969; Clark, 1971). Ripple marks and crossbeds in orthoquartzites (Taylor, 1969, 1970) prove that part of the sequence has been deposited in very shallow water.

Comparison with the hinterland of the Nelson River zone.—The relations east of the Labrador trough invite comparison with the hinterland of the Nelson River zone in northern Manitoba, Saskatchewan, and the adjoining part of the Northwest Territories, of which a summary description has been presented by McGlynn (1970). This terrain is underlain by three major lithic assemblages: (1) zones of volcanic and sedimentary rocks similar to island arcs (Davidson, 1969; McGlynn, 1970); (2) zones of sedimentary rocks characterized by voluminous orthoquartzite or arkose (Davidson, 1969; Bell, 1970; Money, 1968; Money and others, 1970); (3) an infracrustal complex of gneisses, migmatites, and granites.

The volcano-sedimentary zones have a general easterly trend, parallel to the greenstone belts of the Superior Province. Therefore Stockwell (1963, 1969), Davidson (1969), Douglas (1970), and McGlynn (1970) regarded them as essentially Archean. Age determinations (Leech and others, 1963; Davidson, 1969; Coleman, 1970a, 1970b) substantiated this interpretation with one exception (Mukherji, Stauffer, and Baadsgaard, 1971). The data should be interpreted with some caution because the ages obtained by Mukherji, Stauffer, and Baadsgaard (1971) demonstrate that Proterozoic and Archean greenstone basins may exist; the Proterozoic date is shown in figure 1.

The Proterozoic age of the sedimentary zones is well established (Davidson, 1969; Money, 1968; Bell, 1970; Money and others, 1970). The Proterozoic sediments rest in places upon an Archean basement, the age of which has been substantiated by age determinations (Davidson, 1969; Burwash, 1970; Money and others, 1970; Wanless, 1970).

The infracrustal complex comprises metamorphosed equivalents of volcano-sedimentary basins of Archean age (Davidson, 1969), of metamorphosed Proterozoic sediments (Davidson, 1969), and voluminous intrusive granite bodies of Hudsonian age. Archean ages have been reported by Baadsgaard and Godfrey (1967), Money and others (1970), Burwash (1970), Koster and Baadsgaard (1970), and Wanless (1970). They are plotted on figure 1. Hudsonian Rb-Sr isochrons of granites have been obtained by the same authors, by Turek and Peterman (1970), and Mukherji and others (1971). Ages younger than 2150 m.y. have not been plotted in figure 1, except where they can be interpreted as dating the age of a supracrustal volcano-sedimentary basin (Mukherji and others, 1971).

Proterozoic rocks of the assemblage (2) were deposited in more or less unstable basins that evolved upon continental crust (Davidson, 1969; Money, 1968; Bell, 1970; McGlynn, 1970; Money and others, 1970). They are characterized by voluminous arkose, orthoquartzite, and marble, whereas volcanic rocks are subordinate. Most rocks were deposited in relatively shallow water upon a sialic basement. Very great thicknesses of formations indicate an unstable tectonic environment; Bell (1970) and Money and others (1970) therefore qualified their geotectonic environment as that of a "metastable craton".

Kenoran deformation and metamorphism in the Churchill Province.—Archean (> 2400 m.y.) or slightly updated Archean (> 2150 m.y.) K-Ar ages have been obtained from several localities in the hinterland of the Circum-Ungava Geosyncline. Most of them have been summarized in Wanless (1970), except for those determined by Koster and Baadsgaard (1970), and are plotted in figure 1. Rocks yielding Archean K-Ar ages or slightly updated Archean ages evidently suffered neither substantial Hudsonian metamorphism nor significant Hudsonian deformation. Coleman (1970b) obtained an Archean Rb-Sr isochron from late kinematic granite west of Flin-Flon, also evidence for the absence of substantial Hudsonian deformation in the region. Davidson (1969) and Bell (1970) found little metamorphosed rocks of the Hurwitz Group overlying Archean basement in an area west of Hudson Bay and were able to outline a zone in which Hudsonian deformation and metamorphism are slight. Those zones where Hudsonian deformation and/or metamorphisms are known to be weak or absent are compiled in figure 1. McGlynn (1970) presented a more generalized outline of zones where Hudsonian deformation appears to be insignificant.

CONCLUSIONS AND SPECULATIONS

Present knowledge places rigorous restraints on plate-tectonic interpretations of the Churchill Province. Plate boundaries and sutures exist neither in the Labrador trough nor in the Cape Smith belt; it is possible to demonstrate that at least certain segments of both belts are based on continental crust. Other units of the Circum-Ungava belt are too poorly exposed to demonstrate absence (or presence) of sutures.

The Circum-Ungava belt does not represent a continental-rise prism. There is no positive evidence that a continental-rise prism ever existed in the hinterland of the Circum-Ungava belt. Nor is there evidence of volcanic arcs, except perhaps in the hinterland of the Nelson River zone. Proterozoic basins situated about 300 km behind the geosyncline have a filling of sial-derived rocks. At least some of them are demonstrably based on sialic crust. Small areas of the terrain between these basins and the geosyncline give K-Ar ages older than 2150 m.y. or contain late-kinematic granites older than 2400 m.y. These areas therefore suffered neither substantial deformation nor significant metamorphism during the Hudsonian orogeny (1800-1600 m.y. ago). It appears unlikely that the plate-tectonic hypothesis provides a suitable model for the evolution of the part of the Churchill Province discussed here.

An alternate model based on ideas advanced by Wegmann (1953) and Anhaeusser and others (1969) is proposed here only because it leads to conclusions that can be tested. From his work in the easternmost zone of the Labrador trough, the writer has gained the impression that the terrain farther east represents part of an Archean crustal block. During the later part of the Aphebian era this block may have been re-activiated under the influence of relatively high regional heat flow and of compressive forces acting perpendicular to the Circum-Ungava belt. Initial slow rise of infracrustal masses at deep levels may have resulted in warping and faulting at the surface, and therefore may have initiated the evolution of deep sedimentary basins. The lithology of the sediment filling of these basins varied in function of the tectonic processes occurring in their source areas and in function of the velocity of basin subsidence. Gradually heat flow may have increased in certain zones, until it led to diapiric rise of infracrustal masses into higher levels, to gravitative reorganization of the rock masses in a fashion proposed by Ramberg (1967), Henderson (1969), and Martignole and Schryver (1970a, 1970b), and of course to metamorphism of the Proterozoic rocks. Shortening perpendicular to the geosyncline occurred in this "mobile belt" but may have been small. Some areas were little affected by Hudsonian metamorphism and deformation.

Confirmation of such a model could come from integration of detailed stratigraphic, structural, and petrologic work. Proterozoic metasediments east of the trough should have a polymetamorphic sialic basement. Rising infracrustal masses could represent either polymetamorphic basement rocks, their re-mobilized equivalents, or new granitic material. Finally it should be possible to relate the Hudsonian structures in Archean and Proterozoic rocks to the movements of the upwelling infrastructural masses.

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