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GEOLOGY OF SOUTH-CENTRAL NEWFOUNDLAND AND EVOLUTION OF THE EASTERN MARGIN OF IAPETUS

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ABSTRACT. South-central Newfoundland exposes a section from the edge of the Avalon Platform into the axial region of the Central Paleozoic Mobile Belt. It is interpreted as having formed part of the ancient southeastern margin of the Iapetus Ocean.

In the southeast, adjacent to the Avalon Platform are the Little Passage Gneisses, formed from both sedimentary and igneous rocks. They were deformed and metamorphosed before the first deformation of the Ordovician Baie d'Espoir Group, which outcrops to the northwest and with which they are in faulted contact. The gneisses are probably absent farther to the northwest where the Baie d'Espoir Group appears to have been deposited on oceanic crust. The southeastern part of the Baie d'Espoir Group consists of shelf deposits with some bimodal volcanic rocks; the northwestern part consists of turbidites. The group has been deformed twice and regionally metamorphosed in the greenschist to amphibolite facies.

A variety of igneous rocks has intruded the Little Passage Gneisses and Baie d'Espoir Group. The most important of these are foliated megacrystic granite, garnetiferous granite and granodiorite, and perthitic, chloritized, biotite granite. Metamorphism in the Baie d'Espoir Group was temporally and spatially related to the garnetiferous intrusions.

The rocks of south-central Newfoundland are strikingly similar to those along strike in the Gander area. Correlations are made with the Bonavista Bay Gneiss Complex, the Gander and Davidsville Groups, and the granitoid intrusions. Relationships in southern Newfoundland suggest that the Gander and Davidsville Groups are essentially conformable and that the gneisses were deformed and metamorphosed before deformation of the Gander Group.

It is proposed that the Little Passage Gneisses and the Bonavista Bay Gneiss Complex formed by continental accretion at the edge of the Avalon Platform in the Late Precambrian. In line with previous models it is thought that the Baie d'Espoir, Davidsville, and Gander Groups were deposited in an Ordovician back-arc basin. Stratigraphic and radiometric evidence suggests that almost all deformation, metamorphism, and intrusion of these groups was Acadian and was related to continental collision.

INTRODUCTION

The Newfoundland Appalachians, as exposed on the northeast coast of the island, were divided into three belts by Williams (1964). These were named the Western Platform (Kay, 1967), the Central Paleozoic Mobile Belt, and the Avalon Platform (Kay and Colbert, 1965) (fig. 1). The division was based on Late Precambrian to Early Paleozoic depositional and structural histories. The two platforms are considered to have been relatively stable areas on either side of the Iapetus Ocean (Wilson, 1966; Harland and Gayer, 1972), and the remnants of the ocean, together with the continental margins, are preserved in the intervening mobile belt.

The Central Mobile Belt is flanked by two marginal zones, referred to as the Fleur de Lys and Gander Zones (Williams, Kennedy, and Neale, 1974), or the western and eastern crystalline belts (Kennedy, 1975, 1976; Brown and Colman-Sadd, 1976). The marginal zones consist of deformed, medium to high grade metamorphic rocks derived mainly from sediments. The western crystalline belt contains deformed Grenvillian continental basement (de Wit, 1974). The eastern crystalline belt contains gneisses (Kennedy and McGonigal, 1972a; Colman-Sadd, ms), but there is some dispute as to whether these are a preexisting basement or are the result of prograde metamorphism in a conformable sedimentary sequence (Jenness, 1972; Kennedy and McGonigal, 1972b; Blackwood, 1977, 1978). The marginal zones are separated by an axial region lying between the Baie

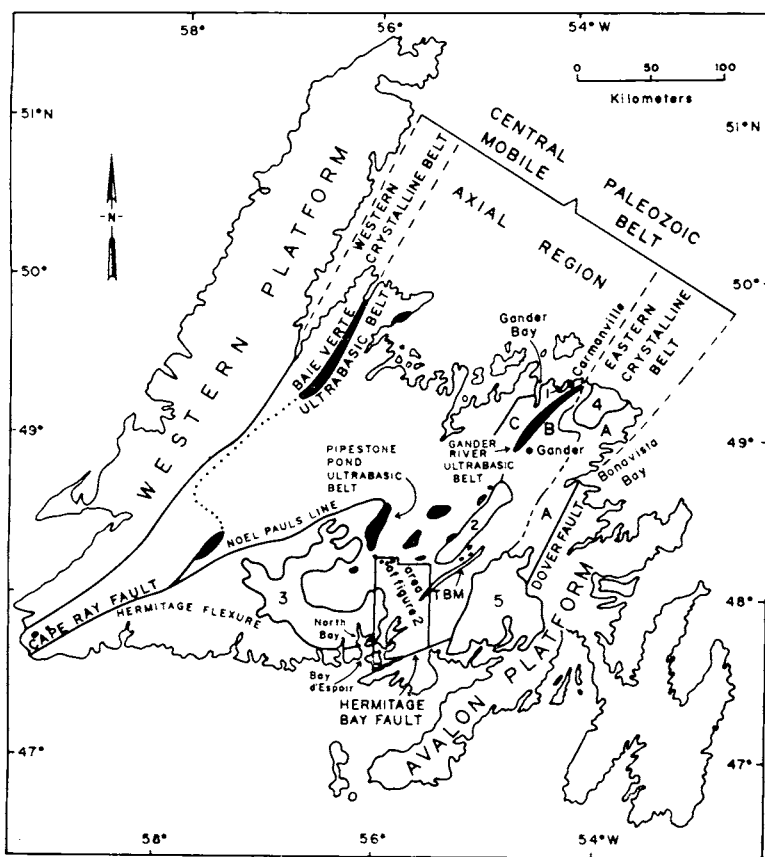


Fig. 1. Location map and structural divisions of Newfoundland. Ultrabasic rocks of Central Paleozoic Mobile Belt are shaded. Selected granitoid intrusions are numbered: (1) Rocky Bay and Frederickton plutons; (2) Middle Ridge Granite; (3) North Bay Granite; (4) Deadmans Bay Granite; (5) Ackley City batholith. (A) Bonavista Bay Gneiss Complex; (B) Gander Group; (C) Davidsville Group (from Williams, 1967; Blackwood, 1978; most granitoid plutons omitted); TBM, Twillick Brook Member.

Verte and Gander River ultrabasic belts. The axial region contains Ordovician and Silurian sedimentary and volcanic rocks of ophiolitic and island arc affinities, and in northeast Newfoundland it is not as intensely deformed or metamorphosed as the marginal zones. The position of the western edge of the eastern crystalline belt is uncertain southwest of Gander. Its extension along Noel Paul's Line and the Cape Ray Fault by Brown and Colman-Sadd (1976) marks the limit of high grade metamorphic rocks; it does not necessarily have any relationship to Lower Paleozoic sedimentary facies belts, which may cut across the structural trends of the Hermitage Flexure.

This paper is concerned principally with the eastern crystalline belt and adjacent parts of the axial region in south-central Newfoundland (figs. 1, 2). The area shown in figure 2 has been mapped at a scale of 1:50,000 (Colman-Sadd, 1976, 1978a,b, 1979). It is bounded in the south-east by the Hermitage Bay Fault (Blackwood and O'Driscoll, 1976), which marks the boundary with the Avalon Platform, and in the north by a zone of serpentine *mélange* in an area included in the axial region by Kennedy (1975, 1976). Correlations are made with northeastern Newfoundland, which lies along strike with respect to both depositional facies belts and orogenic structural trends. Conclusions, based on the geology of the whole belt, are used to reconstruct the history of the eastern margin of Iapetus in Newfoundland.

PROBLEMS OF THE EASTERN CRYSTALLINE BELT

The correlation of rocks along the eastern crystalline belt from Bay d'Espoir to the Gander area was proposed by Murray (Murray and Howley, 1881) and confirmed by Anderson and Williams (1970). Ideas for the development of the two areas have developed in parallel and show similar cycles of opinion.

Murray (Murray and Howley, 1881) concluded in both the Bay d'Espoir and the Gander areas that a basement of Precambrian "Laurentian Gneiss," underlies metasedimentary rocks which he equated to the Ordovician "Quebec Group." He presumed that an unconformity separates the two but was unable to prove it. Jewell (1939), working at Bay d'Espoir, and Jenness (1963), in the Gander area, proposed an alternative interpretation, that all the rocks of sedimentary origin belong to conformable sequences, the Baie d'Espoir Series and the Gander Lake Group. Jewell interpreted Murray's "Laurentian Gneiss" as a granite batholith containing contact-metamorphosed country rocks of the Baie d'Espoir Series. Jenness considered that the "Laurentian Gneiss" had been formed by metamorphism and granitization of the lower part of the Gander Lake Group.

Kennedy and McGonigal (1972a) resurrected the basement-cover concept in their interpretation of the Gander area. They divided Jenness' Gander Lake Group into three parts (fig. 1), separated by two presumed major unconformities. The eastern part was considered to be basement to the eastern crystalline belt and corresponds approximately with Murray's "Laurentian Gneiss;" it was named the Bonavista Bay Gneiss Com-

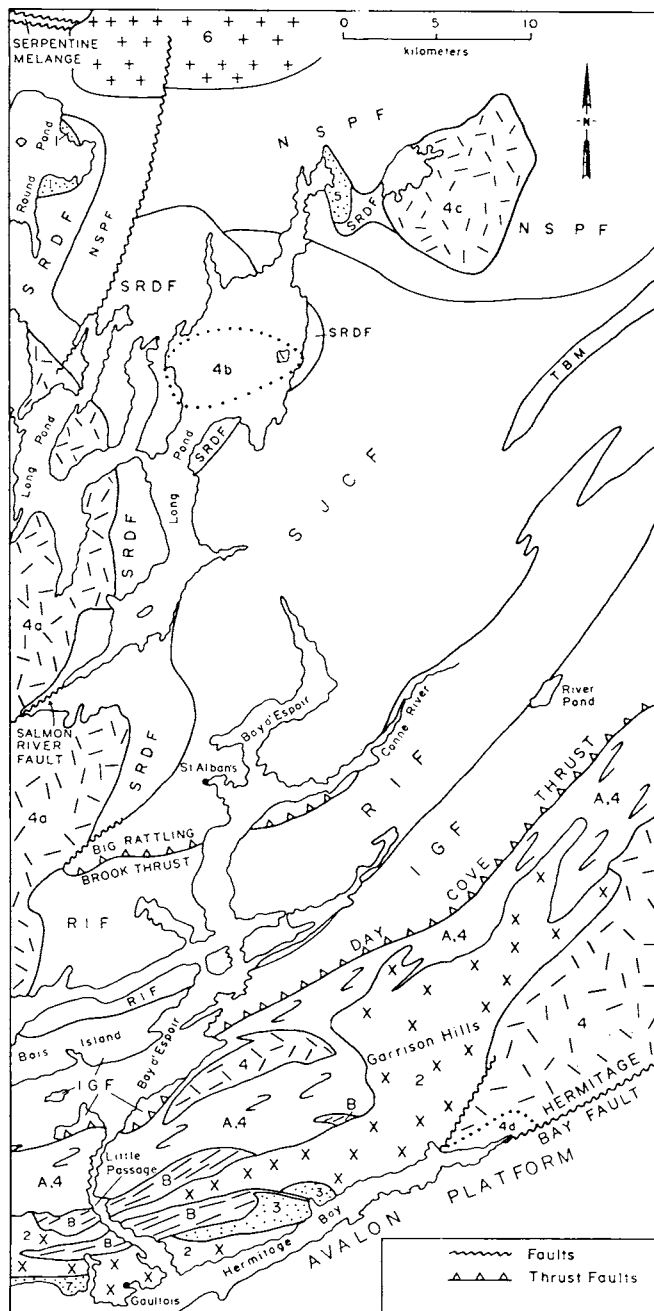


Fig. 2. Geology of south-central Newfoundland. (A) paragneiss and (B) tonalitic gneiss of Little Passage Gneisses. IGF, Isle Galet Formation; RIF, Riches Island Formation; SJCF, St. Josephs Cove Formation; NSPF, North Steady Pond Formation; SRDF, Salmon River Dam Formation; TBM, Twillick Brook Member; all of Baie d'Espoir Group. (1) mafic intrusions; (2) Gaultois Granite; (3) Northwest Cove Granite; (4) garnetiferous granite and granodiorite: (4a) North Bay Granite; (4b) Missing Island Granodiorite; (4c) Matthews Pond Granodiorite; (4d) Straddling Granite; (5) Rocky Bottom Tonalite; (6) Partridgeberry Hills Granite; (7) Piccaire Granite.

plex by Blackwood and Kennedy (1975). The central part of the Gander Lake Group was renamed the Gander Group by McGonigal (ms); it is unfossiliferous but was considered to be pre-Middle Ordovician on the basis of a presumed unconformity separating it from the fossiliferous Middle Ordovician Davidsville Group. The Davidsville Group is equivalent to the western part of Jenness' Gander Lake Group; it outcrops in the axial region of the Central Mobile Belt, west of the Gander River ultrabasic belt which it overlies unconformably (Kennedy, 1975).

Kennedy and McGonigal (1972a) also proposed that the granitic rocks in the Gander area could be divided into three groups: (1) megacrystic granites which were restricted to the basement, (2) garnetiferous leucogranites which intruded the basement and the Gander Group, and (3) tonalites and quartz-diorites which intruded the Davidsville Group. The megacrystic granites and the garnetiferous leucogranites were considered to be pre-Middle Ordovician, since they were deformed with the Gander Group, presumably before the deposition of the Davidsville Group.

In the Bay d'Espoir area the basement-cover interpretation was adopted by Colman-Sadd (ms). He recognized a tectonic contact separating the Baie d'Espoir Group (named after the series of Jewell) from the Little Passage Gneisses (approximately equivalent to Murray's "Laurentian Gneiss") and found megacrystic and garnetiferous granite with similar country rock relationships to those in the Gander area. He was unable to find an upper break corresponding to the presumed Davidsville-Gander Group unconformity.

Recent work in northeast Newfoundland has returned to the "continuous sequence" ideas of Jenness (1963). Currie and Pajari (1977), Pickerill and others (1978), Pajari and Currie (1978), and Currie, Pajari, and Pickerill (1979) were unable to recognize any unconformity between the Davidsville and Gander Groups and suggested that they might be time equivalents. They found that the garnetiferous leucogranites intruded the Davidsville Group as well as the Gander Group; their field evidence is supported by Silurian to Carboniferous Rb-Sr ages on granites that Kennedy and McGonigal (1972a) considered pre-Middle Ordovician (Bell and Blenkinsop, 1975; Bell, Blenkinsop, and Strong, 1977). Blackwood (1978) concluded that the older unconformity of Kennedy and McGonigal (1972a), between the Gander Group and the Bonavista Bay Gneiss Complex, does not exist; he attributed the change in rock type, as had Jenness (1963), to prograde metamorphism in a conformable sequence.

The fundamental problem in the eastern crystalline belt is how to interpret the division of the sedimentary, metasedimentary, and gneissic rocks. Were the gneisses deformed and metamorphosed before the deposition of the Gander and Baie d'Espoir Groups? Was the Gander Group deformed and metamorphosed before the deposition of the Davidsville Group? If these structural breaks are real, do they necessarily imply major stratigraphic unconformities? The answers to these questions are the keys

to an understanding of the Late Precambrian and Paleozoic history of the eastern margin of Iapetus.

GEOLOGY OF SOUTH-CENTRAL NEWFOUNDLAND

The geology of south-central Newfoundland (fig. 2) is described in some detail by Colman-Sadd (1976, 1978a,b, 1979). The following section constitutes a review of this work.

There are three main geologic divisions (fig. 2): (1) Little Passage Gneisses, (2) the metasedimentary and metavolcanic rocks of the Baie d'Espoir Group, and (3) a variety of plutonic igneous intrusions. The Little Passage Gneisses have been formed from both sedimentary and igneous rocks and have been metamorphosed in the amphibolite facies. A well exposed tectonic contact, the Day Cove Thrust, separates them from the Baie d'Espoir Group, which has been regionally deformed twice and metamorphosed at grades ranging from greenschist to amphibolite facies. The plutonic intrusions have mainly granitoid compositions but also include minor mafic rocks.

Little Passage Gneisses

The Little Passage Gneisses consist of three components: (1) amphibolitic gneiss, (2) paragneisses and schists, and (3) tonalitic gneiss.

The amphibolitic gneiss forms xenoliths in the tonalitic gneiss and conformable layers in both the tonalitic gneiss and the paragneisses. It is medium grained and consists of thin hornblende-rich bands separated by discontinuous streaks of andesine and quartz. The banding contains early isoclinal intrafolial fold closures and has been affected by later, tight, similar folds, with an axial-planar crenulation cleavage.

The paragneisses form the greater part of the Little Passage Gneisses and include a wide variety of rocks. The two dominant rock types are fine-grained psammitic gneiss and coarse-grained semipelitic gneiss, both of which have intrafolial folds. They are composed of quartz, varying proportions of plagioclase and perthitic microcline, and mica which is mainly biotite in the psammitic gneiss but is both biotite and muscovite in the semipelitic gneiss. Garnet occurs as augen, and fibrolitic sillimanite is present in the semipelitic gneiss.

The tonalitic gneiss is a medium-grained rock formed from an igneous protolith. The gneissic foliation varies from a poorly segregated fabric with rare intrafolial folds to a banding with several generations of isoclinal folds. In most places the variation is reflected in the amount of deformation of amphibolitic xenoliths and so is attributed to varying strain intensity. In a few places, however, mildly deformed tonalite with a ghost banding has intruded banded tonalitic gneiss, and the variation is attributed to remelting. The tonalitic gneiss consists mainly of quartz, andesine, and biotite, with accessory garnet, muscovite, and fibrolite.

The tonalitic gneiss intruded the amphibolitic gneiss after the latter had acquired its foliation. An intrusive contact in Little Passage shows tonalite injected along and across the foliation in the amphibolitic gneiss. Some of the amphibolite xenoliths in the tonalite have a foliation that is

folded or oblique to the foliation in the tonalite. The contact between the tonalitic gneiss and the paragneisses is highly deformed; since the paragneisses are intimately associated with the amphibolitic gneiss, it is presumed that they too were originally intruded by the tonalite.

Reworking of Little Passage Gneisses.—Within 5 km of the faulted contact with the Baie d'Espoir Group, the Little Passage Gneisses have been affected by two deformations, which increase in intensity toward the fault and postdate the formation of the gneissic foliation (table 1). The second of the deformations is directly related to the faulting. The sequence of events has been worked out in some detail in Little Passage where there is continuous exposure across strike (Colman-Sadd, ms) (fig. 3).

The gneissic foliation has been cut by pink granite veins which are associated with the megacrystic Gaultois Granite (fig. 2). Both the foliation and the granite veins have been openly folded 5 km from the Day Cove Thrust; 1 km farther north the folds have become isoclinal, and an axial-planar fabric has been formed by transposition of the gneissic foliation. White, garnetiferous granite dikes cut the folds and the Gaultois Granite post-tectonically. Open folds appear in the garnetiferous granite dikes and the first reworking fabric about 3 km from the fault; northward

TABLE 1
Structural, metamorphic, and intrusive histories of the Baie d'Espoir Group and Little Passage Gneisses with proposed correlations

BAIE D'ESPOIR GROUP		LITTLE PASSAGE GNEISSES	AGE OF EVENT
<p>SECOND DEFORMATION (recumbent folding to southeast)</p> <p>intrusion of PARTRIDGE-BERRY HILLS GRANITE (?), ROCKY BOTTOM TONALITE, GARNETIFEROUS GRANODIORITE and GRANITE; synchronous REGIONAL METAMORPHISM, greenschist to amphibolite facies</p> <p>FIRST DEFORMATION (isoclinal folding in un lithified sediment; probable formation of serpentine melange)</p> <p>DEPOSITION of Baie d'Espoir Group, on oceanic crust in northwest, on Little Passage Gneisses in southeast</p>	<p>DAY COVE THRUST</p> <p style="writing-mode: vertical-rl; transform: rotate(180deg);">precise relationships obscured during second deformation</p>	<p>SECOND REWORKING DEFORMATION (folds overturned to southeast)</p> <p>intrusion of GARNETIFEROUS GRANITE; synchronous growth of andesine porphyroblasts and possibly sillimanite</p> <p>FIRST REWORKING DEFORMATION</p> <p>intrusion of GAULTOIS GRANITE</p> <p>formation of GNEISSIC FOLIATION, amphibolite facies METAMORPHISM, intrusion of TONALITE</p> <p>DEPOSITION of sediments</p>	<p>ACADIAN OROGENY (MIDDLE SILURIAN TO DEVONIAN)</p> <p>mainly MIDDLE ORDOVICIAN</p> <p>LATE PRECAMBRIAN TO CAMBRIAN</p>

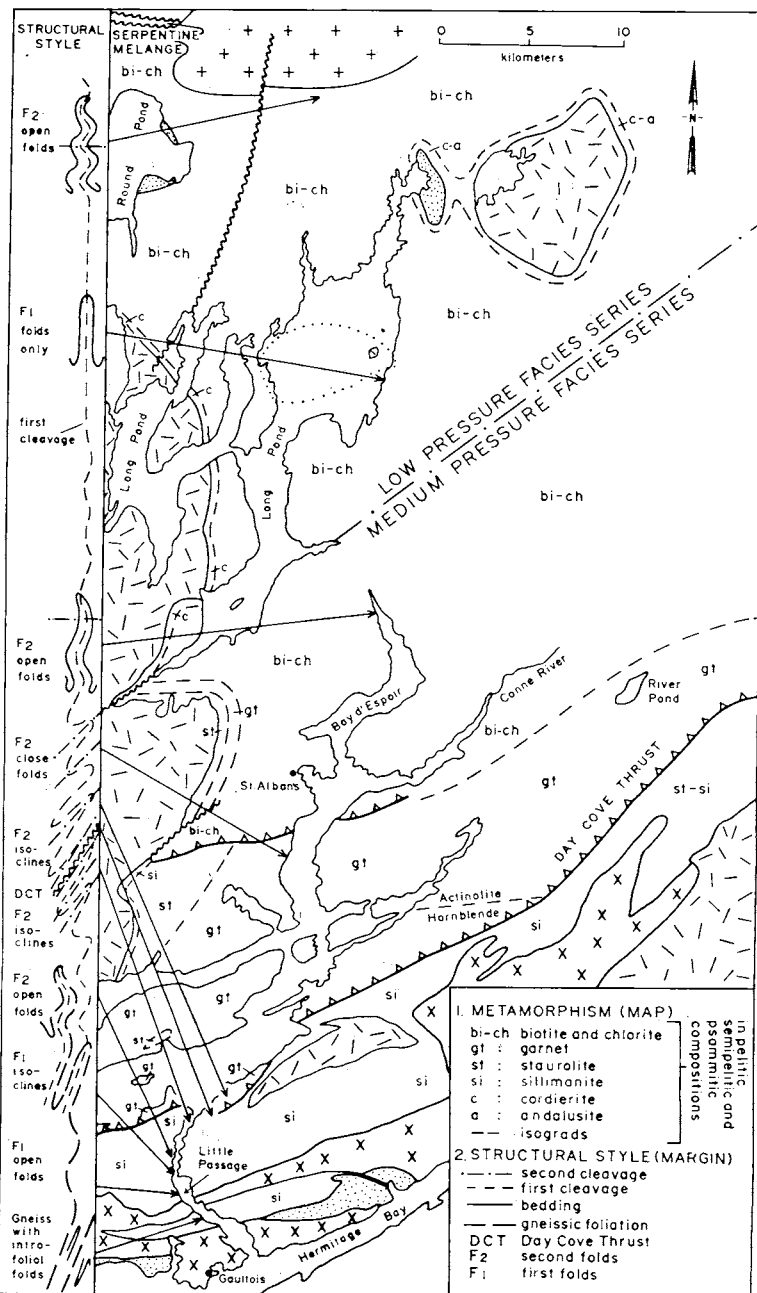


Fig. 3. Structural styles and metamorphic grades in south-central Newfoundland.

these gradually tighten into isoclinal folds, and the first deformation fabric has been transposed to form a second reworking fabric. In several places, within 50 m of the contact with the Baie d'Espoir Group, the gneisses and garnetiferous granite dikes have been mylonitised.

Plagioclase (An 32) poikiloblasts in the paragneisses have overgrown the first reworking fabric but form augen within the second fabric; they therefore formed at the same time as intrusion of the garnetiferous granite dikes. Since they also overgrew foliations that enclose garnet augen, they are considered to result from a metamorphic event that was distinct from earlier metamorphism in the gneisses.

Baie d'Espoir Group

The Baie d'Espoir Group is divided into five conformable formations (Colman-Sadd, 1976 and in press) (figs. 2, 4). The Salmon River Dam Formation plunges beneath and is older than the St. Josephs Cove and North Steady Pond Formations; the latter two have a gradational contact and are lateral equivalents. The relative positions of the St. Josephs Cove, Riches Island, and Isle Galet Formations are uncertain because of the complexities of polyphase deformation; where unfaulted they have interfingering relationships with each other and may also be approximate lateral equivalents.

The age of at least part of the Baie d'Espoir Group has been determined as Middle Ordovician on the basis of a fossil locality at Conne River on the boundary between the Riches Island and St. Josephs Cove Formations (Colman-Sadd, 1976). Other very poorly preserved fossils were reported by Dunlop (ms) from the Riches Island and Isle Galet Formations; they indicated an Ordovician or possibly Cambrian age. Baird and others (ms) and Anderson and Williams (1970) reported Middle Ordovician graptolites from near the southeast margin of the Twillick Brook Member, 40 km northeastward along strike from Bay d'Espoir.

Isle Galet Formation.—The formation is characterized by volcanic rocks, although most of it consists of submarine clastic sedimentary rocks. The most important volcanic rock type is fine-grained, felsic crystal tuff

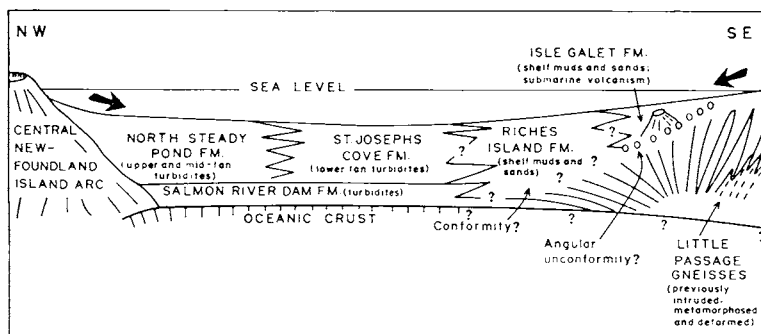


Fig. 4. Schematic section through the Baie d'Espoir Group during the Middle Ordovician, showing the probable stratigraphic relationships. Heavy arrows indicate probable directions of sediment transport. No scale implied.

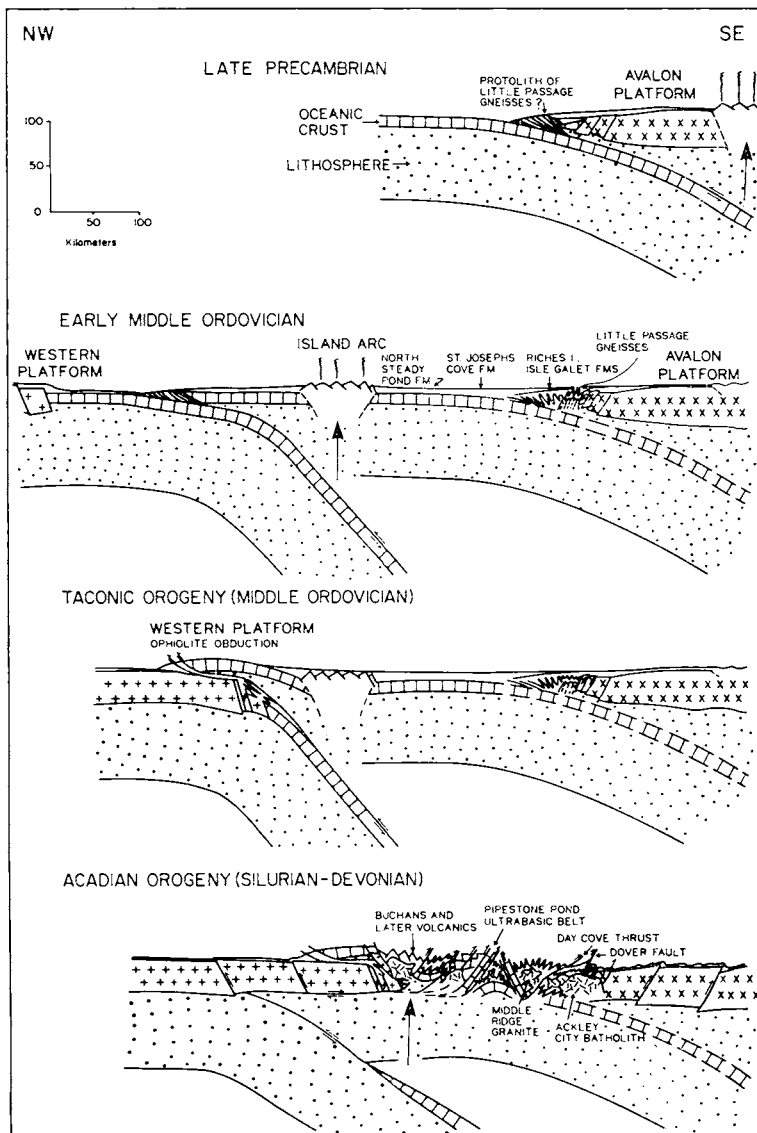


Fig. 5. Model for the evolution of the eastern margin of Iapetus during the Late Precambrian and Paleozoic.

forming massive sheets that locally contain lenses of lapilli tuff. One tuff sheet northeast of River Pond passes laterally into coarse tuff, flow-banded rhyolite, and altered granite, probably indicating the presence of a volcanic vent. Syngenetic lead, zinc, and copper mineralization is associated with the tuff.

Mafic igneous rocks are best developed along the southern shore of Bay d'Espoir, where they form a massive sheet of amphibolite. The sheet occurs in an area of intense deformation, and conclusive evidence of its mode of emplacement has been destroyed. Mafic dikes cutting rocks of the Isle Galet Formation and intruded into the Little Passage Gneisses adjacent to the Day Cove Thrust may be related to emplacement of the mafic sheet. Minor bedded amphibolite occurs elsewhere in the formation and is presumed to have been deposited as mafic tuff.

Sedimentary rocks show a marked lateral facies variation. They consist mainly of graphitic schist on Bois Island and then pass eastward into pebbly psammite and green-gray phyllite. The psammite contains clasts of sedimentary, plutonic, and metamorphic rock types.

Riches Island Formation.—The dominant rock type is parallel laminated green-gray pelite with very thin interbeds of cross- and parallel-laminated siltstone. Much of the pelite is metamorphosed to phyllite, and the siltstone to quartz and garnet. Gray sandstone beds, 3 cm to 5 m thick, are present throughout the formation but are particularly common south of St. Alban's, where they are metamorphosed to quartzite and psammite. Bed contacts are sharp, and coarse cross-bedding and conglomerate lenses occur in a few places.

Graphitic siltstone and pelite form narrow but laterally extensive outcrops. There are a few scattered occurrences of felsic to intermediate volcanic rocks.

St. Josephs Cove Formation.—Most of the formation consists of thin, slightly calcareous siltstone and sandstone beds and medium to thick bedded gray pelite; there are also a few thin interbeds of quartz-sericite phyllite. Parallel and cross lamination, with microscopic grading, is common in the siltstone and sandstone beds, and incomplete Bouma sequences (Bouma, 1962) can be recognized in most exposures. Locally the formation includes sequences of medium- to thick-bedded, graded immature sandstone with thin interbeds of gray pelite.

The only volcanic rocks in the St. Josephs Cove Formation belong to the Twillick Brook Member. Within the area of figure 2, this is a pyroclastic deposit consisting of quartz and andesine crystals set in a foliated, fine-grained matrix, which is locally fragmental. At least part of the northeastward extension of the member is reported to be intrusive (D. Prince, personal commun., 1978). The outcrop of pyroclastic rocks is bounded on the south by graphitic slate which is otherwise absent from the St. Josephs Cove Formation.

North Steady Pond Formation.—The formation is characterized by graded, immature, volcanoclastic sandstone beds, interbedded with green-gray pelite and very thin parallel- and cross-laminated siltstone beds.

Medium-grained felsic crystal-lithic tuff occurs near the Partridgeberry Hills Granite, especially north of Round Pond, where it is associated with massive felsic and intermediate flows. Mafic pyroclastic breccia is present at one locality near the Partridgeberry Hills Granite.

Conglomerate is exposed just east of Round Pond and in a belt extending along the contact with the serpentine mélange. The conglomerate has a sandstone and pelite matrix and forms thick-bedded sequences with very coarse sandstone. The clasts have a slight preferred orientation sub-parallel with bedding, are subrounded to angular, and are poorly sorted. They consist of argillite, siltstone, psammite, fine to medium grained felsic and mafic igneous rocks, chert, calcite, and vein quartz.

Salmon River Dam Formation.—Most of the formation consists of medium- to thick-bedded, purplish gray, calcareous siltstone. Cyclic bedding is generally present, with each cycle consisting of massive, structureless siltstone, parallel-laminated siltstone, and a thin bed of parallel- and cross-laminated, well sorted, fine-grained sandstone. At a few localities there is a thick massive division of graded sandstone. Thin cross-laminated calc-silicate beds occur throughout the formation, and calcareous pelite beds are common around southern Long Pond.

Sedimentary facies of the Baie d'Espoir Group.—Two main difficulties arise in the interpretation of sedimentary facies in the Baie d'Espoir Group. The first is the ubiquitous isoclinal folding during the first deformation; the folding makes reconstruction of paleocurrent directions virtually impossible and has obscured the relative stratigraphic positions of the St. Josephs Cove, Riches Island, and Isle Galet Formations. The second is the destruction of sedimentary structures in the Riches Island and Isle Galet Formations during regional metamorphism and the second deformation. Despite these problems some generalizations can be made about the sources of sediment and the processes of deposition.

The Baie d'Espoir Group can be broadly divided into "turbidite" and "non-turbidite" formations. The "turbidite" formations are the Salmon River Dam, North Steady Pond, and St. Josephs Cove Formations. All show various aspects of the Bouma cycle (Bouma, 1962). The North Steady Pond and St. Josephs Cove Formations, which are considered to be lateral equivalents, can be readily fitted to the submarine fan model of Walker (1978). Pebbly sandstones and conglomerates of the North Steady Pond Formation are interpreted as channel deposits, and the graded sandstone beds as mid-fan turbidites. The fine grained, thin to medium bedded rocks of the St. Josephs Cove Formation are lower fan turbidites.

The tendency of the North Steady Pond Formation to coarsen toward the north and northwest and the exclusively sedimentary and volcanic nature of the clasts suggest derivation from a volcanic terrane in central Newfoundland. The turbidites of the St. Josephs Cove Formation show no coarsening trend and, except for randomly distributed coarse sandstone sequences, are remarkably monotonous. The narrow

northeast striking outcrop of the volcanic Twillick Brook Member and the possibility of a volcanic center at its northeastern end indicate that for these pyroclastic rocks transport was in a predominantly southwesterly direction. Since both pyroclastic debris and turbidity currents may have flowed down the same paleoslope, it is reasonable to suppose that much of the St. Josephs Cove Formation was deposited by axial, southwesterly flowing turbidity currents.

The Riches Island and Isle Galet Formations show no evidence of turbidite deposition. The dominant sedimentary rock type of both formations is green-gray pelite with very thin interbeds of siltstone. These rocks are thought to have been deposited as shelf muds with storm sand layers (Reineck and Singh, 1973, p. 323). The medium to very thick bedded sandstone beds present in both formations may represent coastal sands or offshore shoals. Clasts in these rocks include metamorphic and plutonic types but little volcanic material. They suggest derivation from a source different than the three turbidite formations and may indicate Ordovician erosion of the gneissic rocks presently exposed southeast of the Baie d'Espoir Group. The fine grained graphitic and pyritic sedimentary rocks of the two formations are thought to have been deposited during periods of restricted sea water circulation, and most of the extrusive volcanic rocks are considered to be submarine. In the Isle Galet Formation syndepositional volcanism or deposition close to the shoreline may have caused the several abrupt facies changes along strike.

Structure of the Baie d'Espoir Group.—Two regionally developed deformations have affected the Baie d'Espoir Group.

The first deformation formed northeast-trending, shallowly plunging isoclinal folds throughout the group. The associated axial-planar slaty cleavage is generally subparallel with bedding. On fold hinges many of the sand, silt, and calc-silicate beds have been dismembered and injected along the cleavage surfaces; in well laminated beds, the laminations show chaotic folding. These structures are comparable to those described by Maxwell (1962) and Powell (1972) as the products of tectonic dewatering and indicate that the sediments were unlithified at the onset of deformation. Metamorphism later during the deformation has converted the cleavage into a schistosity in much of the Riches Island and Isle Galet Formations. The serpentine mélange was intruded by granite before or during the second deformation, so it too was probably formed during the first deformation. The mélange consists of brecciated blocks of serpentine up to 600 m across, set in a sheared shaly matrix with fragments of sedimentary and felsic volcanic rocks.

The second deformation postdated the climax of metamorphism. It formed northeast-trending recumbent folds which are asymmetric toward the southeast. In contrast to the first deformation, the second deformation had varying intensity in different parts of the Baie d'Espoir Group (fig. 3). It was most intense in the Isle Galet Formation adjacent to the faulted contact with the Little Passage Gneisses. In this belt, folds are isoclinal, and the first deformation cleavage is transposed; competent

psammitic and volcanic rocks have been cataclastically deformed, and intervening incompetent schist layers have been so fragmented by shearing that primary structures are unrecognizable. At a distance of more than 1 km from the gneisses, there is little evidence of cataclasis, and incompetent layers have maintained their internal integrity. Folds become progressively more open northward, and the axial-planar fabric becomes a crenulation cleavage. At the head of Bay d'Espoir most folds have an obtuse dihedral angle, and the cleavage has only formed in pelitic beds. Second deformation structures are rarely present around the northern part of Long Pond. Open to close folds and an associated crenulation cleavage have affected the first deformation fabric near the Partridgeberry Hills Granite, but it is not certain that this second deformation can be correlated with that farther south.

Three major faults affecting the Baie d'Espoir Group were formed or continued activity during the second deformation. The age of a fourth fault, which trends northeasterly east of Round Pond, is uncertain because of poor exposure. The vergence of second-deformation minor folds changes across the Salmon River Fault, which appears to have cut out the axis of a synform pinched between the two lobes of the North Bay Granite. The Big Rattling Brook Thrust has its maximum displacement near the North Bay Granite, where it brings biotite-grade St. Josephs Cove Formation into contact with granite and sillimanite-grade Riches Island Formation (fig. 3). It appears to have been formed by the interference of the pre-tectonic North Bay Granite with the second deformation recumbent folding, and it dies out to the northeast away from the granite. The third major fault is the Day Cove Thrust, which forms the tectonic contact between the Baie d'Espoir Group and the Little Passage Gneisses. Along most of its length the fault consists of a zone of intensely sheared schist and mylonitized gneiss and granite, up to 100 m wide. It represents the focus of the second deformation; structures decrease in intensity away from it, both in the Baie d'Espoir Group and in the Little Passage Gneisses.

Metamorphism of the Baie d'Espoir Group.—The Baie d'Espoir Group has been regionally metamorphosed in the greenschist, epidote-amphibolite, and amphibolite facies. There is a variation from the medium-pressure facies series (Miyashiro, 1973) in the southeast to the low-pressure series in the northwest (fig. 3). Metamorphism reached its peak between the first and second deformations in almost all parts of the Baie d'Espoir Group. The peak was synchronous with intrusion of the main granitoid plutons, and isograds show a spatial relationship to these intrusions (fig. 3); metamorphic grade, unlike deformation, does not show a consistent increase toward the contact with the Little Passage Gneisses.

The line marking the first appearance of garnet passes obliquely across the Riches Island Formation into the Isle Galet Formation. Staurolite occurs within 2 km of the North Bay Granite, and fibrolitic sillimanite in the contact zone of the granite. The garnet and staurolite

generally contain straight inclusion trails of the first fabric and form augen in the second; the fibrolitic sillimanite, which has formed by replacement of biotite, is inferred, but not proven, to be the same age. Mafic igneous rocks around the southern part of Bay d'Espoir contain hornblende, but farther northeast the amphibole is actinolite. Graphitic rocks are commonly tremolitic.

The St. Josephs Cove Formation and most of the Salmon River Dam and North Steady Pond Formations are metamorphosed in the greenschist facies. Pelitic and semipelitic rocks contain biotite, muscovite, and chlorite defining the first fabric and have static overgrowths of biotite, which has then been crenulated during the second deformation. Calcareous rocks of the Salmon River Dam and North Steady Pond Formations are characterized by tremolite-actinolite and clinozoisite. Close to the North Bay Granite and southeast of the Salmon River Fault, pelite and semipelite of the Salmon River Dam Formation contain garnet and staurolite. In most contact zones north of the fault, chloritized cordierite and sericitized andalusite occur in siltstone and pelite beds respectively; garnet and hornblende are present in calc-silicate beds. All these minerals have overgrown the first fabric and form augen where there is a second fabric.

Only biotite and muscovite have grown as a result of metamorphism adjacent to the Partridgeberry Hills Granite.

Intrusive Rocks

The Little Passage Gneisses and the Baie d'Espoir Group have been intruded by a variety of igneous rocks, ranging from granite to gabbro-norite, but principally with granitoid compositions. Three groups of intrusions are of particular areal importance; these are the foliated megacrystic Gaultois Granite, the garnetiferous granites and granodiorites, and the perthitic Partridgeberry Hills Granite (fig. 2).

Gaultois Granite.—The Gaultois Granite is a coarse, biotite granite with anhedral poikilitic megacrysts of microcline and subhedral prisms of plagioclase, zoned from An₃₈ to An₂₀. Its northeastern parts lack microcline, have less quartz, and may contain hornblende and labradorite, so that the intrusion ranges in composition from granite, through tonalite and diorite, to gabbro. Pink pegmatite and aplite dikes, containing muscovite and tourmaline, cut the granite and surrounding gneisses. A tectonic foliation defined by biotite and recrystallized quartz is present almost everywhere except in the very central part of the intrusion.

The Gaultois Granite has only intruded the Little Passage Gneisses. It does not come in contact with the Baie d'Espoir Group, so its relationship to these rocks is unknown. It was intruded by garnetiferous granite after it acquired its fabric, and this fabric can be correlated with the first reworking deformation of the gneisses.

Garnetiferous granite and granodiorite.—These rocks intruded both the Baie d'Espoir Group and the Little Passage Gneisses. They range in composition from porphyritic biotite-hornblende granodiorite to garnet-

muscovite granite, but are all associated with distinctive aplite and pegmatite dikes, containing red garnet, tourmaline, and muscovite. They were intruded after the first deformation of the Baie d'Espoir Group and the first reworking deformation of the Little Passage Gneisses but before the second deformation.

They form three intrusions into the Baie d'Espoir Group within the area of figure 2. The North Bay Granite (Jewell, 1939) shows the full range of rock types. Medium grained biotite-hornblende granodiorite surrounds a core of migmatite, exposed in North Bay farther to the west (fig. 1). The granodiorite contains euhedral microcline phenocrysts, which are up to 10 cm long and locally have a flow alignment. The outer parts of the granite consist of muscovite-biotite granodiorite and garnet-muscovite granite. The other two intrusions contain either biotite and hornblende (Missing Island Granodiorite) or biotite and muscovite (Matthews Pond Granodiorite). It is probable that the three intrusions are continuous in the subsurface and that their northeasterly alignment is continued into the Gander area by the Middle Ridge Granite (Strong and others, 1974).

Garnet-tourmaline-muscovite granite dikes occur throughout the outcrop of the Little Passage Gneisses and are identical in appearance to those in the margins of the North Bay Granite. The dikes were involved in the second reworking deformation of the gneisses and are terminated abruptly by the Day Cove Thrust; with a solitary exception on Bois Island, there are none in the area between the fault and the North Bay Granite.

The large outcrop of garnetiferous granite in the southeastern part of the Garrison Hills consists of a mass of muscovite, biotite, and two-mica granite dikes, with garnet occurring in muscovite-bearing varieties and in pegmatite veins. The dikes intruded the gneisses, and the Gaultois Granite and many, but not all, have a tectonic fabric.

Partridgeberry Hills Granite.—The Partridgeberry Hills Granite intruded the North Steady Pond Formation and the serpentine mélange after the first deformation but before or during the second deformation.

The granite is coarse grained and equigranular. It contains chlorite, derived by alteration of biotite, and strongly perthitic microcline. The contact between the granite and the country rocks consists of a zone up to 2 km wide in which sedimentary rock has been permeated by magma. Rocks in the zone resemble a deformed medium grained granite; the fabric, however, consists of discrete foliae of country rock in an undeformed granitic groundmass. There are no pegmatite or aplite dikes associated with this intrusion.

Other intrusions.—Three small intrusions occur along the north shore of Hermitage Bay. The Northwest Cove Granite is foliated and rich in muscovite; it appears to be about the same age as the Gaultois Granite. The Straddling Granite (Blackwood and O'Driscoll, 1976) may be younger than the garnetiferous granite, but its boundaries are difficult to define, and it could be a phase of the latter that has been altered

along the Hermitage Bay Fault; the 490 ± 10 Ma age for this granite (Blenkinsop, Cucman, and Bell, 1976) was based on samples from south-east of the fault which may not have come from the same intrusion. The Piccaire Granite has intruded the Gaultois Granite post-tectonically. There are other small intrusions of diabase, dacite, and tonalite in Little Passage.

The Baie d'Espoir Group has been intruded by small bodies of gabbro-norite, diorite, tonalite, and diabase. The Rocky Bottom Tonalite, which contains hornblende and prominent poikilitic phenocrysts of biotite, was intruded between the first and second deformations; it is remarkably similar to the Frederickton and Rocky Bay Plutons of the Carmanville area (Strong and others, 1974).

Tectonic Development of Southcentral Newfoundland

There were three main events in the tectonic development of the Baie d'Espoir Group (table 1):

1. First deformation forming isoclinal folds in unmetamorphosed and largely un lithified sediments; this was probably accompanied by the formation of the serpentine *mélange* along a fault.
2. Granitoid intrusion and spatially related regional metamorphism.
3. Second deformation forming recumbent folds, related to the Day Cove Thrust contact with the Little Passage Gneisses.

Part of the structural development of the Little Passage Gneisses can be matched to that of the Baie d'Espoir Group.

The second reworking deformation in the gneisses is equivalent to the second deformation of the Baie d'Espoir Group. The folds have the same asymmetry and show the same increasing intensity of deformation toward the faulted, mylonitized contact at the Day Cove Thrust.

The intrusion of granitoid rocks into the Baie d'Espoir Group and the accompanying regional metamorphism are matched in the gneisses by the intrusion of garnetiferous granite dikes and the growth of andesine poikiloblasts; it is also likely that fibrolitic sillimanite in the gneisses is of this age. This amphibolite-facies metamorphism in the gneisses is not related to earlier metamorphism that caused the widespread growth of garnet; the garnet forms augen within a foliation overgrown by the andesine poikiloblasts. Metamorphism in the Baie d'Espoir Group increases toward the granitoid intrusions; before the second deformation, a similar progressive increase in the grade of this granite-related period of metamorphism must have been superimposed across the contact between the Baie d'Espoir Group and the Little Passage Gneisses. Fault displacement along the Day Cove Thrust during the second deformation is responsible for the present sharp increase in metamorphic grade across the contact and the abrupt termination of the garnetiferous granite dikes that cut the gneisses. An analogous relationship occurs within the Baie d'Espoir Group, where the Big Rattling Brook Thrust brings biotite-grade St. Josephs Cove Formation into contact with North Bay Granite and sillimanite-bearing Riches Island Formation.

The intrusion of garnetiferous granite and its accompanying metamorphism was preceded in the Little Passage Gneisses by the first reworking deformation, the intrusion of the Gaultois Granite, the deformation and metamorphism that originally created the gneisses, and the intrusion of the protolith of the tonalitic gneiss. The only early event in the Baie d'Espoir Group was a period of isoclinal folding in initially unmetamorphosed sediment. Clearly there is substantial structural and metamorphic disharmony between the Baie d'Espoir Group and the Little Passage Gneisses.

The first deformation of the Baie d'Espoir Group and the first reworking deformation of the Little Passage Gneisses cannot be correlated directly, because their structures are separated by a zone of intense second deformation strain (the Day Cove Thrust) that obscures earlier structure. The correlation, however, is supported by the available evidence on the timing of events. The Baie d'Espoir Group is in part equivalent to the Davidsville Group in northeast Newfoundland (table 2); the latter was probably deformed with the Silurian Botwood Group (Blackwood, 1979), and the first deformation, therefore, is tentatively dated as Middle Silurian or later. The Gaultois Granite is a foliated megacrystic granite and has been deformed by the first reworking deformation of the gneisses; it is similar to the foliated megacrystic granites near Bonavista Bay that have yielded a maximum radiometric age of 400 ± 15 Ma from the Cape Freels Granite (Bell and Blenkinsop, 1975). The first reworking deformation is therefore also dated indirectly as Middle Silurian or later. The first deformation of the Baie d'Espoir Group may have represented the reaction of still unlithified sediment to movement in underlying, lithified, rocks.

The first reworking deformation was superimposed on the gneisses after a substantial interval of time had elapsed since their previous deformation. It does not represent the last movement of a composite structural and metamorphic event. It is separated from the formation of the gneissic foliation, not only by the intrusion of the Gaultois Granite, but also by the intrusion of dacite dikes and a small tonalite body (Colman-Sadd, ms). The dikes contain angular xenoliths of tonalitic gneiss, which have been broken off the wall rocks by brittle fracture; they indicate intrusion in an extensional environment but bear the later imprint of both reworking deformations. Furthermore, where the first reworking deformation is only moderately developed, it has deformed the gneisses by parallel folding, associated with kinking of micas, but not recrystallization. This is not the behavior that would be expected if deformation took place during amphibolite-facies metamorphism and was closely related to the intrusion of the tonalitic gneiss.

It is instructive to compare the Little Passage Gneisses to the parts of the Riches Island Formation adjacent to the North Bay Granite. Both groups of rocks have been extensively intruded by garnetiferous granite dikes and at the same time have been metamorphosed to sillimanite grade. Both groups of rocks have been deformed before and after meta-

morphism. Rocks of the Riches Island Formation, unlike those of the Little Passage Gneisses, are not gneissic and bedding is still visible; there is no evidence of an earlier metamorphic or intrusive history.

It is concluded that the Little Passage Gneisses were intruded, metamorphosed, and deformed before the first deformation of the Baie d'Espoir Group. They, therefore, indicate an early period of tectonism that may well have taken place before the Baie d'Espoir Group was deposited in the Ordovician.

CORRELATION WITH NORTHEAST NEWFOUNDLAND

Similarities and Dissimilarities

Many authors (for example, Murray and Howley, 1881; Jenness, 1963; Anderson and Williams, 1970; Kennedy and McGonigal, 1972a)

TABLE 2
Geologic divisions in southcentral Newfoundland and proposed correlations with northeast Newfoundland

SOUTH-CENTRAL NEWFOUNDLAND	Rock types, sedimentary facies	NORTHEAST NEWFOUNDLAND
PARTRIDGEBERRY HILLS GRANITE	perthitic granite	not represented
represented by ACKLEY CITY BATHOLITH east of figure 2	unfoliated mega-crystic granite	DEADMANS BAY GRANITE, ETC. (4)
ROCKY BOTTOM TONALITE	hornblende tonalite, granodiorite	ROCKY BAY, FREDERICKTON PLUTONS (4)
NORTH BAY GRANITE, MISSING ISLAND, MATTHEWS POND GRANODIORITES, ETC.	garnetiferous granodiorite, granite	ASPEN COVE, RAGGED HARBOUR, MIDDLE RIDGE GRANITES (4)
GAULTOIS GRANITE	foliated mega-crystic granite	CAPE FREELS (4), LOCKERS BAY (5) GRANITES
SERPENTINE MELANGE		
BAIE D'ESPOIR GROUP	North Steady Pond F. St. Josephs Cove F. Salmon River Dam F.	[west] DAVIDSVILLE [east] GROUP (2) not represented
		GANDER RIVER ULTRABASIC BELT (1)
	shelf sediments shelf sediments and volcanic rocks	GANDER GROUP (3) volcanic rocks very rare
LITTLE PASSAGE GNEISSES	tonalitic gneiss	Hare Bay Gneiss (6)
	paragneiss	Square Pond Gneiss (6)
		BONAVISTA BAY GNEISS COMPLEX (5)

References: 1, Jenness (1958); 2, Kennedy and McGonigal (1972a); 3, McGonigal (ms); 4, Strong and others (1974); 5, Blackwood and Kennedy (1975); 6, Blackwood (1977).

have pointed out that the geology of south-central Newfoundland is continuous with that in the Gander area. Table 2 shows the detailed correlations proposed in this paper.

Paragneisses and tonalitic gneiss are common to both the Little Passage Gneisses and the Bonavista Bay Gneiss Complex. Near Gander, however, the metamorphic grade in the paragneisses is, in places, as low as greenschist facies, and Blackwood (1977, 1978) has described relict bedding and apparent conformity with the Gander Group.

Sedimentary facies in the Gander and Davidsville Groups have the same variation from southeast to northwest as is found in the Baie d'Espoir Group. The Gander Group (fig. 1), which is correlated with the Riches Island Formation, was interpreted as a continental shelf or rise deposit by Pickerill and others (1978). The southeastern part of the Davidsville Group, except that part immediately adjacent to the ultrabasic belt, was described as distal turbidites by Currie, Pajari, and Pickerill (1979); these rocks are considered equivalent to the St. Josephs Cove Formation. The same authors described a westward transition of the Davidsville Group into more proximal turbidites and noted the common occurrence of conglomerate boulders at Gander Bay; conglomerate was found *in situ* by Blackwood (1979). The same variation is found from the St. Josephs Cove to North Steady Pond Formations. The only notable difference in sedimentary facies is the almost total absence in the northeast of the volcanic rocks that characterize the Isle Galet Formation. These appear to either wedge out or be truncated by the Ackley City batholith about 60 km northeast of Bay d'Espoir (Moore, 1953).

The pattern of deformation in south-central Newfoundland also occurs in the northeast. Kennedy and McGonigal (1972a) reported two main deformations in the Gander Group with the second being responsible for southeasterly directed recumbent folds; the structure of the southeastern part of the Baie d'Espoir Group is comparable. The Davidsville Group has a single penetrative slaty cleavage, axial planar to isoclinal folds, and a locally developed crenulation cleavage (Blackwood, 1979); similar structures occur in the northwestern part of the Baie d'Espoir Group, where the second deformation was only weakly developed.

Metamorphism in the Gander and Davidsville Groups varied from greenschist to amphibolite facies and in many cases appears to have been related to the granitoid intrusions (Kennedy, 1975; Currie and Pajari, 1977). Facies series (Miyashiro, 1973) were the medium and low pressure types. The same pattern of metamorphism occurred in the Baie d'Espoir Group.

Foliated megacrystic granite, similar to the Gaultois Granite, is restricted to the gneissic terrane in northeastern Newfoundland (Blackwood, 1978), and garnetiferous granite and granodiorite intrude the gneisses, the Gander Group, and the Davidsville Group (Kennedy and McGonigal, 1972a; Currie and Pajari, 1977). Hornblende-biotite granodiorite forms the Rocky Bay and Frederickton plutons to the west of the

main garnetiferous intrusions, in the same relative position as the Rocky Bottom Tonalite. The unfoliated megacrystic granites of northeast Newfoundland such as the Deadmans Bay Granite are not found in the area of figure 2 but are represented just to the east by the Ackley City batholith (fig. 1).

The Gander River ultrabasic belt (Jenness, 1958) does not occur in the Baie d'Espoir Group where it might be expected, between the St. Josephs Cove and Riches Island Formations. If the belt represents an overthrust of oceanic crust onto the Gander Group (Blackwood, 1979; Currie, Pajari, and Pickerill, 1979), its correlative may be the serpentinite mélange north of the North Steady Pond Formation. Thus, if the belt is present, it has been stepped outward toward the center of the Central Mobile Belt.

Implications

Relationships observed in the Baie d'Espoir Group and Little Passage Gneisses suggest solutions to the controversy surrounding the conformity or unconformity of the Davidsville Group, the Gander Group, and the Bonavista Bay Gneiss Complex.

The St. Josephs Cove Formation, which is correlated with part of the Davidsville Group, and the Riches Island Formation, which is correlated with the Gander Group, are demonstrably conformable and even appear to be lateral equivalents. It follows that, although the Davidsville Group is unconformable on rocks of the Gander River ultrabasic belt, it is likely to be essentially conformable with the Gander Group (Currie and Pajari, 1977). It also follows that the principal distinction between the two groups is one of sedimentary facies (Pickerill and others, 1978). There is no evidence for a pre-Middle Ordovician Ganderian orogeny (Kennedy, 1975) in the Baie d'Espoir Group.

The recognition that metamorphism and deformation in the Little Passage Gneisses pre-dated that in the Baie d'Espoir Group implies that at least part of the Bonavista Bay Gneiss Complex was also affected by early tectonism before the deformation of the Gander Group (Kennedy and McGonigal, 1972a). Such tectonism is not incompatible with a continuous stratigraphic sequence (Jenness, 1963; Blackwood, 1978), if the protolith of the gneisses was originally formed as sediments at the edge of the same continental margin as the Gander Group. Sedimentation would have been continuous as long as a land-sea interface existed; it could have continued while sediments already deposited were being deformed and metamorphosed. It is quite possible for a sequence of rocks to be essentially conformable, even though deformation, metamorphism, and intrusion have affected one part before the deposition of another part. The proof of an early tectonic history in the gneisses of the eastern crystalline belt depends on the identification of a set of structural, metamorphic, and intrusive events that have been overprinted by all the events affecting the Baie d'Espoir or Gander Groups. In south-central Newfoundland, easily defined tectonic, metamorphic, and magmatic episodes, coupled with continuous coastal exposure, make the proof

of an early history possible. In the Gander area, its recognition may have to rely on the rather more intuitive reasoning of Kennedy and McGonigal (1972a).

If it is valid to equate the two main deformations of the Gander Group with the two main deformations of the Riches Island Formation, then these must also be equated with the first, penetrative, and the second, crenulation, cleavages of the St. Josephs Cove Formation and its probable correlative, the Davidsville Group. Since the penetrative cleavage of the Davidsville Group also appears to affect the Botwood Group (Blackwood, 1979; Currie, Pajari, and Pickerill, 1979), which contains Middle Silurian fossils (Williams, 1962), there is a strong possibility that all or most deformation in the Gander and Baie d'Espoir Groups was Middle Silurian or later, that is Acadian. Currie, Pajari, and Pickerill (1979) consider that the Llanvirn-Llandeilo age for the unconformity between rocks of the Davidsville Group and the ultrabasic belt dates the emplacement of the belt. They indicate that this event marked the deformation and termination of deposition in the Gander Group. While the evidence presented here is not sufficiently strong to refute this argument, it does suggest an alternative explanation; the unconformity may have formed on oceanic crust before thrusting and may have been rafted into place during the Acadian deformation. It is significant that, just southwest of the Gander River ultrabasic belt, ultrabasic rocks have been emplaced into siltstones of the Silurian Botwood Group (Kean, 1974).

Rb-Sr radiometric dates on the granitoid rocks of northeast Newfoundland (Bell and Blenkinsop, 1975, 1977; Bell, Blenkinsop, and Strong, 1977) indicate the probable ages of similar rocks in the south, northwest of the Hermitage Bay Fault, where they are in general agreement with K-Ar determinations (Anderson and Williams, 1970). The dates range from the Silurian to the Carboniferous and suggest that the intrusion of most of the granitoid rocks, together with the accompanying regional metamorphism, took place during the Acadian orogeny.

EVOLUTION OF THE EASTERN MARGIN OF IAPETUS

The Little Passage Gneisses and the Bonavista Bay Complex preserve little evidence of their early history. They could be part of the craton that was originally rifted to form the Iapetus Ocean (Kennedy, 1975). Alternatively they could be rocks deposited after rifting and accreted onto the continental margin of the Avalon Platform before the Ordovician. The latter is considered most likely, because the rock units and structures show a gross parallelism with the Appalachian trend, which would be fortuitous if they were part of an earlier craton. Furthermore, this is the only way that the early tectonic events recorded in the Little Passage Gneisses can be reconciled with conformity between the Gander Group and the Bonavista Bay Gneiss Complex (Blackwood, 1978).

Strong (1977) proposed a subduction zone dipping eastward beneath the Avalon Platform to account for Late Precambrian and Cambrian volcanism; his hypothesis is supported by the geophysical evidence of

Haworth, Lefort, and Miller (1978). He pointed out that the Late Precambrian date for the rifting of the Western Platform to form the Iapetus Ocean (Williams and Stevens, 1969; Dewey and Bird, 1970) does not necessarily apply to the rifting of the Avalon Platform. It is proposed that the gneissic rocks of the eastern crystalline belt formed by sedimentation on the eastern margin of Iapetus in the Late Precambrian (fig. 5). Deformation of these rocks may be related to the same subduction process that caused volcanism on the Avalon Platform; subduction of a spreading ridge, which has been proposed to explain the variations in this volcanism through time (O'Brien, ms), could have provided a heat source for metamorphism and plutonism in the gneisses (DeLong and Fox, 1977).

The sedimentary rocks of the Baie d'Espoir, Davidsville, and Gander Groups were deposited in a Lower to Middle Ordovician back-arc basin separating the island-arc sequences in the axial region of the Central Mobile Belt (Kean and Strong, 1975; Strong, 1977) from the Avalon Platform. The faunal evidence of Stouge (1979) conflicts with the contention of McKerrow and Cocks (1977) that a major suture is present between the Davidsville Group and volcanic rocks of Notre Dame Bay. The North Steady Pond Formation and the west part of the Davidsville Group were formed of detritus from the island arc. The Gander Group and the Isle Galet and Riches Island Formations were derived by erosion of the rocks of the Avalon Platform to the east and possibly also of the earlier formed gneisses. The St. Josephs Cove Formation and the eastern part of the Davidsville Group were deposited in the center of the basin and included detritus from both sources and, in the case of the Davidsville Group, from the ocean floor itself. The presence of volcanic rocks in the Isle Galet Formation may indicate that the island arc and Avalon Platform coalesced just southwest of Bay d'Espoir and pinched out the back-arc basin.

The island arc in central Newfoundland was formed above an easterly dipping subduction zone (Strong, 1977). The closing of Iapetus began with the obduction of ophiolites in the Middle Ordovician (Rodgers, 1965), as the leading edge of the Western Platform was subducted beneath the arc-trench gap. This event, the Taconic orogeny, did not mark actual continental collision, and relative movement between the Western and Avalon Platforms did not end at this time, as has been supposed by Strong (1977) and Strong and Dickson (1978).

Comparison with Mesozoic and Cenozoic orogenic belts shows that ophiolite obduction is only the first stage in the process of continental collision. In the Zagros suture zone of Iran, ophiolite obduction took place in the Late Cretaceous, but the main deformation caused by collision did not start until the Late Miocene (Falcon, 1974); subduction is still continuing (Nowroozi, 1972). In the Himalayas obduction was also in the Late Cretaceous, but again the main deformation was post-Eocene, and granitoid intrusions have cooling ages of 9 to 15 Ma (Gansser, 1974).

In both cases, the time interval between ophiolite obduction and the main deformation was 40 to 50 Ma, and in the Himalayas the interval between obduction and the cooling of intrusions was about 60 Ma. In Newfoundland, Taconic ophiolite obduction was separated from major Acadian deformation by about 50 Ma and from the cooling of most granitoid intrusions in the eastern crystalline belt by 50 to 120 Ma (the Middle Brook and Lockers Bay Granites, for which the interval is smaller and greater respectively, are excluded) (Bell and Blenkinsop, 1977; Bell, Blenkinsop, and Strong, 1977; Strong and Dickson, 1978; Bell and others, 1979).

It is assumed, therefore, that plate convergence continued after the Taconic orogeny, causing telescoping of the remains of the arc-trench gap and of the arc itself. The concept of "flake" tectonics (Oxburgh, 1972) is used in figure 5 to allow crustal shortening, without creating space problems in the lithosphere by lateral migration of the subduction zone. Relative movement between the two cratons that had bordered the Iapetus Ocean did not end until the main deformation in the Acadian orogeny. At this stage of collision, polyphase deformation affected the back-arc basin, crushing Ordovician sediments against previously deformed rocks at the edge of the Avalon Platform. It is probable that this was also the time of upthrusting of ophiolitic basement to form the Gander River and Pipestone Pond ultrabasic belts. Regional metamorphism and anatexis resulted from crustal thickening and frictional heating, as the two cratons ground each other to a halt. The magma that was generated formed the voluminous Silurian to Carboniferous plutons of the Central Mobile Belt and the Avalon Platform. The absence of these plutons from the Western Platform reflects the asymmetry of collision, which was inherited from the asymmetry of subduction.

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