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THE APPALACHIANS IN NORTHEASTERN NEWFOUNDLAND—A TWO-SIDED SYMMETRICAL SYSTEM*

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ABSTRACT. Northeastern Newfoundland displays one of the most complete cross sections of the Appalachian mountain system and furnishes an opportunity to study a variety of well-defined Precambrian rocks which are poorly exposed or absent farther southwest along the eastern seaboard of North America. The Appalachian Paleozoic mobile belt in northeastern Newfoundland is symmetrical, bounded both on the northwest and on the southeast by Precambrian rocks overlain by Lower Paleozoic shelf deposits.

INTRODUCTION

Location.—The island of Newfoundland forms the northeastern extremity of the Appalachian mountain system, which extends 2000 miles northeastward from the southeastern United States. The Appalachians in northeastern Newfoundland consist of a central Paleozoic mobile belt bounded by Precambrian rocks on both sides, which in turn are followed northwestward by the Precambrian Canadian Shield and southeastward by the Atlantic Ocean. Northeastward the system extends beyond the exposed continental crust into the North Atlantic Ocean. The general geology of the Canadian Appalachian region and the location of the northeastern Newfoundland cross section of the Appalachians are shown in figure 1.

Purpose and scope.—The regional pattern of sedimentation and tectonism in the Appalachians of Newfoundland has long been neglected, yet along the northeastern coast one of the most complete cross sections of the Appalachian system is exposed. The two-sided nature of the mobile belt there has long been known, but the idea has never taken root among students of regional tectonism, particularly the proponents of continental accretion. The purpose of this paper is to summarize the sedimentary and tectonic features of northeastern Newfoundland from the viewpoint that here the Appalachian system is two-sided and that the Paleozoic mobile belt is symmetrical about a central axis.

Most of the author's knowledge of the geology of Newfoundland has been gained from standard reconnaissance mapping in the north-central part of the island and from compiling the recently published reconnaissance maps of adjoining areas. The details of stratigraphy and structure are still imperfectly understood, but recent reconnaissance work has tended to bring out similarities, rather than differences, among many widely separated previously mapped areas, making it now possible to draw certain generalizations concerning sedimentation and orogenic history.

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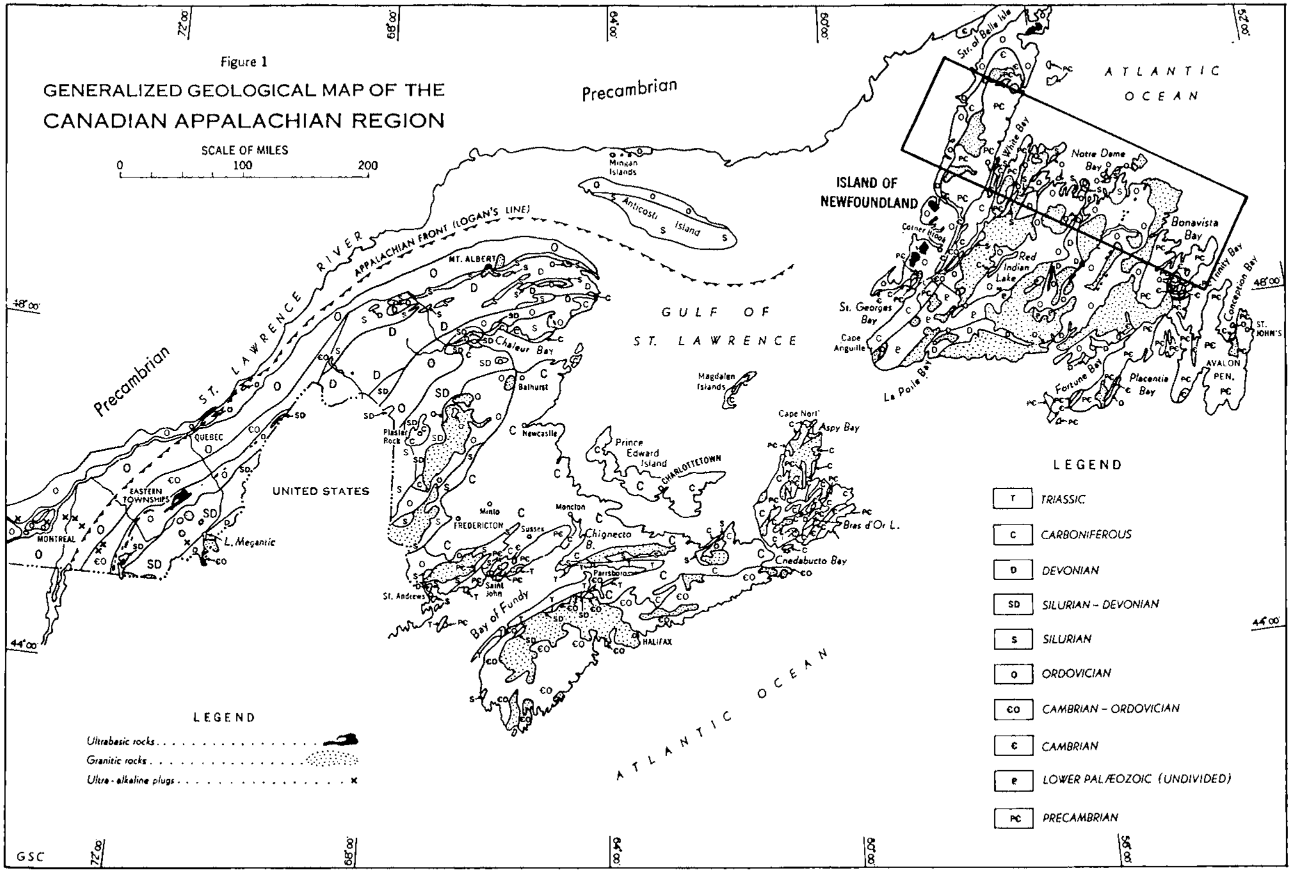

Fig. 1. Generalized geologic map of Canadian Appalachian Region (after Neale and others, 1961); figure shows location of area under discussion in northeastern Newfoundland. (Rocks shown as Devonian in northeastern Newfoundland are now interpreted as Silurian.)

History of investigation.—The pioneer geologists of Newfoundland, J. B. Jukes, Alexander Murray, and J. P. Howley, classified the Precambrian rocks in eastern Newfoundland and noted Precambrian crystalline complexes throughout western Newfoundland. In the central part of the island they recognized Paleozoic rocks of several ages, including mafic and ultramafic intrusions and extensive granitic intrusions. Very little systematic mapping of the island was undertaken until the period from 1930 to 1949 when numerous areas were mapped under the sponsorship of the Geological Survey of Newfoundland. Studies in northeastern Newfoundland during this period were made by Heyl (1936, 1937), Espenshade (1937), Foley (1937), Cooper (1937), Betz (1939, 1948), Fuller (1941), MacLean (1947), Watson (1947), Hayes (1948), and Rose (1948).

After 1949, following confederation with Canada, much of the mapping of Newfoundland was carried out by the Geological Survey of Canada. This has included studies in eastern Newfoundland by Christie (1950), Rose (1952), Hutchison (1953, 1962), Jenness (1963), and McCartney (1954, 1956, 1957, 1958, in press), and in northeastern and western Newfoundland by Hriskevitch (1950), Baird (1951, 1958, 1959), Hayes (1951a and b), Kalliokoski (1953, 1955), Smith (1958), Riley (1957, 1962), Patrick (1956), Neale and Nash (1963), and Williams (1962, 1963, 1964). The Geological Survey of Newfoundland also carried out some mapping during this period, notably studies of the eastern ultramafic belt by Grady (ms) and Jenness (1958) and traverses across the Great Northern Peninsula by Fritts (1953).

In 1934 Schuchert and Dunbar published the results of their stratigraphic studies in western Newfoundland, and in 1937 Twenhofel and Shrock gave the first detailed accounts of Silurian rocks in northeastern Newfoundland. Other pertinent publications, which deal with the regional geology of parts of the island, are those of Snelgrove (1928), Twenhofel (1947), Kindle and Whittington (1958), Clifford and Baird (1962), and Rodgers and Neale (1963). Summaries of Newfoundland geology have been prepared by Snelgrove and Baird (1953) and Weeks (1963) and geological map compilations by Baird (1954) and Weeks (1955).

Subdivisions of the Appalachians in Northeastern Newfoundland.—Structural features in the Appalachians of northeastern Newfoundland trend northeasterly, and the rocks can be subdivided into three major tectonic belts arranged symmetrically as shown in figure 2. In the west the dominant structural feature is the Precambrian Long Range complex of the Great Northern Peninsula, which in some places is overlain unconformably by and in others is separated by faults from Lower Paleozoic shelf-type deposits. The Long Range complex is separated from Precambrian rocks to the east by a Paleozoic geosynclinal basin or mobile belt that shows the following symmetrical elements: (a) its margins are marked on both sides by extensive sedimentary clastic deposits or their metamorphosed equivalents; (b) these clastic deposits are bounded toward the center of the basin by thin zones of ultramafic intrusions; (c) these ultramafic zones are followed inward by extensive thicknesses of Ordovician and Silurian volcanic and sedimentary rocks. The Precambrian

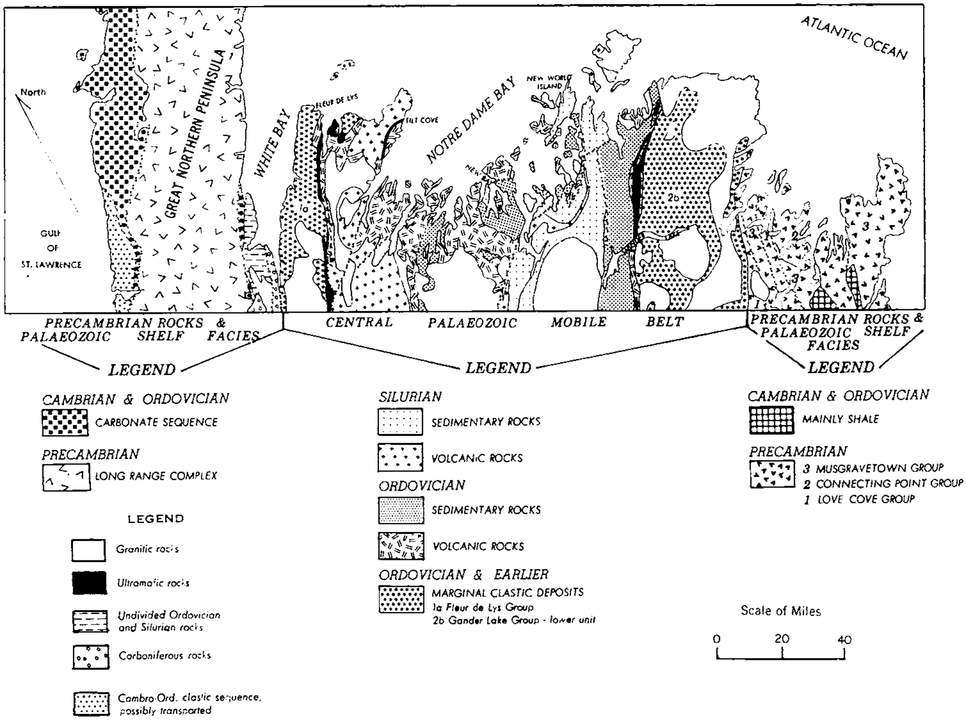

Fig. 2. General geology and major tectonic belts in northeastern Newfoundland.

rocks to the east cannot be correlated with the Long Range complex. although some of them may be of the same age. They are overlain by Lower Paleozoic shallow-water deposits and apparently formed a shelf or platform that lay to the east of the Paleozoic geosynclinal belt.

In the discussion that follows the Appalachians of northeastern Newfoundland are described under the heading of the three major tectonic belts as follows:

(1) western Precambrian rocks and Lower Paleozoic deposits,
(2) central Paleozoic mobile belt,
(3) eastern Precambrian rocks and Lower Paleozoic deposits.

WESTERN PRECAMBRIAN ROCKS AND LOWER PALEOZOIC DEPOSITS

The Precambrian rocks of western Newfoundland, as shown in figure 2, form the central portion of the Long Range complex (Baird, 1959; Neale and Nash, 1963). They are bounded on the west by Cambrian and Ordovician sedimentary rocks, and lithologically similar rocks also occur to the east of the Long Range complex on the west side of White Bay. Those at White Bay are overlain by Silurian clastic rocks with volcanic members or by much less deformed Carboniferous strata, and all are separated from the central Paleozoic mobile belt by a major fault trending northeastward through White Bay.

Western Precambrian Rocks

The Long Range complex consists of an assemblage of schists and gneisses, which are described as psammitic schists and gneisses, quartzites, pelitic and semipelitic schists and gneisses, and hornblendic schists and gneisses (Clifford and Baird, 1962). Most of the rocks are thought to be of sedimentary origin, but no attempt has been made to determine their stratigraphy. The mineralogy of the metamorphic rocks is monotonous, and assemblages of amphibole and plagioclase, with local occurrences of sillimanite, suggest regional metamorphic conditions typical of the amphibolite facies. The metamorphism is definitely dated as Precambrian, for nearby Cambrian strata are relatively unmetamorphosed. These schists and gneisses are cut by several large bodies of granite and a few small intrusions of gabbroic anorthosite. Two potassium-argon age determinations, 945 and 960 million years, have been made on micas from two different granites that cut the Long Range complex (Lowdon and others, 1963). These fall into the pattern established within the Grenville geological province in nearby parts of the Canadian Shield.

Diabase dikes cut indiscriminately across all the Precambrian rocks and probably represent feeders for altered basalts which occur locally at the northeastern extremity of the complex (Clifford and Baird, 1962). Similar relationships are displayed in the Blue Ridge Mountains of northern Virginia where basic dikes cut crystalline basement rocks and are believed to have acted as feeders for overlying Catoctin greenstones (Reed, 1955).

The rocks of the Long Range complex were not affected by Paleozoic orogeny, except for faulting and possible retrogressive metamorphism. Most evidence suggests that the Precambrian rocks acted as a buttress and protected surrounding Paleozoic strata from the intense folding so evident in the nearby central Paleozoic mobile belt. A possible exception is found west of White Bay where Lower Paleozoic rocks are folded and intruded by porphyritic granite of a type that is correlated lithologically with granite found in the nearby Long Range complex (Heyl, 1937; Neale and Nash, 1963).

Southwestward along strike the Long Range complex is not exposed, but small areas of retrograded Precambrian intrusive and metamorphic rocks are known north of St. Georges Bay (fig. 1), and possible Precambrian anorthosites occur 20 miles to the east (Riley, 1962). The St. Georges Bay rocks are dated radiometrically at a minimum of 900 million years (Lowdon and others, 1963), and the anorthosites to the east at 451 million years (Leech and others, 1963). The latter date was made on chloritized rocks and is suspect, but if the anorthosites are Precambrian the radiometric date suggests Paleozoic deformation in this southern area.

Lower Paleozoic Deposits

The Paleozoic rocks west of the Longe Range complex belong to two separate facies, each many thousands of feet thick. One contains a well established sequence of dolostone, limestone, and sandstone units, which have been called the carbonate sequence by several workers including Rodgers and Neale (1963); the other is a clastic assemblage consisting of shale, sandstone, conglomerate, and lime-breccia. Mafic volcanic rocks and mafic and ultramafic intrusions are associated with the clastic assemblage to the south of the area shown in figure 2.

The carbonate sequence ranges in age from Cambrian to Middle Ordovician and rests with marked unconformity upon the Precambrian Long Range complex where its contacts are not marked by faults. Rodgers and Neale (1963) have interpreted the carbonate and associated rocks as shallow water deposits, which probably accumulated on wide shoal banks. The same authors have drawn attention to the similarities between these rocks in western Newfoundland and strata of the same age and lithology in the Taconic region of New York.

The relationships between the carbonate and clastic sequences in western Newfoundland are not generally well established. The clastic sequence is surrounded by carbonate rocks along its eastern side and appears to lie stratigraphically above them, but the recent work of Kindle and Whittington (1958) has shown that the clastic sequence is at least partly equivalent in time to the Cambrian and Ordovician carbonate sequence. Clifford and Baird (1962) regarded the clastic sequence as possibly autochthonous and possibly deposited in fault-bounded embayments within the carbonate depositional environment; in contrast, Rodgers and Neale (1963) regarded the same clastic rocks as allochthonous, forming a possible klippe in western Newfoundland of dimensions similar to those of the possible Taconic klippe in western New York. These authors suggested that the proposed klippe originated east of the carbonate deposits near the western side of the central Paleozoic mobile belt; the rocks presumably were uplifted, then emplaced in Middle Ordovician time by westward gravitative sliding.

Tectonic Significance of Western Belt

The tectonic relationships in western Newfoundland are in general similar to those displayed along the west side of the entire Appalachian chain. There is little doubt that the Long Range complex represents an uplifted block of Precambrian crystalline basement rocks, and as Clifford and Baird (1962) have pointed out, the lithology and structure of the complex, along with Precambrian radiometric dates, led inevitably to the conclusion that it is a Grenville inlier. Its structural position in the northeastern Newfoundland Appalachians is analogous to the position of the Green Mountains in Vermont and to Precambrian schists and gneisses exposed within the Appalachian Blue Ridge province of the southeastern United States. The Long Range complex Grenville inlier lies within the Appalachian geosyncline, in contrast to the Adirondack inlier of New York, for the former is bordered to the west by Lower Cambrian rocks which occur elsewhere throughout the Appalachians but which are absent along the eastern border of the Adirondack Mountains and throughout central North America; moreover Paleozoic rocks are deformed all around the Long Range complex but are undeformed (except by normal faults) around the Adirondacks.

The Lower Paleozoic carbonate sequence of western Newfoundland has the facies of a typical platform sedimentary deposit, though much thicker, and is analogous to Cambrian and Lower Ordovician strata found along the west side of the Appalachians as far as Alabama. These rocks were apparently deposited where shallow seas transgressed upon the slightly submerged and gently subsiding eastern margin of the central craton of the North American continent.

The significance of the Lower Paleozoic clastic sequence is less obvious, particularly if the rocks are considered to be in their original place of deposition. If however the rocks are part of a large klippe, as suggested by Rodgers and Neale (1963), then they originated in the depositional environment of the central Paleozoic mobile belt. Many of the klippe rocks, such as mafic volcanic rocks, graptolitic slates, graywackes, and ultramafic intrusions, are a good sampling of the rocks in the central Paleozoic mobile belt, but others, such as coarse lime-breccia beds, are unknown in Newfoundland outside of the possible klippe.

CENTRAL PALEOZOIC MOBILE BELT

The central Paleozoic mobile belt of northeastern Newfoundland is approximately 140 miles wide and is made up almost entirely of Ordovician and Silurian rocks which have been folded, faulted, and cut by a variety of intrusions. Possible Precambrian rocks occur along its margins on the eastern side of White Bay and around the eastern end of Gander Lake. Almost all the large granitic intrusions in Newfoundland are localized throughout this belt, and many of the mafic and ultramafic intrusions lie in two linear zones near its margins. The rocks are not highly metamorphosed in northeastern Newfoundland, except in marginal zones less than 20 miles wide, but southeastward along strike toward the south coast of the island, metamorphic rocks are dominant.

Marginal Clastic Deposits

Extensive clastic deposits or their metamorphosed equivalents occur on each side along the boundaries of the central Paleozoic mobile belt. To the west these rocks are known as the Fleur de Lys group, and their counterpart to the east is the lower unit of the Gander Lake group, as seen in figure 2. The rocks are similar in that they are dominantly of clastic sedimentary parentage, but in the west they are everywhere regionally metamorphosed and represented by schists and gneisses. Locally, the Fleur de Lys group contains marble beds, presumably near its top, which are unknown in the lower unit of the Gander Lake group. None of the rocks has been dated by fossils in northeastern Newfoundland, but they are no younger than Middle Ordovician and probably no older than Late Precambrian.

East of White Bay the Fleur de Lys group rocks are continuous along strike for approximately 70 miles and are thought to be continuous with similar gneisses and schists many tens of miles to the southwest. In addition they possibly extend to the islands 60 miles northeast of White Bay (fig. 1), thus suggesting continuity for several hundred miles. The lower unit of the Gander Lake group is likewise continuous and has been mapped across central Newfoundland by Jenness (1963) and tentatively correlated with lithologically similar rocks in the Bay d'Espoir area on the south coast of the island.

Fleur de Lys Group.—Fuller (1941) named the Fleur de Lys group from exposures along the eastern headland at the entrance to White Bay and estimated its total thickness at 20,000 feet. East and southwest of this type area Watson (1947) and Betz (1948) referred similar rocks to the Rattling Brook group, Mings Bight formation, and the White Bay group, respectively. Subsequently rocks of the type area were studied by Baird (1951) and Neale (1959b), and their southwest continuation was mapped by Neale and Nash (1963).

The Fleur de Lys group is apparently structurally conformable below probable Ordovician volcanic rocks along its eastern boundary, but in places the contact has been interpreted as a fault (Watson, 1947; Neale and Nash, 1963). Elsewhere the group is in fault contact with or unconformably overlain by Carboniferous rocks. The gneisses and schists are cut by granite, which is dated radiometrically in one locality at 358 million years (Lowdon and others, 1963). This suggests a Devonian age for the intrusion and agrees with a date of 355 million years (Lowdon and others, 1963) obtained from muscovite schist of the Fleur de Lys group, which presumably dates the latest metamorphism.

The Fleur de Lys rocks are described as chiefly coarse-grained light- to medium-gray biotite and muscovite schists and gneisses which are typically composed of pale gray sodic plagioclase, platy quartz, biotite, and muscovite in various proportions (Neale and Nash, 1963). Some of the layers are quartzitic and in places have preserved cross bedding and scour-and-fill structures. Garnetiferous muscovite schists, thin layers of graphitic schist, and rare beds of white marble occur as concordant lenses within the gneisses; also present are gneissic conglomerates, which contain stretched quartzite pebbles. Along the eastern shore of White Bay pink and white coarsely crystalline marble beds are prominent. Sills and dikes of meta-gabbro occur within the Fleur de Lys group, and chloritic schists and gneisses or hornblendic gneisses are common near the eastern boundary where the Fleur de Lys rocks are in contact with volcanic and ultramafic rocks.

Murray (Murray and Howley, 1881) correlated the major part of the Fleur de Lys group with the gneisses of the Long Range complex and the marble beds along the east shore of White Bay with Lower Paleozoic marble beds along the west shore of the bay. Fuller (1941), Watson (1947), and Baird (1951) all interpreted the northeastern exposures of the group as Precambrian, chiefly on the basis of metamorphic grade. Neale (1959a) suggested an Early Paleozoic age because of apparent structural concordance with amphibolitized volcanic rocks of the tentative Ordovician Baie Verte group. More recently Neale and Nash (1963) have interpreted the group as occupying a northeast-trending anticlinorium and on structural grounds favor an interpretation whereby the rocks along both the east and west flanks are of Early Paleozoic age with the gneisses in the core of the anticlinorium being Early Paleozoic or Precambrian.

Fleur de Lys group rocks are largely covered by Carboniferous strata southwestward along strike. However, in the Corner Brook area Riley (1957) has mapped similar schists and gneisses with associated marble beds which appear to underlie conformably metamorphosed Cambrian rocks of the western Newfoundland carbonate sequence. In the same general area McKillop (1963) mapped schists and gneisses of the Mount Musgrave formation which also appear to underlie concordantly metamorphosed Cambrian deposits. These relationships suggest that the Fleur de Lys group is a clastic sequence basal to the carbonate rocks of western Newfoundland and possibly an eastward intertonguing facies equivalent of the carbonate rocks in its upper parts. According to this interpretation, marble beds within the Fleur de Lys group along the eastern shore of White Bay represent intertonguing strata of the lower part of the carbonate shelf deposits. Furthermore, along the eastern margin of the Fleur de Lys group in the type area, the gneisses and schists contain a higher proportion of chloritic and hornblendic rocks than elsewhere. and locally the gneisses and schists are overlain conformably by metamorphosed mafic volcanic rocks. The Fleur de Lys group, therefore. appears to represent a transition between two different environments of deposition, and the writer suggests that the eastern edge of the carbonate shelf in western Newfoundland was not far removed from areas of Ordovician volcanism to the east.

Gander Lake group—lower unit.—The term Gander Lake group (Jenness, 1958) is a modification of the earlier term Gander Lake series proposed by Twenhofel (1947) for a great thickness of shales. slates, and sandstones exposed along the shore of Gander Lake (fig. 2). The Gander Lake series of Twenhofel was much more restricted than the present group of the same name. It did not include volcanic rocks and excluded large areas of sedimentary and metamorphic rocks subsequently included by Jenness (1958, 1963) and Williams (1964).

Jenness (1963) divided the Gander Lake group into three broad lithologic units: a lower unit composed chiefly of arenaceous rocks, a middle unit composed chiefly of mixed sedimentary rocks and a well-defined belt of volcanic rocks, and an upper unit composed chiefly of argillaceous rocks. The upper and middle units have been dated by fossils and are Middle Ordovician. The age of the lower unit is as yet unknown. but it appears to underlie conformably Ordovician volcanic rocks and slates of the middle unit. The base of the lower unit is also vague where it is in contact with Precambrian rocks of the Love Cove group (Jenness, 1963) to the east, and its relationships to the Precambrian rocks are in doubt. The actual contact has not been observed, but it has been interpreted as a fault rather than an unconformity chiefly because of apparently less intense metamorphism displayed in the Precambrian rocks where the two types are in juxtaposition (Jenness, 1963).

Rocks of the lower unit constitute a monotonous sequence of micaceous quartzose sandstones, graywackes, quartzites. siltstones, and slates, which underlie an area nearly 30 miles wide. Many of the rocks are light to dark gray. of medium grain, and composed mainly of quartz with minor plagioclase and rock fragments in a clayey or micaceous matrix. Where metamorphism has not been intense the rocks are thinly bedded—less than a foot in thickness and commonly not more than a few inches thick. Many of the rocks have a wafered appearance and break along closely spaced micaceous parting planes, which are thought to represent original thin shaly intercalations in the arenaceous rocks; other primary features are not apparent. Volcanic rocks are almost entirely absent in this extensive clastic assemblage. Jenness (1963) noted a single exposure of dark green meta-andesite southwest of Gander Lake, and only two or three outcrops of possible volcanic rocks have been observed in 400 square miles of outcrop area to the northeast.

The grade of regional metamorphism increases across the lower unit from the chlorite zone in the northwest to the biotite zone in the southeast (Jenness, 1963). The rocks are intruded by a variety of granites and are thermally metamorphosed in the northeast to coarsely crystalline gneisses and schists containing garnet, staurolite, kyanite, and locally sillimanite. Two of the granites have been dated radiometrically at an average age of 365 million years (Lowdon, 1960; 1961).

The rocks have been tightly folded, with dips generally moderate to steep toward the northwest. They are interpreted as deep-water marine deposits mainly because of a lack of shallow-water depositional characteristics and because they are overlain by graptolitic slates. The upper parts of the lower unit are probably of Early or Middle Ordovician age, but the basal parts may be as old as Late Precambrian.

Ultramafic Intrusive Rocks

Ultramafic rocks in northeastern Newfoundland are chiefly localized in two elongate belts, which parallel the inner sides of the marginal clastic rocks described above (fig. 2). In the western belt the ultramafic rocks are bordered by gneisses and schists of the Fleur de Lys group along the northwestern side and are closely associated with volcanic rocks of the Baie Verte group on the southeastern side. In the eastern belt the ultramafic rocks occur largely among volcanic rocks that form part of the middle unit of the Gander Lake group. Both belts are highly deformed, with the ultramafic rocks occurring as discontinuous lenticular bodies among altered mafic intrusions and volcanic rocks. Rarely are the ultramafic rocks surrounded by sedimentary rocks.

In the western belt brown-weathered peridotites and pyroxenites in places contain relict olivine and pyroxene, but generally these minerals have been altered to aggregates of green serpentine and chlorite, or talc and carbonate. The ultramafic rocks are associated with altered green lavas, schistose or locally pillowed mafic lavas, and mafic pyroclastic rocks. The associated volcanic rocks have not been dated but are lithologically similar to nearby volcanic rocks which are interlayered with fossiliferous sedimentary rocks of Early and Middle Ordovician age. In the eastern belt ultramafic rocks are represented by serpentinite or talc-carbonate alteration products, but the most abundant rock type is altered pyroxenite. Associated volcanic rocks are interlayered with Middle Ordovician slates and consist of altered green mafic varieties with pyroclastic rocks more abundant than lavas.

Locally at Tilt Cove, near the western ultramafic belt of figure 2, a serpentinized ultramafic sill is associated with Lower Ordovician volcanic rocks of the Snooks Arm group (Snelgrove, 1931). Elsewhere throughout the central Paleozoic mobile belt of northeastern Newfoundland widely separated occurrences of ultramafic rocks have been reported, but most of these are unaltered gabbros without associated serpentinites.

The association of ultramafic intrusions and Ordovician or tentative Ordovician mafic volcanic rocks is characteristic of both the eastern and western ultramafic belts. Where ultramafic intrusions are in contact with rocks of possible Silurian age, the contacts have been interpreted as faults (Neale and Nash, 1963). At Tilt Cove ultramafic rocks appear to cut tentative Silurian rocks of the Cape St. John group (Baird, 1951), but detailed studies have shown that conglomerates of the Cape St. John group contain pebbles of the ultramafic rocks, and the intrusive relationships are interpreted as the result of later remobilization of serpentinite (Neale, 1957). In the eastern belt the ultramafic intrusions cut volcanic rocks that are interlayered with fossiliferous Middle Ordovician strata, and the intrusions are altered by nearby granites that are dated radiometrically as Devonian (Jenness, 1963). Most relationships, therefore, suggest that the ultramafic intrusive rocks are of Ordovician age.

Central Area of Ordovician and Silurian Rocks

A large proportion of the stratified rocks in the central Paleozoic mobile belt are of volcanic parentage, and the thicknesses and facies are very different from those seen in the Paleozoic shelf deposits of western and eastern Newfoundland. Ordovician and Silurian volcanic rocks are more widespread in the western part of the central Paleozoic mobile belt and sedimentary rocks are more abundant in the east.

The Ordovician system contains thick accumulations of altered lava—now greenstone, basaltic pillow lava, basic pyroclastic rocks, intermediate to acid volcanic rocks, graywackes, siltstones, slates, ribbon cherts, and minor limestones, all of marine origin. The dominantly volcanic assemblages have been referred to in different areas as the Snooks Arm (Snelgrove, 1931), Baie Verte (Baird, 1951), Lushs Bight (MacLean, 1947), Cutwell (Espenshade, 1937), and Wild Bight groups (Williams, 1964); and the Mortons, Breakheart (Heyl, 1936), and Roberts Arm formations (Espenshade, 1937). Most of these assemblages are bounded by major faults, but the Wild Bight group is overlain by thick accumulations of graywackes, siltstones, and graptolitic slates of Ordovician age, which form parts of the Exploits group (Williams, 1962).

Rocks of Silurian and tentative Silurian age are lithologically unlike Ordovician rocks in most respects although both thick volcanic and sedimentary assemblages are represented. Many of the Silurian sedimentary rocks are red and gray sandstones characterized by cross bedding, current and oscillatory ripple marks, mud cracks, and rain prints, indicating shallow-water deposition. Associated volcanic rocks are dominantly silicic in places, but mafic varieties are abundant in others. The volcanic rocks are rarely pillowed and locally contain fragments of red sandstones, which suggest that much of the Silurian volcanism was terrestrial. Eastern and western belts of Silurian rocks are recognized as outlined in figure 2. The dominantly sedimentary eastern belt has been dated by fossils in several places, whereas the dominantly volcanic western belt is known to contain Silurian fossils in only one place, near its center. Other fossiliferous Silurian rocks occur in the vicinity of New Bay and on New World Island.

Silurian rocks of the eastern belt are referred to the Botwood group (Williams, 1962) and consist of red and gray conglomerates, graywackes, mafic to intermediate volcanic rocks, red and gray quartzose sandstones, slates, and minor coralline shales and limestones. On the western side of the belt conglomerates, volcanic rocks, and red sandstones occur from older to younger in that stratigraphic order; elsewhere these rocks may be interlayered. Conglomerates and volcanic rocks are almost entirely absent along the southeastern side of the belt. Silurian conglomerates contain numerous fragments of Ordovician rocks and plutonic rocks, and locally the conglomerates contain boulders of coralline limestones and volcanic rocks, lithologically similar to nearby Silurian limestones and Silurian volcanic rocks.

Rocks of the western Silurian belt are dominantly volcanic with not more than 10 percent sedimentary strata. The rocks toward the southeastern part belong to the Springdale group (MacLean, 1947), and those in the extreme northeast, near Tilt Cove (fig. 2), belong to the Cape St. John group (Baird, 1951). Most of the intervening rocks have not been formally named but Neale (in preparation) refers to them as Cape St. John group. The Springdale group consists of a lower unit of red arkosic sandstones with thin conglomerate interbeds overlain by approximately 10,000 feet of silicic and mafic volcanic rocks, in turn succeeded by red conglomerates, arkosic sandstones, limy siltstones, and shales (Neale and Nash, 1963). The mafic volcanic and sedimentary rocks are lithologically similar to Silurian rocks of the Botwood group whereas the acidic volcanic rocks are more typical of those found in the western and northern parts of the western Silurian belt. In the latter localities, the volcanic rocks are rhyolitic, trachytic, and latitic flows, pinkish crystal and lithic tuffs, agglomerates, and quartz-feldspar porphyries. Their stratigraphic succession is not known, but in places conglomerates and sandstones form the base of the sequence.

The relationships between the Ordovician and Silurian rocks are not everywhere clear. Many lines of indirect evidence suggest a major orogenic event toward the end of the Ordovician, but throughout the eastern Silurian belt where the relationships are best exposed there is no apparent structural discordance between the rocks of the two systems. The situation is best explained if the region is considered one of predominant subsidence during Ordovician and Silurian time with both large and small upwarps in the Middle and Late Ordovician.

Rocks of the central Paleozoic mobile belt are intruded extensively by granitic plutons, many of which are of batholithic dimensions. Most range in composition from granite to granodiorite and quartz diorite but in places they include large amounts of quartz syenite, syenite, monzonite, diorite, and gabbro. Most of the plutonic rocks are massive medium- to coarse-grained rocks that cut sharply across structures of the country rocks; a few are foliated or granulated and are concordant. Thermal metamorphic aureoles are usually developed, but most are very thin compared to the size of the plutons, and high-grade metamorphic minerals are absent. Almost all the major granitic bodies are considered to be Devonian, either on geological data or radiometric determinations. However, older plutons must have existed nearby as sources for the plutonic boulders so common in Silurian conglomerates. Recently Neale and Nash (1963) have reported probable Ordovician granites east of White Bay, which are unconformally overlain by conglomerates tentatively correlated with the Cape St. John group.

In the central Paleozoic mobile belt the rocks are folded about northeast- to east-trending axes with plunges toward the northeast or southwest. Most of the folds are characterized by large amplitudes and short wave lengths, and some are isoclinal and overturned to the northwest. Major faults trend parallel to fold axes and cut the region into segments composed of contrasting rock types. Very little is known about the absolute movements of the faults, but commonly overturned Silurian strata, with tops facing northwest, are followed northwestward by Ordovician rocks. The relationship suggests that faults separating the strata are steeply dipping normal faults, which followed folding. Examples are found west and southwest of New Bay and on New World Island. Other faults may have large strike-slip components, and some are thrusts, in places interpreted as pre-folding (Williams, 1963).

Tectonic Significance of Central Belt

Symmetrical elements recognized in the central Paleozoic mobile belt probably have the same tectonic significance on both sides, although they may not necessarily be of exactly the same geologic age.

The most striking feature indicating symmetry is the extent and continuity of the marginal clastic deposits. The age and relationships of these deposits relative to surrounding rocks are not well known, but from the information at hand two interpretations of their depositional history seem most likely. First, the rocks may be essentially of Late Precambrian age and represent elongate prisms of sediment built up parallel to ancient shorelines formed by the Precambrian rocks of eastern and western Newfoundland. Secondly, the rocks may be chiefly of Paleozoic age and represent facies equivalents of the Early Paleozoic shelf deposits of eastern and western Newfoundland. Combinations of these theories are also possible.

An early concept in the historical geology of Newfoundland was that of the New Brunswick geanticline (Schuchert and Dunbar, 1934), a supposed landmass of basement rocks trending northeastward across the center of the island. This landmass presumably served as a barrier in Early Paleozoic time separating two areas of deposition: the St. Lawrence geosyncline to the northwest and the Acadian geosyncline to the southeast. Its existence was proposed to explain the absence of Cambrian strata in central Newfoundland as well as the contrasting Pacific and Atlantic affinities of the Cambrian faunas found on both sides of the presumed barrier. It is now doubtful that such a landmass existed, at least in the manner envisaged by its early proponents. Depending upon the interpretation of the marginal clastic deposits, central Newfoundland could have been either a deep basin starved of sedimentary material during Cambrian time or else a basin of active Cambrian deposition. The

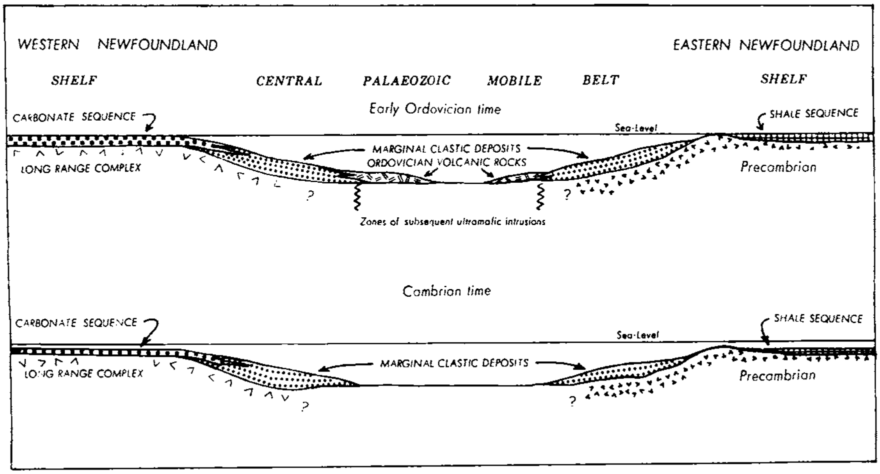

Fig. 3. Interpretation of the geologic development of the central Paleozoic mobile belt in northeastern Newfoundland in early Paleozoic time. (Note that the Precambrian rocks of eastern Newfoundland include both rocks deformed before the Paleozoic and unconformably overlain by Paleozoic deposits and rocks transitional up into the Paleozoic strata and deformed with them.)

writer's conception of the Early Paleozoic development of the central Paleozoic mobile belt is illustrated in figure 3.

The fact that ultramafic intrusions in northeastern Newfoundland follow two well-defined zones suggests that such zones coincide with major tectonic features, and as the intrusions are closely associated with Ordovician volcanic rocks, the intrusions were possibly emplaced along existing channelways which served earlier as conduits for extensive outpourings of Ordovician lava. Hess (1940) has noted a double row of small ultramafic intrusions along the entire length of the Appalachians and has attributed a significant role to ultramafic intrusions in the time and space relationships of Alpine-type mountain systems, such as the Appalachians. Hess interpreted the intrusions as occurring along the axis of most intense deformation and being emplaced during the first great event deforming the system. If the ultramafic rocks occupy intensely deformed axial zones, then this implies the existence of less deformed outer zones, and nowhere throughout the Appalachians are eastern outer zones and a two-sided system better displayed than in northeastern Newfoundland.

The central Paleozoic mobile belt of northeastern Newfoundland is analogous in most respects to the Piedmont province of the southeastern United States; the latter being much wider with its eastern part hidden by post-Paleozoic deposits of the Atlantic Coastal Plain. King (1950) has given an excellent summary of the tectonic features of the southeastern United States and has discussed the possibility that the Appalachian system is two-sided and that the Piedmont is a central zone of intense deformation rather than an easternmost outer zone.

Although the Piedmont corresponds to the central Paleozoic mobile belt of northeastern Newfoundland, the differences in degree of metamorphism and structural style between the two warrant further comment. King (1950) has indicated that at several times during the Paleozoic Era the Piedmont province acted as a source area for the numerous westward-thinning clastic wedges exposed in the sedimentary Appalachians of the Valley and Ridge province. The Piedmont was therefore uplifted and deformed repeatedly throughout the Paleozoic; consequently, it is deeply eroded. In northeastern Newfoundland indications that the central Paleozoic mobile belt acted as a source area in the same way as the Piedmont are few or lacking, for clastic wedges like those so common along the western margin of the southern Appalachians are not observed. It is therefore reasonably clear that the central Paleozoic mobile belt of northeastern Newfoundland furnishes a cross section of the same part of the Appalachians as the Piedmont but at a much higher level in the crust.

EASTERN PRECAMBRIAN ROCKS AND LOWER PALEOZOIC DEPOSITS

Eastern Newfoundland is made up mainly of a variety of Precambrian rocks overlain locally by fossiliferous Cambrian and Ordovician strata. None of the Precambrian rocks can be correlated with the Long Range complex of western Newfoundland, but some of them may be of the same age, although less metamorphosed. Cambrian and Lower Ordovician strata are exposed as synclinal or downfaulted remnants throughout the eastern Precambrian terrane.

Eastern Precambrian Rocks

The Precambrian rocks of eastern Newfoundland can be broadly subdivided into three groups: the Love Cove, Connecting Point, and Musgravetown groups (fig. 2). These are thought to be equivalent at least in part to the Harbour Main, Conception, Hodgewater and Cabot groups, respectively, exposed to the southeast of figure 2. The rocks have not as yet been directly correlated except for parts of the Hodgewater and Musgravetown groups (McCartney, in press). All the rocks are strongly deformed locally, but each group is less deformed than the preceding one (Jenness, 1963).

Love Cove group.—The Love Cove group (Jenness, 1963) is described as being of mixed facies, including clastic sediments and volcanic rocks with alternating individual units generally less than 50 feet and the entire group probably about 15,000 feet thick. Volcanic rocks are principally acidic lavas and pyroclastic rocks, with intermediate compositions present, as well as probable basaltic rocks represented by chlorite-epidote schists. Sedimentary rocks are dominantly of sandy facies and are mainly feldspathic graywackes but also include metamorphosed conglomerates and slates (Jenness, 1963). All the rocks have been metamorphosed to the greenschist facies, and where intruded by Paleozoic granites to the northwest they have been locally feldspathized and granitized (Jenness, 1963). The Love Cove group is everywhere bounded by presumed faults, although its contact with the lower unit of the Gander Lake group could be an angular unconformity. Pebbles of Love Cove chlorite schist have been reported in basal conglomerates of the Musgravetown group (Jenness, 1963), and as the Love Cove rocks are more highly folded and metamorphosed than the Connecting Point group, they are thought to be among the oldest Precambrian rocks of eastern Newfoundland. Weeks (1963) has compared the Love Cove group with the Harbour Main Group, which outcrops to the southeast in Conception Bay (fig. 1). The Harbour Main group is overlain with angular unconformity by Cambrian strata and intruded by the Holyrood granite batholith, which is dated radiometrically at 910 million years (Fairbairn, 1958).

Connecting Point Group.—The Connecting Point group (A. O. Hayes, 1948) is of geosynclinal facies and consists of black and gray slates, sandy and silty graywackes, and minor conglomerates, pyroclastic rocks, lavas, and cherty quartzites. Together these rocks comprise an estimated total thickness of 25,000 to 30,000 feet (Jenness, 1963). The base of the group is not exposed, but comparative structure and metamorphism indicate that the Connecting Point rocks were separated from the Love Cove rocks by an angular unconformity. Fold axes in the Connecting Point group trend a little west of north in places and are at variance with the prominent northeast-trending fold axes in rocks of the overlying Musgravetown group. The Connecting Point group has many lithological and structural aspects in common with the Conception group exposed around Conception Bay, but direct correlation of the two is not possible.

Musgravetown group.—Rocks of the Musgravetown group (A. O. Hayes, 1948) are described as chiefly red and green conglomerates, subgraywackes, arkoses, and acidic to basic lavas (Jenness, 1963). These rocks are of relatively shallow-water continental or epicontinental origin and are markedly different from the relatively deep-water marine graywackes and slates of the Conception group. The Musgravetown group is estimated to be 10,000 feet thick and includes at least four recognizable formations, which in order of decreasing age are the Cannings Cove, Bull Arm, Rocky Harbour, and Crown Hill formations. The Bull Arm formation is made up dominantly of volcanic rocks with an estimated thickness of 2500 feet at one locality (Jenness, 1963). The volcanic rocks appear fresh and include basaltic and andesitic lavas, trachytes, rhyolites, red felsites, and acidic tuffs.

The Musgravetown group overlies the Connecting Point group with angular unconformity. Folds within the group are generally broad and gentle, and the rocks appear less folded than those of the Connecting Point group and not more deformed than overlying Cambrian and Ordovician strata. McCartney (in press) has traced Musgravetown strata through facies changes into parts of the Hodgewater group, which in turn closely resembles the Cabot group to the east.

Lower Paleozoic Deposits

A complete but relatively thin succession of Lower, Middle, and Upper Cambrian strata together with some Lower Ordovician strata, constitute the Lower Paleozoic rocks of eastern Newfoundland. They are a miogeosynclinal sequence of dominantly shaly rocks of marine shallow-water deposition which have been referred to as a marine shelf facies (Jenness, 1963). The Cambrian rocks are abundantly fossiliferous in places, and the faunas are dominated by trilobite species that are known in a few other parts of eastern North America and also in northwestern Europe within the so-called Atlantic faunal realm; no trilobites known from the Pacific faunal realm, which includes western Newfoundland, are represented (Hutchinson, 1962).

The lowermost fossiliferous Cambrian strata are separated from the underlying Precambrian Musgravetown group by a dominantly white quartzitic unit, generally 200 to 300 feet thick, known as the Random formation (A. O. Hayes, 1948). South and east of figure 2 similar relationships are displayed between the Hodgewater group and Cambrian strata. The Random formation is generally conformable with underlying and overlying strata, although locally it may be slightly disconformable, and as the Random lies near the Precambrian-Cambrian time boundary its age has been a controversial subject. Jenness (1963) has described the lithology of the formation as transitional between the dominantly continental facies of the underlying Musgravetown group and the marine facies of the overlying Lower Cambrian strata. McCartney (1958, in press) has observed similar transitions and interpreted the Random as a shoreline deposit formed by a transgressing sea. This interpretation is attractive and emphasizes the futility in attempts to define a Precambrian-Cambrian time boundary among unfossiliferous rocks deposited under similar conditions during continuous processes.

The lithology, stratigraphic nomenclature, and paleontological zones of the Cambrian and Ordovician rocks of eastern Newfoundland have been described by Hutchinson (1962). The thickness of the Cambrian strata ranges from less than 1000 to an estimated maximum of 4000 feet (Hutchinson, 1962), and the lithologic sequence of the deposits remains remarkably uniform throughout most of the region. Locally in the vicinity of Fortune Bay (fig. 1) Middle Cambrian sandstones are more abundant than elsewhere to the east. Ordovician rocks are of limited occurrence and are lithologically similar to underlying Upper Cambrian strata, except that they contain more sandstone beds (McCartney, personal communication).

The degree of folding and deformation of the Cambrian and Ordovician strata varies from place to place, but the simple fold patterns displayed by both the Paleozoic and the underlying Musgravetown group rocks suggests only one period of deformation. Southeast of figure 2 the Cambrian and Ordovician strata are relatively unfolded where they unconformably overlie older Precambrian rocks of the Harbour Main group.

Tectonic Significance of Eastern Belt

The variety of Precambrian rocks present in eastern Newfoundland and the relationships displayed among them indicate a long and involved geologic history for this part of the Appalachian system. Precambrian rocks such as the Love Cove and Harbour Main groups may be as old as the Long Range complex, but their role in the development of the Appalachian system is uncertain. Possibly the Love Cove and Harbour Main groups represent eastward volcanic phases of Grenville deposition, but subsurface relationships are unknown, and it is not clear whether or not the whole of northeastern Newfoundland is underlain by Precambrian rocks of Grenville age. Harbour Main and Love Cove group rocks are folded about axes that generally trend northeasterly and roughly parallel to the Precambrian belts of outcrop. The northeast parallel arrangement draws attention to the characteristic northeast structural trend of the entire Appalachian chain and indicates that in places the trend was established in Precambrian time. Later Paleozoic events were therefore controlled by existing tectonic features.

The later Precambrian rocks of the Connecting Point and Musgravetown groups of figure 2, and the Conception, Hodgewater, and Cabot groups to the southeast, are all apparently younger than the Long Range complex of western Newfoundland. None of these rocks are known to be intruded by Precambrian granites, and the Musgravetown and Hodgewater groups underlie fossiliferous Cambrian strata with no major break in the stratigraphic succession. The rocks are therefore considered to be an integral part of Appalachian geosynclinal deposition.

At the onset of Paleozoic time most of the Precambrian rocks were peneplaned and gradually submerged beneath a transgressing sea which existed until the Early Ordovician. The strata deposited in eastern Newfoundland during this time represent a stable shelf facies, overlying Precambrian rocks to the east of the central Paleozoic mobile belt just as the carbonate sequence of western Newfoundland overlies the Precambrian Long Range complex to the west. The Lower Cambrian strata of eastern Newfoundland thin westward, and this feature has been interpreted to support the idea of the New Brunswick geanticline along the western margin of the Cambrian sea. The reasoning seems sound, but a limited temporary landmass would probably explain the situation as well as a more regional and permanent one including all of central Newfoundland. Furthermore, the geologic history of the central Paleozoic mobile belt does not support the view that central Newfoundland was completely emerged in Late Precambrian and Early Paleozoic time.

OROGENIC HISTORY

The Precambrian Long Range complex of western Newfoundland (a crystalline inlier of The Canadian Shield) was folded, intruded, and stabilized in Grenville time (800 to 1100 million years ago). It then constituted a stable craton and was not appreciably affected by later Paleozoic orogeny. Another stable block, affected only by faulting in the Paleozoic Era, is represented by the Harbour Main group of eastern Newfoundland. It was also intruded in Grenville time and apparently shielded overlying Cambrian and Ordovician strata from Paleozoic folding that affected all surrounding post-Harbour Main rocks.

The Connecting Point and Musgravetown groups of figure 2, and the Conception, Hodgewater, and Cabot groups to the southeast, represent an integral part of Appalachian geosynclinal deposition. Some of these groups were deformed in Precambrian time, as shown by the differences in degree of deformation and unconformable relationships. The Precambrian deformation, however, was not intense compared to later Paleozoic orogeny that affected all these rocks.

Three Paleozoic orogenies are recognized in northeastern Newfoundland. The first is referred to as the Taconic and is considered to have occurred in Middle to Late Ordovician time (Neale and others, 1961). It did not appreciably affect the shelf-type deposits, which directly overlie Precambrian rocks of eastern and western Newfoundland, and appears to have been most intense in the central Paleozoic mobile belt, probably chiefly along its western side. It was marked by the intrusion of mafic and ultramafic rocks, as well as the probable intrusion of granitic rocks (Neale and Nash, 1963). Other criteria suggesting Taconic orogeny in the central Paleozoic mobile belt are as follows: apparent absence of Upper Ordovician rocks, marked facies differences between Ordovician and Silurian rocks, differences in style of deformation displayed locally between Ordovician and Silurian rocks, and the occurrence of coarse Lower Silurian conglomerates. Following this deformation, Silurian rocks were laid down either in basins on the Taconic folded zone or in the still shoal or submerged parts of Ordovician basins that were unaffected by the Taconic orogeny.

The second phase of Paleozoic orogeny involved Silurian and all older rocks, with the exception of two earlier stabilized blocks: the Long Range complex and its Paleozoic cover in western Newfoundland, and the Harbour Main group and its Paleozoic cover in eastern Newfoundland. The orogeny was accompanied by widespread folding, metamorphism, and granitic intrusion, which left the central Paleozoic mobile belt of northeastern Newfoundland as a stable folded zone, locally converted into schists and gneisses along its margins. This event is referred to as the Acadian orogeny. In Newfoundland the orogeny is dated as post-Early Devonian and pre-Carboniferous, for it locally transformed Lower Devonian rocks of southwestern Newfoundland into schists and gneisses but did not affect nearby Carboniferous rocks. In addition almost all granitic plutons in northeastern Newfoundland either are known to cut Silurian rocks or are dated radiometrically as Devonian.

The third and final period of deformation is marked along a narrow zone in western Newfoundland by tilting and folding of Carboniferous rocks. Its effects among pre-Carboniferous rocks are limited to faulting and local metamorphism immediately adjacent to the faults.

CONCLUDING REMARKS

The general geology and tectonic setting of the Appalachians in northeastern Newfoundland led to the conclusion that the system is two-sided and that elsewhere to the southwest along the Atlantic seaboard much of the Precambrian eastern part is hidden either by Cenozoic cover rocks or the Atlantic Ocean. This view warrants further consideration, for it does not agree with the commonly held opinion that the Appalachian system is essentially a Paleozoic welt that formed the southeastern border of North America in Paleozoic time. It is obvious that the North American continent was thickened profoundly in Paleozoic time along the site of the Appalachian mountain system, but continental expansion by the accretion of a Paleozoic welt is much less obvious, and in northeastern Newfoundland the geology contradicts such a view. Possibly the oldest Precambrian rocks of eastern Newfoundland constituted a seaward volcanic arc that formed the continental border and represented continental spreading in Precambrian time. If so the eastern limit of the continent was then established, and Paleozoic geosynclinal rocks accumulated toward the continental side of this feature.

The geologic history of the Appalachians goes back far beyond the Paleozoic, and this early history must be included in any complete treatment of their evolution. Only when this is done will the regional tectonic significance of the system with respect to the rest of North America be fully appreciated.

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