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Tectonics and Sedimentation in Northeastern Maine and Adjacent New Brunswick: Outline of the Pleistocene Geology of Northern Maine and Adjacent Canada

New England Intercollegiate Geological Conference (NEIGC)

Roy, David C.

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A Guidebook to

THE GEOLOGY OF NORTHEASTERN MAINE AND NEIGHBORING NEW BRUNSWICK

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The 72nd Annual Meeting of the
New England Intercollegiate Geological Conference

Presque Isle, Maine: October 10-13, 1980

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Printed by Boston College Press
1980

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NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

Informally organized in 1901 by William M. Davis, the NEIGC provides an opportunity for students, faculty, and industrial geologists to share the results of recent geologic studies in New England. With the exception of eight years during the two World Wars, the conference has met every fall since the original trip to the Connecticut Valley led by Prof. Davis. The 1980 meeting in Presque Isle is the 72nd one held by the conference and the tenth meeting in Maine. It was not until 1925 (in Waterville) that the conference held its first meeting in Maine and the state was revisited about every ten years until 1960 (1934, Lewiston; 1950, Bangor; 1960, Rumford). Since 1960 the conference has been returning to Maine more frequently which attests to the increasing amount of new work being done in New England's largest state and the greater ease with which people can travel to and within the state (1965, Brunswick; 1966, Katahdin; 1970, Rangeley; 1974, Orono; 1978, Calais). This year's meeting is the first in Aroostook County, Maine's largest, and it is fitting that trips in neighboring New Brunswick are included since the northwestern part of the province has many geological and cultural ties to "The County."

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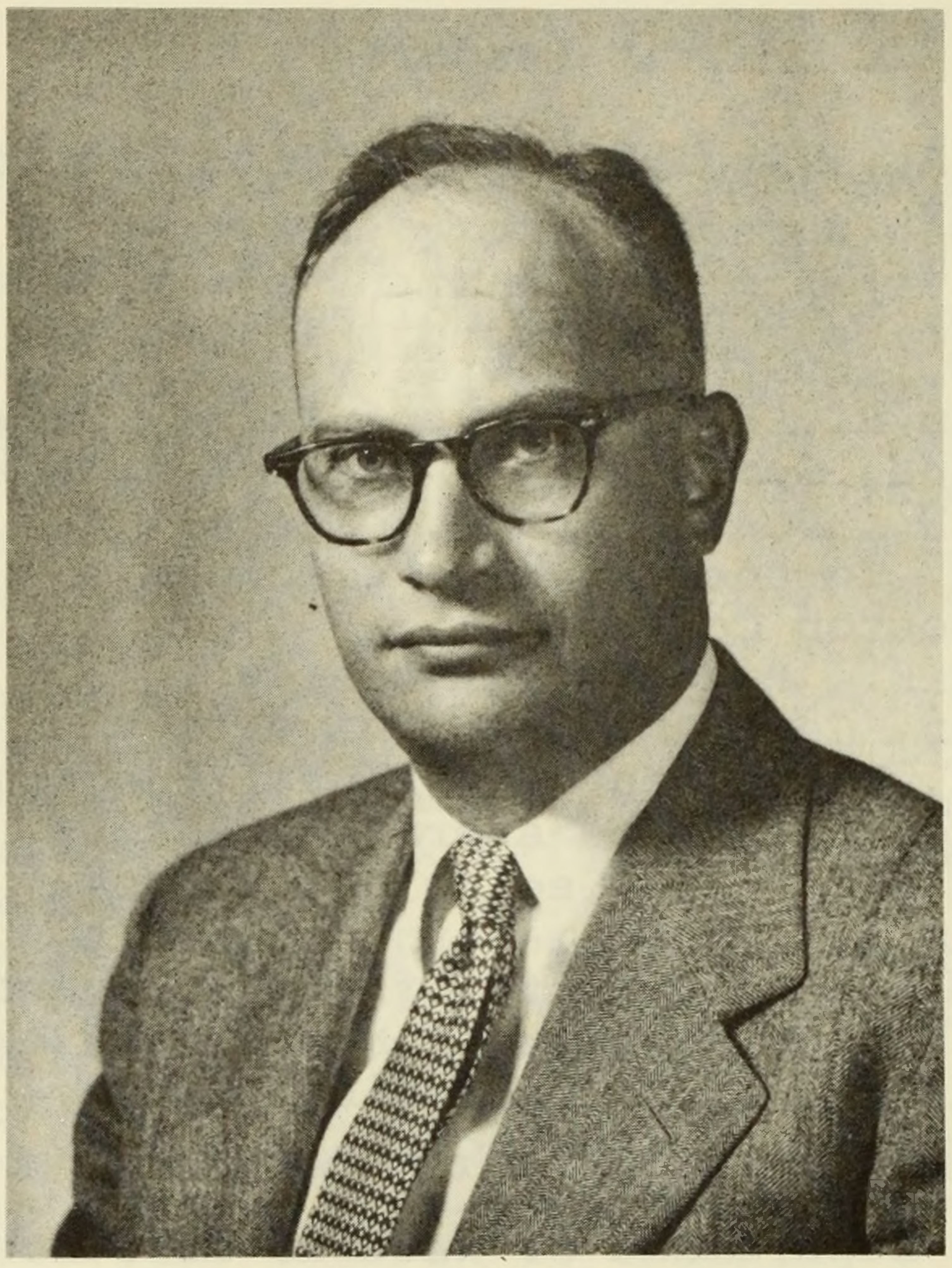
Acknowledgment

The editors wish to thank Marjorie H. Roy for her assistance in the final assembly of this Guidebook.

IN DEDICATION



Ely Mencher
1913 - 1978

This guidebook is dedicated to Ely Mencher who was a friend, teacher, and colleague to over a generation of students at MIT and later at City College. His work from 1962 to 1976 and those of his undergraduate and graduate students in northern Maine established the foundation upon which much of this conference is based. His quiet wit, generosity, and sense of responsibility endeared him to those of us who had the privilege to meet and work with him.

CONTENTS

TECTONICS AND SEDIMENTATION IN NORTHEASTERN MAINE AND ADJACENT NEW BRUNSWICK

by

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The field trips of the 1980 NEIGC will examine the bedrock and surficial geology of a large region in northeastern Maine and neighboring New Brunswick as shown in Figure 1. The history of intensive geologic studies in this region is more recent than for more southerly parts of New England but the results of the studies are important to the "big picture" because the major rock belts within the central part of the northern Appalachian range pass through it and are seen at lower metamorphic grade. In fact, the best fossil-dated stratigraphic cross-section of the range from the Connecticut Valley-Gaspe Synclinorium through the Bronson Hill-Boundary Mountain Anticlinorium and across the western flank of the Merrimack Synclinorium is present in northern Maine and western New Brunswick.

The bedrock trips during the conference will not show the complete section but will give participants a clear view of the complex stratigraphy from the Bronson Hill-Boundary Mountain terrain across the Aroostook-Matapedia Belt, to the Miramachi Belt of northern New Brunswick. The essential features of the stratigraphy of the region are summarized in Figure 2. As will be illustrated below, the early Paleozoic stratigraphy of the region of this year's conference is similar to that seen at higher metamorphic grade during the 1970 Rangeley conference and more recently during the 1974 conference in Orono. The purpose of this article is to provide an overview of the regional stratigraphy in the region covered by the conference. In addition an attempt is also made to show both the interplay of tectonics and sedimentation suggested by the stratigraphic variations and to illustrate the broad regional continuity of the resulting tectono-stratigraphic picture. It is hoped that the treatment will help participants to keep track of the formational "players" in the game and to begin to see the positions they may have played during the evolution of this part of the northern Appalachians.

Pre-Middle (pre-Caradocian) Ordovician Stratigraphy

In northern Maine our view of the pre-Middle Ordovician is very restricted. A sparsely fossiliferous but relatively thick pre-Caradocian section has been described by Neuman (1967; Neuman and Rankin, this volume) in the core of the Weeksboro-Lunksoos Lake Anticline. These rocks include the Grand Pitch Formation (varigated slate and quartzite) and the overlying Shin Brook Formation (tuffaceous volcanic rocks and minor sedimentary rocks). Rocks similar to the Late Precambrian/Early Cambrian Grand Pitch have been mapped to the northwest of the Weeksboro-Lunksoos Lake anticline by Hall (1970) as the Chase Brook Formation. The lower quartzite-rich unit of the Tetagouche Group of the Miramachi Anticlinorium in New Brunswick is commonly considered to also be equivalent to the Grand Pitch (Rast, St. Peter, and Lutes, this volume).

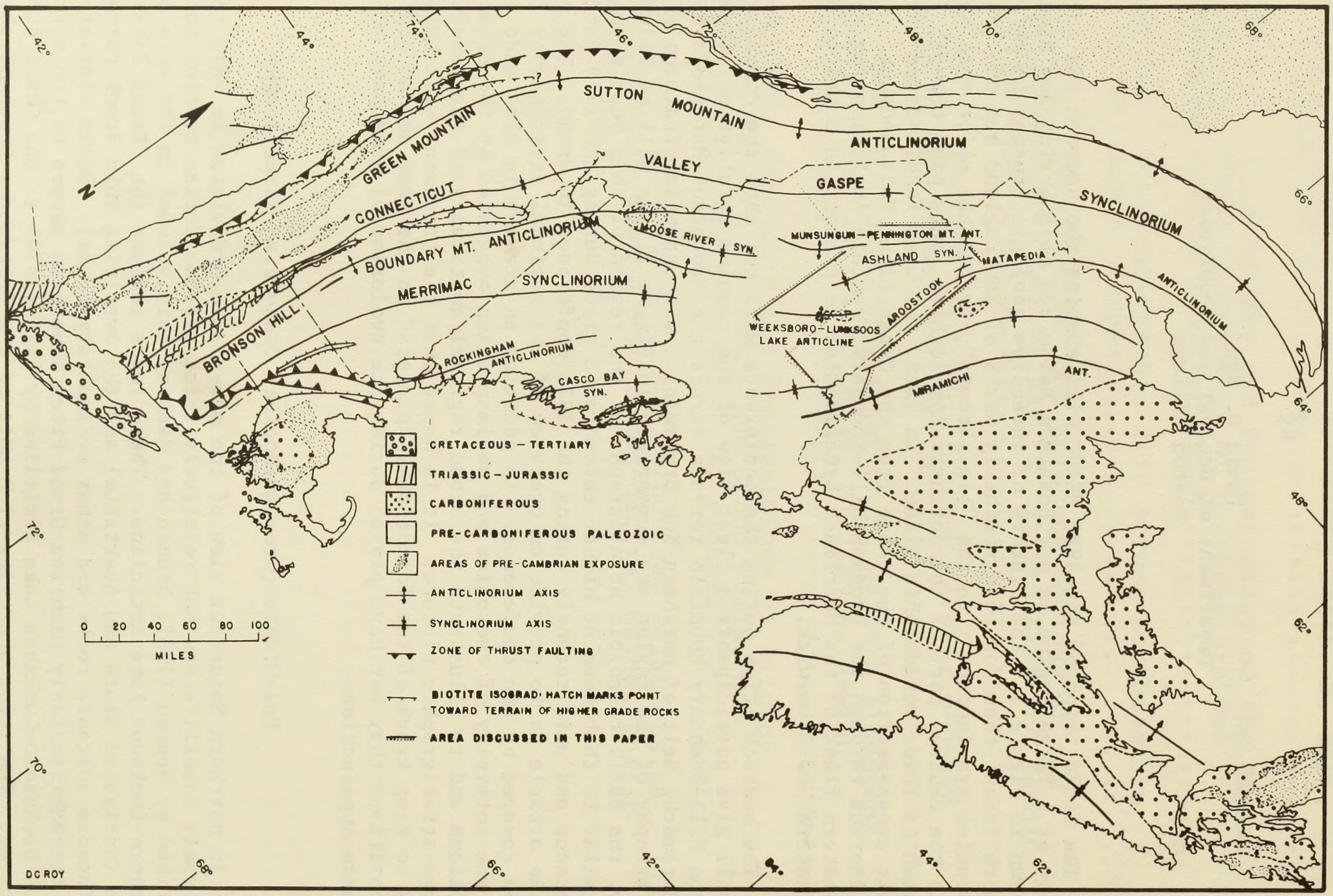

Figure 1: Principal tectonic features of the Northern Appalachians in New England, Eastern Quebec, and New Brunswick.

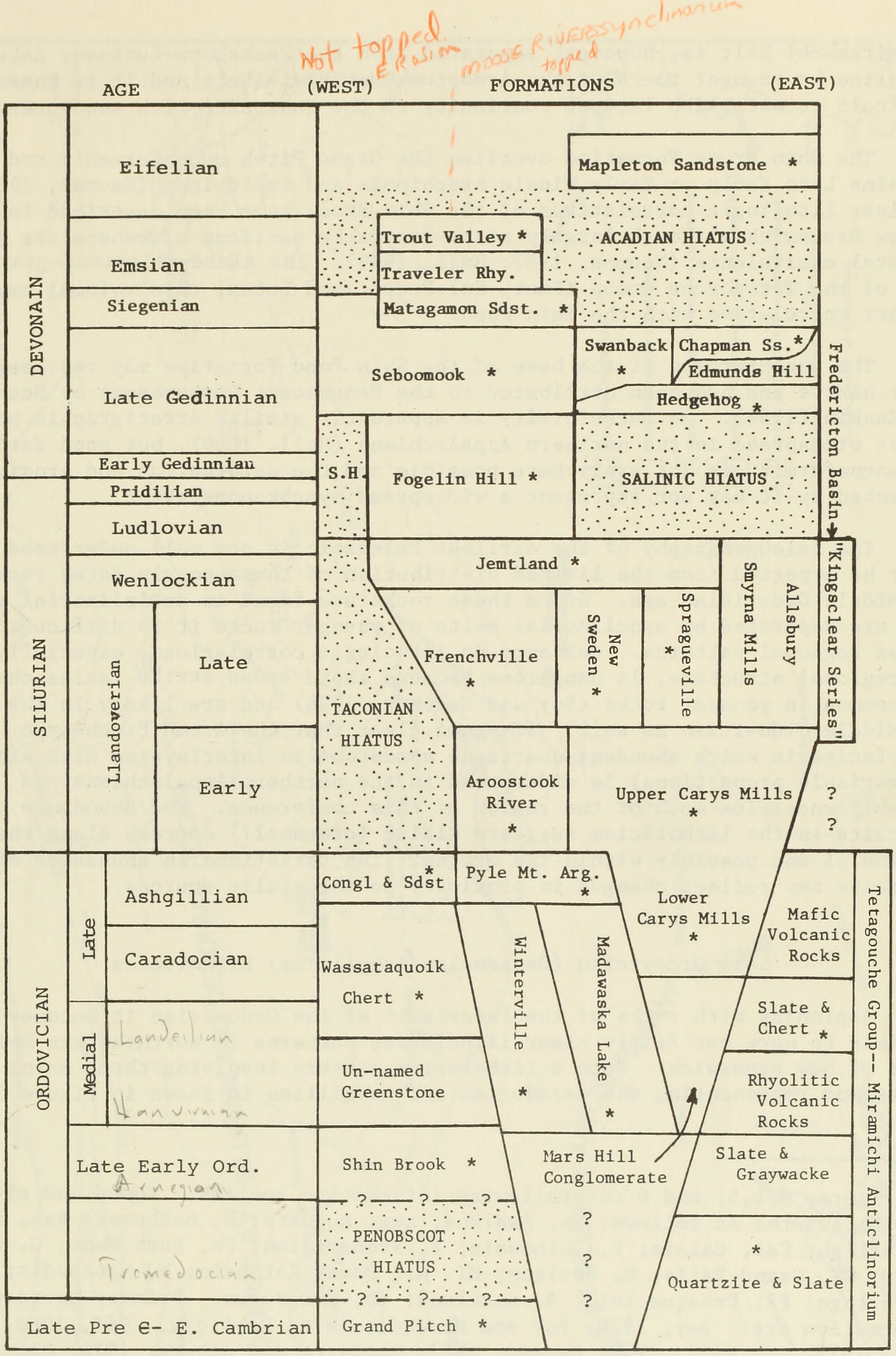

Figure 2: Stratigraphy of northeastern Maine and adjacent parts of New Brunswick. Star indicates that the unit is dated by fossils.

The Miramachi belt is, however, separated from the Weeksboro-Lunksoos Lake Anticline by younger rocks of the Aroostook-Matapedia Belt and it is therefore difficult to establish lateral continuity of the quartzite-rich sequences.

The Shin Brook Formation overlies the Grand Pitch unconformably and contains Late Early or Early Middle brachipods and trilobites (Neuman, 1967). No clear lithologic correlatives of the Shin Brook have been described in Maine or New Brunswick although largely slate-graywacke sections elsewhere are probable temporal equivalents (Neuman, 1967; Hall, 1969). The slate-siltstone-graywacke unit of the Tetagouche Group (Rast, St. Peter, and Lutes, this volume) may be in part correlative with the Shin Pond.

Brook?

The unconformity at the base of the Shin Pond Formation may represent a major hiatus and has been attributed to the Penobscott Disturbance by Neuman and Rankin (1966). An unconformity in apparently similar stratigraphic position may be widespread in the northern Appalachians (Hall, 1969), but good dating of the unconformity is not everywhere possible and the deformation and erosion suggested by it may not represent a widespread synchronous event.

The paleogeography of the earliest Paleozoic is not well understood as might be expected from the limited distribution of these poorly dated rocks of pre-Middle Ordovician age. Since these rocks are found in anticlinorial tracts that are separated by synclinorial belts of younger rocks it is difficult to access regional patterns. Reliance on lithologic correlations, especially across the regional structure, is dangerous because rapid cross-strike facies changes are common in younger rocks (Roy and Mencher, 1976) and are likely in the pre-Middle Ordovician as well. It seems clear that the Grand Pitch-type lithofacies in which abundant quartzose sandstone is interlayered with slate (in variable proportions) is widespread in the northern Appalachians and probably underlies much of the region of this conference. The abundance of quartzite in the lithofacies suggests sialic (cratonal?) sources along the margins of and possibly within the orogen. The variations in abundance of quartzite may reflect changes in proximity to the sialic sources.

Late Ordovician (Caradocian/Ashgillian) Lithofacies

Beginning with rocks of the later part of the Ordovician it becomes possible to work out fairly clear lithofacies patterns in northeastern Maine and parts of New Brunswick. Such a lithofacies pattern involving three major lithofacies and representing the Caradocian and Ashgillian is shown in Figure 3.[1]

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[1]In figures 3,4,5, and 6 the following information applies. Towns and cities are abbreviated as follows: A, Ashland; Aug, Augusta; B, Bathurst; Ban, Bangor; C, Caribou; Cal, Calais; D, Dalhousie; F, Fredericton; FK, Fort Kent; G, Greenville; GF, Grand Falls; H, Houlton; MT. K., Mount Katahdin; M, Matapedia; P, Portage; PI, Presque Isle; R, Rockland; VB, Van Buren. Primary sources of information are: Roy, 1970; Roy and Mencher, 1976; Pavlides, 1965, 1968, 1971, 1972, 1973; and Hall, 1970; Neuman, 1967; Boudette and others, 1976; St. Julien and Hubert, 1975; Boudette and Boone, 1976; Boone, 1973; Anderson, 1968; Hamilton-Smith, 1969, 1970; Boucot, 1961, 1969a, b; Boucot and others, 1964; Moench, 1970a, b, 1971, 1973; Ludman, 1976; (foot-note continued on the next page)

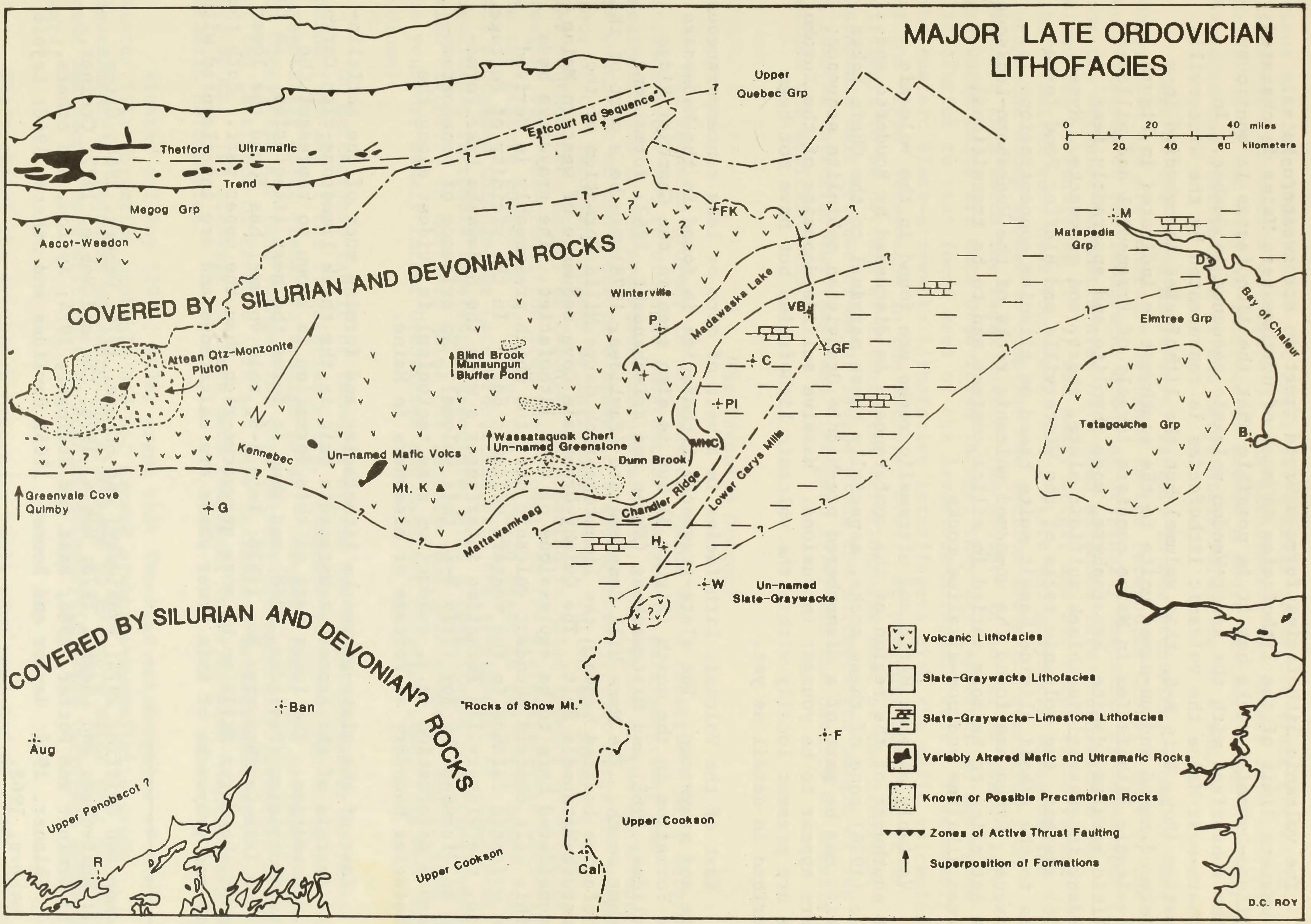

Figure 3: Distribution of major Late Ordovician (Late Caradocian largely) lithofacies in Maine and adjacent Canada prior to the Taconian Orogeny.

The volcanic lithofacies forms a broad tract in northwestern Maine. The western limit of the lithofacies in much of northwestern Maine is obscured by Siluro-Devonian rocks but it is possible that the lithofacies is continuous in the subsurface with the Ascot-Weedon volcanic sequence in Quebec. In northern-most Maine the volcanic lithofacies is represented by the Winterville Formation (Roy, Trip B-6, this volume) but the lithofacies is embodied in a variety of named and un-named units to the southwest as indicated in Figure 3. The volcanic lithofacies in Maine consists largely of fragmental and pillowed spilitic basalts, dacite, karatophyre, soda rhyolite and apparently less abundant interstratified black sulfidic slate, chert, and graywacke. Hynes (1976) assigns the volcanic rocks of the Winterville and Bluffer Pond formations to the alkali olivine basalt suite based on titanium concentrations in pyroxene. Hynes has found the un-named volcanic rocks of the Weeksboro-Lunksoos Lake Anticline to be more varied in silica content and to be transitional between alkaline and non-alkaline rocks.

Variably altered Mafic and ultramafic rocks are found in the volcanic belt southwest of the region of the conference. As discussed by Boudette and Boone (1976) some of these rocks, especially those marginal to the Chain Lakes Massif, may be part of a dismembered pre-Middle Ordovician ophiolite sequence; others appear to be younger intrusions. Massive sulfide deposits of the Kuroko type are present locally within the volcanic lithofacies but have not been described in detail as yet.

East of the Volcanic Lithofacies is a belt of more or less contemporaneous slate and graywacke. The slate-graywacke lithofacies is found in the Madawaska Lake Formation in the north (Figure 3) but is also seen in the Chandler Ridge (Pavlides, 1968) and Mattawamkeag (Ekren and Frischknecht, 1967) formations farther south. The Mars Hill Conglomerate (Pavlides, 1978) may be a part of this lithofacies located beneath the limestone-rich Carys Mills Formation of the Aroostook-Matapedia Belt. The Quimby-Greenvale Cove sequence of western Maine is considered here to be expressions of this lithofacies. The graywacke beds of this belt contain abundant volcanic detritus which presumeably is derived from volcanic islands in the western volcanic belt. In the vicinity of Portage, Maine, the Winterville Formation interfinger's with the Madawaska Lake Formation as discussed by Roy (Trip B-6, this volume). No evidence of penecomtemporaneous deformation (e.g. subduction zone tectonism) is evident along the lithofacies boundary at Portage or elsewhere in Maine.

East of the slate-graywacke lithofacies and forming much of the anticlinorial terrain of the Aroostook-Matapedia belt is the thick limestone-rich Carys Mills Formation. The lower part of this formation is known to represent the Upper Ordovician (Pavlides, 1968) and thus it forms the next lithofacies. In the Presque Isle-Caribou area Roy (1978; Trip B-6, this volume) has found the lower part of the Carys Mills to be more graywacke-rich than the upper part. Both the slate and graywacke of this lower phase are calcareous and are interlayered with

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[1] Ludman and Griffin, 1974; Pankiwskyj and others, 1976; Osberg, 1968; Gates, 1961; Ruitenberg and Ludman, 1978; Noble, 1976; Lee and Noble, 1977; Greiner, 1973; Greiner and Potter, 1966; Rast and Stringer, 1974; Ayrton, and others, 1969; Skinner, 1964; Naylor and Boucot, 1965; Pavlides and others, 1968; Lajoie and others, 1968.

minor micritic limestone. The lower Carys Mills forms the slate-graywacke-limestone lithofacies of Figure 3. The lithofacies may extent into central Maine but it can only be inferred to extend a short distance south of Houlton based on the distribution of the Carys Mills Formation as a whole.

East of the Carys Mills belt, largely in New Brunswick, rocks of Late Ordovician age are generally assigned to the Tetagouche Group. Most of the subdivisions of the Tetagouche Group as originally described by Helmstaedt (1971) for the Bathurst-Newcastle area have been extended into southwestern New Brunswick by Venugopal (1979) and Rast, Lutes, and St. Peter (this volume). In the Miramichi zone near Woodstock, N.B., slate and graywacke units of the Tetagouche Group appear to comprise the section above the quartzite-rich sequence that forms the basal unit of the group. In so far as these slate-graywacke units are Late Ordovician in age, they may represent an analogous lithofacies to that found west of the Aroostook-Matapedia belt. Presumeably the eastern slate-graywacke lithofacies interfingers with the mafic volcanics of the "type" Tetagouche in the Bathurst area. At present, however, it is difficult to be certain of lithofacies relationships east of the Aroostook-Matapedia belt because of major faults along the northwestern margin of the Miramichi Anticlinorium (Rast and Stringer, 1974) and the paucity of fossils within the anticlinorium.

The Taconian Orogeny

The Taconian Orogeny in northeastern Maine was a relatively mild deformational event but it produced substantial changes in paleogeography and sedimentation in the Aroostook-Matapedia basin. The region of the conference is southeast of the Thetford Ultramafic trend (Figure 3) that marks the suture zone of the Taconian Orogeny as invisioned by St. Julien and Hubert (1975). The southeastern extent of Taconian deformation in Maine appears to coincide roughly with the transition from the volcanic to the slate-graywacke lithofacies. In the eastern townships of Quebec the Taconian began in the Early Ordovician and proceeded through the Late Ordovician with the development of large-scale overthrust tectoncis apparently associated with a complicated obduction/subduction history. In northern Maine the Taconian was less dramatic and is seen to be younger, namely latest Ordovician and earliest Silurian (Roy, Trip B-6, this volume).

No metamorphic fabric of Taconian origin has been reported in northern Maine from any of the lithofacies belts. Cleavage in Ordovician slate is essentially axial planar to Acadian folds. Volcanic rocks and graywacke beds of Ordovician age (and younger for that matter) are generally incleaved north of the lattitude of Presque Isle but show increasing foliation along strike to the south. The cleavage in these more competent rocks is also consistent with Acadian deformation.

Richter and Roy (1974, 1976) argue that Taconian metamorphism of the Winterville Formation probably did not exceed prehnite-pumpellyite grade. Assessments of Taconian metamorphism elsewhere in northern Maine have not been made and become more difficult as Acadian metamorphic grade increases southwestward.

The rocks of the Aroostook-Matapedia basin have produced no clear evidence of Taconian deformation. Early recumbent folds reported by Rast, Lutes, and St. Peter (this volume) in the Carys Mills near Woodstock represent pre-Acadian deformation that may be as old as Taconian. However, it is also possible that these early folds are non-tectonic and represent syndepositional slump folds as described elsewhere in the Carys Mills (see Stringer and Pickerill, this volume) or they may be tectonic folds associated with Salinic deformation at the close of the Silurian (see below).

Taconian deformation of the Miramichi zone is well established (Rast and Stringer, 1974; Rast and others, this volume) and probably carried the Tetagouche rocks to at least the greenschist grade locally (Helmstaedt, 1971). Skinner (1974) has proposed an early northwest-trending fold system followed by the generation of younger more open folds with northeast-trending axes for the Bathrust area but he does not attempt to assign ages to the fold events.

Lower Silurian Lithofacies

Following the Taconian Orogeny substantial paleogeographic changes are revealed by Llandoverian lithofacies. Figure 4 shows the distributions of the major lithofacies for the Late Llandoverian-Early Wenlockian time period and the approximate limits of emergent areas. A paleogeographic map for the Early Llandoverian produced by Ayrton and others (1969) is similar to that shown for a slightly later time period in Figure 4. One major difference between the early and late Llandoverian lithofacies pictures is the presence of the upper "ribbon-rock" facies of the Carys Mills in the interior of the Aroostook-Matapedia basin during the earlier part of the Llandovery. The Late Llandoverian-Wenlockian interval was selected for Figure 4 because of the larger amount of paleontologic data available and greater complexity of the lithofacies pattern.

The land area called "Taconia" was probably contiguous with the pre-Taconian North American Craton since the ocean-basin closure described by St. Julien and Hubert (1975) appears to have completely removed marine conditions from northwestern Maine and adjacent Quebec. The thick sequence of coarse clastic sediments of the Frenchville-Rangeley belt represents deposits along the newly established continental margin in Maine. In northeastern Maine these coarse clastic sequences give way eastward to much finer grained deep-water lithofacies in the Aroostook-Matapedia Basin (Roy, Trip B-6 and C-5, this volume). Similar off-shore lithofacies changes can be seen from western to central Maine along the western flank of the Merrimack Synclinorium.

The Miramichi terrain appears to have also been uplifted by Taconian deformation as evidenced by coarse sediments deposited in the Bathurst Basin (Noble, 1976). The extent of "Miramichia" in southwestern New Brunswick is not well known and faulting has been largely responsible for limiting our understanding of the detail lithofacies picture in the Woodstock area.

It is of interest to note that by Late Llandoverian time the broad Merrimack Synclinorium in Central Maine seems to have been divided by Miramichia into two basins, the Aroostook-Matapedia Basin and the Fredericton Basin, in New Brunswick as pointed out by McKerrow and Ziegler (1971) who figured a map similar to that shown in Figure 4. McKerrow and Ziegler (1971) suggest that the Fredericton Basin was the main oceanic continuation of the Merrimack Basin and that the Aroostook-Matapedia Basin was a branch that terminated in the Gaspe Peninsula.

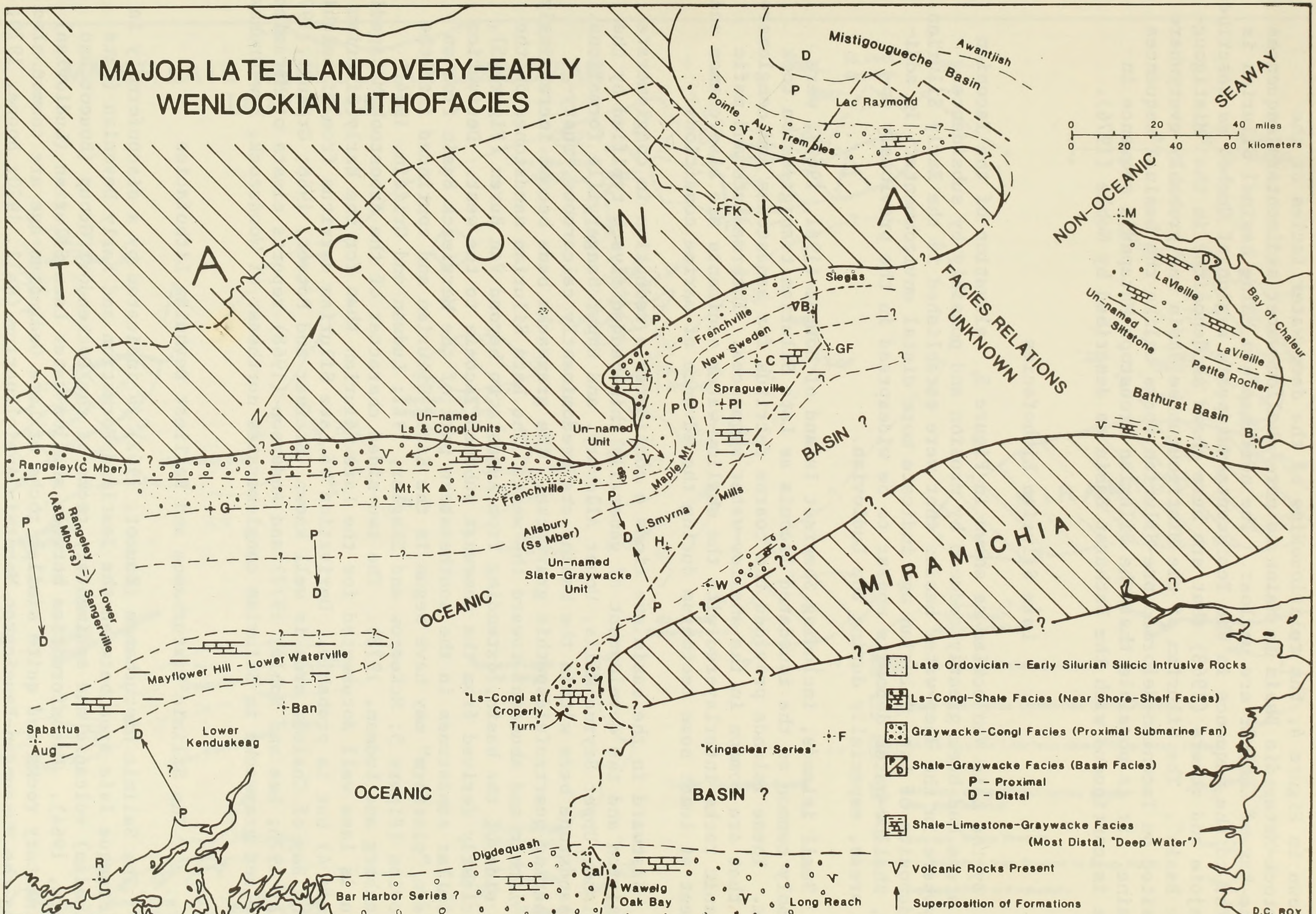

Figure 4: Distribution of major Late Llandovery-Early Wenlockian lithofacies in Maine and adjacent Canada following the Taconian Orogeny.

As shown in Figure 4, the relationships of the deep-water facies of the Aroostook-Matapedia Basin in Maine to more shallow-water sedimentary sequences in the Bay of Chaleur are unclear. The northeastern Maine basinal Silurian is similar to the sequence in the Temisconta-Matapedia region of Quebec as described by Lajoie and others (1968) that are here shown as deposited in the "Mistigougueche Basin". The Silurian of the Mistigougueche Basin was probably everywhere deposited on Taconian-deformed pre-Silurian rocks unlike the basinal sequences in Maine. It is possible that the Silurian Aroostook-Matapedia sequence in Maine is continuous with the Bathurst Basin as described by Noble (1976).

Late Silurian Lithofacies

By the Late Wenlockian as shown in Figure 5, elevation of the Taconian land areas had been greatly reduced by erosion and possibly by subsidence. Everywhere in the deep-water basins that were established in the Early Silurian the deposits of Late Silurian age indicate more distal environments. In addition, shallow-water deposits appear to be widespread in the previously upland areas, especially during the Ludlovian.

Small islands, including Somerset Island of Boucot (1961, 1969), were probably common on the inundated Taconia as Late Silurian transgression took place. These islands provided the coarse detritus for sandstones and conglomerates that are common in the shallow-water sequences. Intermediate and mafic volcanic rocks interlayered with the shallow-water sediments are also common and suggest at least some tectonism during the advance of marine conditions.

Eastward in the basin one finds a considerable reduction in conglomerate deposition and the development of generally thin-bedded flysch typified by the Jemtland, Upper Smyrna Mills, Upper Allsbury, and Upper Sangerville formations. The sandstone beds within the basins are predominantly calcareous, rusty-weathering quartzofeldspathic graywacke. The graywacke beds become increasingly more lithic and abundant toward the west. The Late Silurian sandstones on the west side of the basin, extending from Augusta to beyond Van Buren (Figure 5), are clearly derived from the somewhat subdued Taconia to the west. Derivation of similar sandstones in the southeastern part of the Merrimack Basin from an eastern "platform" may have begun in the Early Silurian and continued into the Ludlovian (Figure 5; McKerrow and Ziegler, 1971; Ludman and Griffin, 1974; Ruitenberg and Ludman, 1978). The two-sided character of the Aroostook-Matapedia Basin is less well documented for the Late Silurian than for the Early Silurian (Figure 4) but is probable. Derivation of Late Silurian detritus from Miramichia in the Bay of Chaleur area is well known (Greiner and Potter, 1966; Greiner, 1973; Noble, 1976; Lee and Noble, 1977) and Anderson (1968) reports clasts of Miramichia slate and graywacke in Silurian conglomerates northeast of Woodstock, New Brunswick.

The Salinic Disturbance and Earliest Devonian Lithofacies

The Salinic Disturbance (Boucot, 1962) is indicated by a disconformity in the Presque Isle area between the Jemtland Formation and Early Devonian (Late Gedinnian) volcanic and sedimentary rocks of the Dockendorf Group (Boucot and others, 1964). Unconformities between shallow-water Late Silurian (Ludlovian) sedimentary rocks and quite similar rocks of Late Gedinnian age are common also along the Munsungun-Pennington Mountain Anticlinorium (Hall, 1970; Boone, 1970;

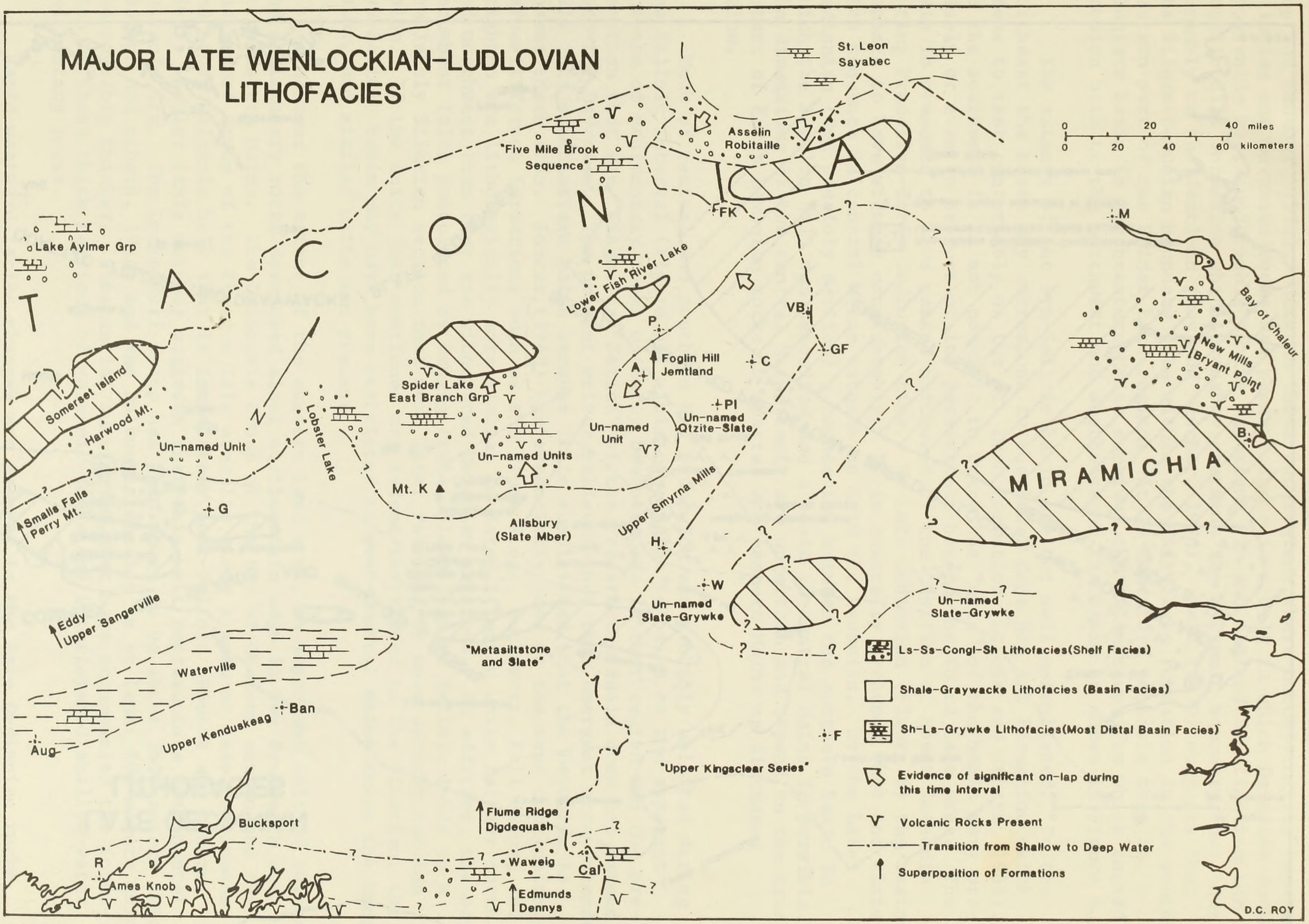

Figure 5: Distribution of major Late Wenlockian-Ludlovian lithofacies in Maine and adjacent Canada.

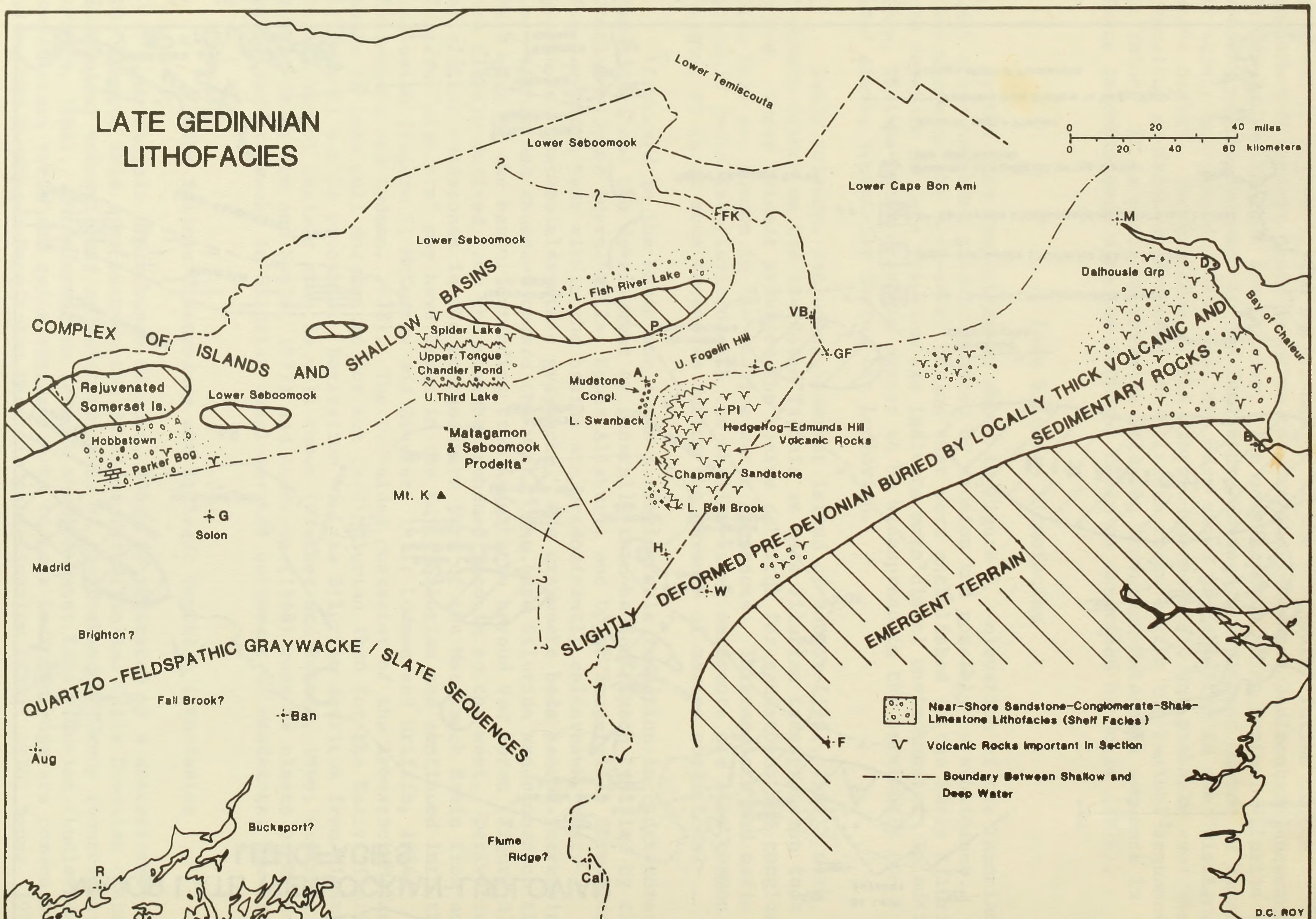

Figure 6: Distribution of major Late Gedinnian lithofacies in Maine and adjacent Canada following the Salinic Disturbance.

Roy and Mencher, 1976). Between these two regions where unconformities between Silurian and Devonian rocks are present there is a belt in which Devonian rocks apparently rest conformably on the Silurian. In the Ashland Synclinorium the Fogelin Hill Formation which probably contains the systemic boundary rest conformably on the Jemtland (Roy and Mencher, 1976). Hall (1970) suggests that the Siluro-Devonian boundary lies within the Third Lake Formation in the southeastern part of the Spider Lake region. It is therefore possible that an elongate basin in northeastern Maine survived the Salinic uplifts which caused erosion both to the northwest and southeast of the basin as shown in Figure 6..

The extents of the syn-Salinic basin are not well established. To the northeast the basin may correspond to the lower Cape Bon Ami Formation which seems to rest conformably on the St. Leon Formation (Lajoie and others, 1968). To the southwest it is not possible to trace the "axis" of the basin very precisely or even to be sure of its persistence beyond the Third Lake area. The axis is presumed to have passed northwest of the position of Mount Katahdin during Predolian-Early Gedinnian time. By Late Gedinnian (Figure 6) the basin appears to have widened considerably. It is generally presumed that the slate-rich sequence in central Maine extends up into the Devonian. By the Late Gedinnian (and possibly earlier) a connection between the northern basin in which the Fogelin Hill was deposited and a basin in central Maine is possible. The dimensions of the central Maine basin are uncertain and depend on the true extent of Early Devonian rocks in central and eastern Maine as discussed below.

Much of central and southern New Brunswick was probably uplifted during the Salinic interval (Figure 6). This conclusion is based on the apparent absence of sedimentary rocks of Early Devonian age in that region and the presumption that the "Kingsclear Series" of the Fredericton Basin does not extend into the Devonian. The present writer believes that this emergent area extended well into southeastern Maine because it is suspicioned that the Devonian is absent there also. Boucot (1968) has essentially come to the same conclusion. Unfossiliferous formations such as the Flume Ridge, Bucksport, Fall Brook, and Brighton are lithologically more similar to dated Silurian units farther north and northwest than they are with dated Devonian sections. In addition, the early recumbent folds postulated by Osberg (this volume) may be Salinic folds in a completely Silurian section that were later refolded by more upright Acadian folds. If the units just mentioned are indeed restricted to the Silurian, the syn-Salinic basin may have been restricted to west-central Maine where the Madrid, Solon, and similar units are present.

Whatever the extent of the eastern land area, an important belt of volcanic and sedimentary rocks developed along northwestern edge in New Brunswick and northeastern Maine. The Dalhousie Group of the Bay of Chaleur region and the Dockendorf Group of the Presque Isle area lie along a more or less continuous and broad volcanic belt that is immediately post-Salinic (Boucot and others, 1964). Naylor (this volume) suggests that this belt represents a continental volcanic arc. The Dockendorf Group has been shown to be about 3600 meters thick (Boucot and others, 1964) and the Dalhousie section is at least 600 meters thick and possibly thicker. Substantial subsidence must have accompanied the formation of these thick sections of volcanic rocks and interlayered shallow-water sedimentary rocks.

Rapid westward facies changes are present in the Late Gedinnian rocks between Presque Isle and Ashland. In Ashland mudstone conglomerate, limestone, polymictic conglomerate and sandstone beds are interlayered with slate. The mudstone conglomerates are usually monomicitc with clasts of either volcanic rocks or clasts from the Jemtland Formation (some containing graptolites).

In the Matagamon Lake area (see Neuman and Rankin, this volume) there is good evidence of a large delta involving the Seboomook Formation and Matagamon Sandstone (Hall and others, 1976). Hall and others (9176) conclude that the deltaic sediments were derived from the east beginning in the Gedinnian, and that the delta prograded westward during the Siegenian. The delta implies a major upland to the east and the presence of a relatively deep basin offshore to the northwest. Additional such deltas with coarsening-upward sections may be present in western Maine (e.g. the Madrid-Carrabassett sequence of Boone, 1973). Such delta sequences may reflect continuation of the southeastern source area into the Maine Slate Belt.

Siegenian Time and The Seboomook Formation

The term "Seboomook" has been applied over the years to the widespread gray slate and graywacke sequences in northwestern Maine. Boucot (1970) has reviewed the distribution of such sequences in Maine and elsewhere within the northern Appalachians and summarized the paleontological control on their ages.

In the Ashland-Portage area and in much of northwestern Maine, the Devonian section is divisible into two parts. The lower part is a lithologically variable section made up of conglomerate, lithic sandstone and limestone interlayered with cleaved mudstone or slate. This lower part usually is fossiliferous (both fauna and flora) and up to about 1 km or so thick. The upper part consists of generally fine-grained, well-cleaved slate with minor but typically cyclically interlayered thin beds of graywacke. The upper part is unfortunately rarely fossiliferous and has no defined "top".

The Seboomook of the Matagamon Lake Area (Hall and others, 1970) and the Moose River Synclinorium (Boucot, 1961, 1969), on the other hand, coarsens upward and is succeeded by fossiliferous shallow-water sandstone units (Matagamon and Tarratine sandstones) followed by silicic volcanic sequences (Traveller Rhyolite and Tomhegan Formation). These stratigraphically "topped" Seboomook sections are difficult to reconcile with the Seboomook further north and west that seems to not have a definable stratigraphic top and indeed may have been "terminated" by the Acadian Orogeny. As pointed out by Boucot (1970), very careful mapping within this monotonous sequence must be done in order to subdivide the now broad "Seboomookland" into subbasins and sources of sediment supply.

The work of Hall and others (1970) is just such an effort. At the time of his death, Ely Mencher was also attacking this very problem in a broad subdivision of "Seboomookland" west of Ashland. Ely's approach was to try and piece together the facies variations in the lower, better-dated part of the section in a large region where fossils were likely to be found due to low regional grade. Ely's field style and meticulous attention to detail were well suited to the task and it is a shame he could not finish it.

The Acadian Orogeny

The principal fold and cleavage producing event in northern Maine post-dates Siegennian deposition and is assigned to the Acadian Orogeny. The Mapleton Formation of Late Middle Devonian age (Schopf, 1964; White, 1975; Boucot and others, 1964; see Naylor, this volume) rests unconformably on nearly vertical lower Devonian and Silurian rocks and provides the best stratigraphic evidence for the end of the orogenic phase of the Acadian.

Folds

The style of Acadian folding varies from place to place depending primarily on the rocks involved in the folded sections (Pavlides and others, 1964; Roy, 1970; Pavlides, 1974). Where thick volcanic or sandstone-conglomerate sections are present the folds are more open and concentric and flexure-slip mechanisms predominated. The Chapman Syncline (involving the Dockendorf Group), the Stockholm Mountain Syncline (involving the Frenchville Formation), and the Castle Hill Anticline (involving both the Winterville and Frenchville formations) are good examples of major folds that are simple in form (see Figures 1 and 2, Roy, Trip B-6, this volume). Where the stratigraphic section is dominated by pelite more tightly appressed, generally symmetric and steeply plunging folds of either concentric or similar form are present. Pelite mobility in these folds is indicated by common pelite injection along cleavage planes in limestone and graywacke beds as well as hinge thickening of pelite beds (Pavlides, 1965; Roy, 1970).

Disharmonic folding is seen locally (Pavlides, 1973) and is common on an outcrop scale in the laminated Silurian ironstones (Roy, 1970). Disharmonic folding on a large scale has been suggested for the Chapman Syncline (less competent pre-Devonian versus the competent Devonian volcanic rocks) by Pavlides (1974) and may be characteristic of the Pennington Mountain Anticlinorium where a thick previously deformed and volcanic-rich Winterville Formation is overlain by the thick slate-rich Seboomook Formation.

Pavlides (1965, 1971, 1972) has documented complicated fold geometries (including overturned fold plunges) in the Ordovician and Silurian pelite-rich units in the Aroostook-Matapedia Anticlinorium. Outcrop size and spacing have so far precluded complete analysis of possible pre-Acadian folding in these rocks, but they are generally thought to have undergone only one deformation (Pavlides, 1974, Roy, 1970). Early folds may be more common than previously recognized, but reports are rare (Hamilton-Smith, 1970; Rast, Lutes and St. Peter, this volume) and their distinction from non-tectonic folds is difficult.

Cleavage

A prominant S_1 cleavage is present in the pelitic rocks. The S_1 cleavage is generally parallel or nearly parallel to axial planes of Acadian folds. Massive sandstone and conglomerate beds or volcanic rocks in the northern part of the conference area typically show no cleavage; thin graywacke beds in slate-rich sections, however, do show a fracture cleavage. Southward from the lattitude of Presque Isle sandstone beds and volcanic rocks show increasingly well developed foliation.

Cleavage in pelitic intervals varies from fracture cleavage in which there is a low degree of micaceous alignment to flow cleavage in which there is pervasive orientation of micaceous minerals parallel to cleavage surfaces. In subgreenschist slates fracture cleavage is characteristic of non-calcareous slate whereas flow cleavage is typical of calcareous slate. Calcareous slates are usually phyllitic in appearance. Pressure solution effects, as discussed by Stringer and Pickerill (this volume), are probably of widespread importance in cleavage formation, especially in low-grade slates.

A late northwest trending fracture cleavage (S_2) is associated with the broad Houlton Oroflex which folds the axial surfaces of the Acadian folds in the vicinity of Houlton (Pavlides, 1974).

Metamorphism

Acadian metamorphism in the northern part of the region of the conference did not exceed prehnite-pumpellyite grade (Combs and others, 1970; Richter and Roy, 1976). The grade there increases from the prehnite-analcime subfacies in the northwest (Pennington Mountain Anticlinorium) to the pumpellite-epidote-Actinolite subfacies to the south and southeast. Metamorphism continuous to increase southward from Presque Isle so that in the Bridgewater-Houlton area low greenschist grade is present (Pavlides, 1965, 1971). Similarly, to the south and southwest, grade becomes low greenschist in the Spider Lake area Hall, 1970) and in the Weeksboro-Lunksoos Lake Anticline (Neuman, 1967).

The prehnite-pumpellyite paragenesis in the north, which is seen only in volcanic rocks and in lithic graywacke beds, appears to be prograde. It is not clearly associable with an Acadian fabric since the rocks containing the diagnostic minerals are not foliated. A regional increase in fluid CO_2 content appears responsible for suppression of the diagnostic minerals of the facies in volcanic rocks of suitable composition in the Presque Isle area (Richter and Roy, 1976). Confirming the southeastward temperature increases suggested by the changes in diagnostic sub-greenschist minerals are preliminary paleotemperature results by Anita Harris of the USGS (Personal communication, 1976) on Silurian and Devonian conodonts. Her results suggest a temperature increase from 50°C (lower Devonian Square Lake Limestone) in the prehnite-analcime zone to 190-250°C within the pumpellyite-epidote-actinolite zone in the Castle Hill Anticline and Chapman Syncline (Lower Silurian Frenchville and Spragueville formations).

Plutonism

Widely scattered granitic Acadian plutons are present in the area covered by the conference. The two largest plutons are the Katahdin Quartz Monzonite (Hon, this volume; Neuman and Rankin, this volume) and the Bottle Lake Complex (Ayuso and Wones, this volume); both will be examined during the conference. North of these large plutons are several smaller intrusives: the Nickerson Lake and Pleasant Lake plutons south of Houlton (Pavlides, 1971); the Munson Pluton just northwest of Presque Isle (Boucot and others, 1964); the Deboulli Stock northwest of Portage (Boone, 1962); and the Chandler Lake Pluton southwest of Ashland.

All of the plutons cut the Acadian cleavage and have well-defined metamorphic aureoles. For the most part the plutonic rocks are not strongly foliated.

Acknowledgements

Early versions of some of the material presented in this paper were reviewed by J. Rehmer, J.C. Hepburn, C.J. Roy, and R.S. Naylor who gave valuable suggestions. Sally Sargent gave able assistance in the preparation of Figures 2,3,4, and 5.

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OUTLINE OF THE PLEISTOCENE GEOLOGY OF NORTHERN MAINE AND ADJACENT CANADA

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INTRODUCTION

For some time, questions concerning the intensity, style, and limits of glaciation throughout northern New England, adjacent Canada, and the Maritime Provinces have been the subject of much controversy.

Initially, Chalmers (1895) put forth the concept of glaciation based on the influence of local centers of ice accumulation. These local ice centers were to have coalesced at maximum glaciation but were thought to have still remained partially independent. As investigations continued this view remained viable and is still considered tenable (Prest and Grant, 1969; Grant, 1977) although modified with respect to specifics concerning limited isostatic rebound, areas showing limited or no traces of glaciation, and stratigraphy.

Alternatively, because of characteristics and features related to strong regional ice flow, lithologic transport, and alpine glaciation, Goldthwaite (1924) advanced the concept of continental glaciation which was controlled by southward flowing lobes of ice emanating from a massive continental ice sheet.

This latter view has been expanded to a more sophisticated level by using modern day analogues such as Antarctic (Hughes, 1973; Borns, 1979, pers comm.) and Greenland (TenBring, 1974) glaciers, along with concepts of calving bays (Thomas, 1977), ice streams (Hughes et al., 1977) and, more recently, models employing the concept of the thermal regime of ice masses (Sugden, 1977; Hughes, 1979, pers. comm.).

Currently, both perspectives are receiving renewed stimulus.

With the exception of the classic work of Leavitt and Perkins (1935) northern Maine has only recently begun to be mapped on a reconnaissance basis, primarily because in the past, access was difficult in what were generally regarded as "wilderness" areas. However, land use planning considerations in conjunction with accelerated logging operations led to various programs starting several years ago involving reconnaissance surficial mapping (Prescott, 1973a; 1973b). It was primarily through these programs, fostered and sponsored by the Main Geological Survey, that northern Maine became an active area of Pleistocene geological investigation. Fortunately so, for prior to these programs most Pleistocene investigations were concentrated along southern and coastal Maine leaving a large, unmapped void between that area and Canada, where Canadian colleagues were working.

As it turns out, this region of northern Maine and adjacent Canada seems destined to play a pivotal role in the deciphering of Pleistocene events along the northeastern corridor of the United States and Canada.

Areally, northern Maine consists of the largest counties in the state; Aroostook County (the largest) forms the northwest, north, and eastern borders of Maine as it abuts Quebec and New Brunswick, separated from Canada to the north by the St. John River (international boundary); Franklin and Somerset Counties delimit the western border of Maine where they join the Quebec border which is roughly coincident with the Boundary Mountains; Piscataquis and Penobscott Counties consititute the central - southern region of northern Maine.

For the most part, the region is underlain by the cyclically bedded grey slate and metasandstone Seboomook Formation. Some large areas of metamorphosed volcanic rocks occur scattered throughout the region. In central Piscataquis County biotite - muscovite granites and quartz monzonites outcrop, increasing in occurrence to the south. Metamorphosed sandstone, siltstones, and limestones outcrop near the eastern Maine-New Brunswick border (See Figures 1 and 2 of Roy, Trip B-6, this volume)

Topographically, the area is a dissected upland plateau with regional bedrock structures trending northeasterly to southwesterly, transverse to known ice-flow direction.

STRATIGRAPHY AND EVENTS

The stratigraphy of glacial deposits of southern Quebec and the events which they represent (Table 1) is based on work by McDonald and Shilts (1971). They determined that the last glacial advance in southern Quebec is represented by the Lennoxville Till, having a northwest provenance, and that southeastern Quebec was deglaciated by about 12,500 years BP..

This Lennoxville Till is correlated with the surface till of Maine (Borns and Calkin, 1977). Coastal Maine was covered by ice 13,200 years BP.(Schlee and Pratt, 1970) and readvances to the coast occurred during general ice recession (Borns, 1966; 1973). An active ice margin existed along the eastern coast of Maine (Borns, 1966) approximately 13,300 years BP.. At about the same time an active ice margin existed in southwestern New Brunswick (Gadd, 1973). Both McDonald and Shilts, and Borns and Calkin consider the Lennoxville Till as representing the entire late Wisconsinan time interval. Borns and Calkin (1977) suggest that the final deglaciation of Maine occurred by thinning and stagnation of ice throughout the uplands of northwestern Maine with no reorganization of flow to form an active center of ice dispersal. In support of this contention, they suggest that cirque glaciers did not develop in the mountains of west-central Maine following dissipation of the ice. This implies that the regional snow line had become elevated above the highest mountains prior to their emergence. This view is supported by Davis (1976) but is in opposition to views held by Thompson (1960, 1961a, 1961b) and Caldwell (1966).

Borns and Calkin (1977) visualize that by the time the ice margin had retreated to the proximal side of the coastal moraine belt all

Time-Stratigraphic Unit		Rock-Stratigraphic Unit	Chronologic Control
Wisconsin Stage	late	post-Lennoxville Sediments	12,640±190 - peat (GSC-312) 12,570±220 - peat (GSC-419) 12,000±230 - marine shells (GSC-936) 11,500±160 - marine shells (GSC-475-2)
Wisconsin Stage	middle	Lennoxville Till	
Wisconsin Stage	middle	Gayhurst Formation	> 20,000 B.P. (GSC 1137) Ca 4000 varves
Wisconsin Stage	middle	Chaudière Till	
Wisconsin Stage	early	Massawippi Formation	> 54,000 B.P. (Y-1683) > 41,000 B.P. (GSC-507) > 40,000 B.P. (GSC-1084)
Wisconsin Stage	early	Johnville Till	
		pre-Johnville Sediments	

Table I. Quaternary Stratigraphic Column, Southeastern Quebec; (after McDonald and Shilts, 1971)

Canadian ice flow was southward within the active ice mass north of the Boundary Mountains. During this period of stagnant ice in Maine, the Canadian ice constructed successive frontal moraines as the ice margin receded to the St. Lawrence lowland of Quebec (Gadd, 1964; McDonald and Shilts, 1971).

Glacial Lake Madawaska was formed in New Brunswick when the St. John River at Grand Falls, New Brunswick was dammed by the Grand Falls Moraine (Lee, 1955). Recession of the ice front from Grand Falls had to have occurred well before 10,200 years BP. because peat overlying till at Green River, New Brunswick has been dated at 10,200 ± 350 years BP. (Lee, 1955). Kite (1979) has had this peat redated and concludes that it possibly could be as old as approximately 12,000 years BP. Until recently (Genes and Newman, 1979; Brewer, 1980) end moraines had not been reported between the end moraine belt around Pineo Ridge, at coastal Maine, and the international border at the west side of the Boundary Mountains. Therefore, the limitations imposed by previous investigations of adjacent areas required the conclusion that all of the surface till of Maine be Lennoxville in age, that is, it is a simple remnant of the last major advance to the coast. In turn, this implied that subsequent to the invasion of the Champlain Sea, approximately 13,000 years BP., Laurentide ice did not transgress into Maine (Lasalle et al., 1977) or even at all during late Wisconsinan time (Grant, 1977).

It must be mentioned that there are extremely divergent views as to the behaviour of the ice in southeastern Canada. Gadd (1973) envisions the Highland Front Moraine system in Quebec as having been emplaced as a recessional moraine during normal retreat of the margin of southerly flowing ice. Lasalle et al. (1977) visualize the system as having formed from northerly flowing ice which resulted from the division of the Laurentide ice sheet into separate lobes by the Champlain Sea embayment. Grant (1977) because of his adherence to the concept of Appalachian ice centers maintains that Laurentide ice never reached Maine.

Field mapping in northern Maine and southern Canada now implies that deglaciation was more complex than previous work has suggested.

Evidence from striations, moraines, outwash overrun and capped by till, and three or possibly four distinct tills can be interpreted as having resulted from multiple glaciations; from different flow regimes within a single ice sheet; or from penecontemporaneous deposition from different ice centers.

The following considerations are implicit in any interpretation regarding the late Wisconsinan history of northern Maine and adjacent Canada:

1) A late Wisconsinan readvance formed the Pineo Ridge Moraine along the eastern coast of Maine at approximately 12,700 years BP. (Borns, 1966). The minimum age of deglaciation of southwestern New Brunswick is implied to be 12,600 ± 279 years BP. (Gadd, 1973).

2) The date of 12,600 years BP. for the Highland Front Moraine (Gadd, 1964) in Quebec, represents the minimum date for the incursion of the Champlain Sea into the St. Lawrence Valley. This date also represents the minimum date at which the Laurentide ice became detached from the Laurentide ice north of the St. Lawrence River.

3) All observed evidence indicates that northern Maine was overrun by ice moving in a southeasterly direction, and that glacial recession was accomplished by downwasting and recession from coastal to northern Maine. Evidence in northwestern Maine indicates ice flow to the north.

In light of these controversies, this years' surficial field trips should prove interesting indeed.

Claude Gauthier has been deciphering the New Brunswick Pleistocene for several years and will lead a trip on the New Brunswick side of the St. John River Valley. Glacial stratigraphy around Edmunston, a reappraisal of Glacial Lake Madawaska, and sections of the Grand Falls Moraine complex, will be discussed. (Trip B-9)

Kite and Borns will discuss deposits associated with Glacial Lake Madawaska as they relate to both sides of the middle reaches of the St. John River. Although, primarily concerned with Holocene events, they suggest important concepts regarding the determination of deposits and how they should be mapped. (Trip C-4)

Wisconsinan stratigraphy along the southern bank of the St. John River, including multiple till sections which permit interpretation of late Wisconsinan deglaciation in northern Maine, is the subject of the trip by Genes and Newman. (Trip B-8)

Genes, Newman, and Brewer will examine moraines, eskers, and other landforms in northern Maine which suggest the mode and extent of till emplacement in that region. (Trip C-6)

D. Caldwell will review the Wisconsinan alpine glaciation of Mt. Katahden. In case a climb is not possible because of inclement weather, a surficial trip of the area is planned. (Trips A-3, B-2)

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