

THE SILURIAN OF NORTHEASTERN  
AROOSTOOK COUNTY, MAINE

by

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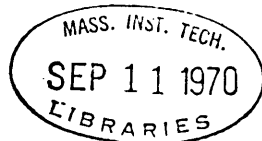
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by

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## ABSTRACT

In northeastern Aroostook County, Maine, 10,500 feet of strata representing almost the entire Silurian has been established and there are indications that the entire system is present. The Silurian stratigraphy is revised and three new formations are proposed. The Aroostook River Formation, a flysch sequence composed of slate interlayered with graywacke turbidites, and the upper Carys Mills Formation, composed largely of thinly interbedded limestone and slate, make up the lower Llandoveryian. The middle Llandoveryian-Early Wenlockian rocks are divided into three formations: the Frenchville Formation, a western sandstone and conglomerate sequence; the New Sweden Formation, a medial slate and manganiferous ironstone unit; and the Spragueville Formation, an eastern thinly layered calcareous mudstone-silty limestone succession. Based on sandstone composition and the abundance of conglomerate and slate, the Frenchville Formation has been subdivided into the graywacke, conglomerate, feldspathic sandstone, sandstone-slate, and quartzose sandstone members. The Jemtland Formation and at least the lower portion of the overlying Fogelin Hill Formation, together with an unnamed sandstone-slate sequence in the Ashland area, make up the upper Wenlockian-lower Ludlovian. Both the Jemtland and Fogelin Hill formations are thinly interbedded flysch sequences, with the former containing a proximal (western) graywacke facies and a distal (eastern) slate facies, and the latter composed of red and green slate interlayered with fine graywacke.

The Winterville, Madawaska Lake, and lower Carys Mills formations, together with the Pyle Mountain Argillite, comprise the pre-Silurian (Ordovician) of the area. The Winterville Formation, composed of volcanic rocks and interlayered slate, graywacke, and chert, interfingers eastward with the slate and graywacke of the Madawaska Lake Formation, which, in turn, grades eastward into the lower Carys Mills Formation. The Pyle Mountain Argillite, of Ashgillian age, is only locally present, overlying the Winterville Formation in the Castle Hill Anticline.

The Silurian stratigraphy records the history of a basin marginal to emergent areas that were uplifted during the Taconic orogeny. The Taconic movements began in the earliest Llandoveryan as evidenced by the influx of turbidity-current deposits in the Aroostook River Formation. During the period of maximum uplift and closest proximity of the emergent terrains to the study area, the conglomerates and lithic sandstones of the Frenchville Formation were deposited along the margin of the basin at, or near, the base of a slope, while the finer grained and more calcareous lithofacies of the New Sweden and Spragueville formations were being deposited farther out in the basin. Subsidence of the basin, along with advance of the sea onto the land areas, took place during the deposition of the Frenchville Formation and its lateral equivalents. The Jemtland Formation conformably overlies the three Late Llandoveryan-Early Wenlockian formations, and represents deposition in a more offshore environment in which turbidity currents played a prominent role. In the Stockholm Mountain Syncline, the Jemtland is overlain conformably by the Fogelin Hill Formation, a more distal turbidite lithofacies that may have persisted into the Early Devonian; elsewhere, the Jemtland Formation, or its equivalent, is overlain disconformably by Early Devonian sedimentary and volcanic rocks.

A provenance study of sandstones and conglomerates from the Silurian units shows that they were derived from Ordovician rocks of the region, principally from portions of the Winterville and Madawaska Lake formations. Quartz diorite was a primary source for lithic graywackes in the feldspathic sandstone and quartzose sandstone members, and a secondary source for conglomerates locally in the conglomerate member of the Frenchville Formation. It is concluded that the iron and manganese of the lenticular ironstone bodies of the New Sweden Formation were derived from the weathering of volcanic rocks of the Winterville Formation.

The sedimentation of each Silurian lithofacies is discussed with special emphasis on the Frenchville and Jemtland formations. It is shown that all lithofacies developed offshore, and it is suggested that mass transport of sediment in the form of slumps, grain flows, and turbidity currents was important. Lithofacies distributions, provenance variations, and paleocurrent data document the persistence of western and southwestern sources at least through the deposition of the Jemtland Formation. The abundant paleontologic data (119 fossil localities) allow not only precise correlations, but permit estimates of minimum rates of sedimentation for the Frenchville (15-30 cm/10<sup>3</sup> yrs) and Jemtland (12-15 cm/10<sup>3</sup> yrs) formations. Brachiopod communities present in the Frenchville,

New Sweden, and Spragueville formations lead to the conclusion that these units were deposited in water which was at least hundreds of feet deep.

Thesis Supervisor: Robert R. Shrock

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We come now to the geological part. This is the one where the evidence is not all in, yet. It is coming in, hourly, daily, coming in all the time, but naturally it comes with geological carefulness and deliberation, and we must not be impatient, we must not get excited, we must be calm, and wait. To lose our tranquillity will not hurry geology; nothing hurries geology.

Mark Twain

Letters from the Earth

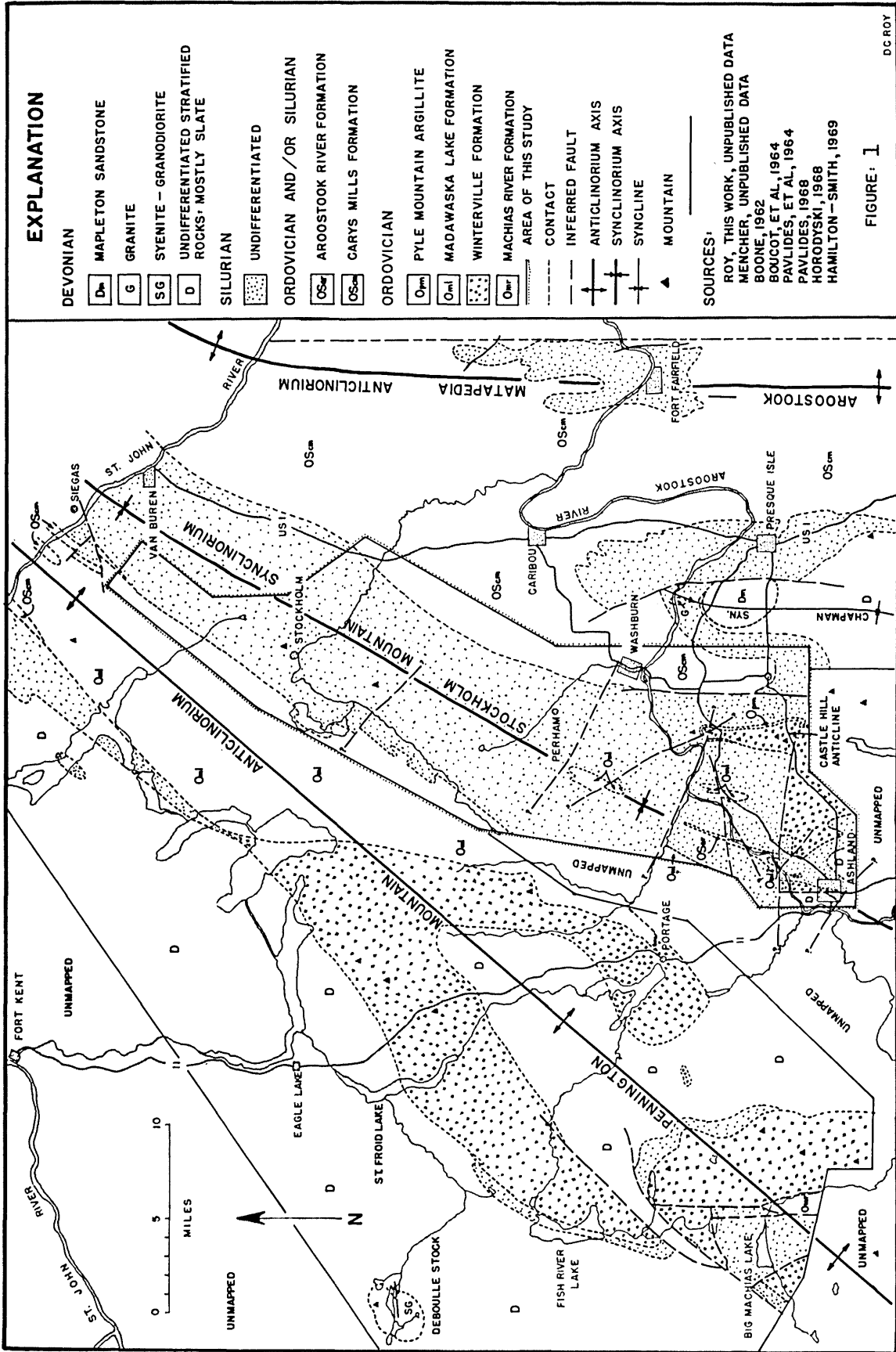
#### INTRODUCTION

Numerous recent studies have shown that northern Maine offers a unique opportunity to study the development of the axial region of the northern Appalachian geosyncline. The moderate deformation, low metamorphic grade, numerous fossil localities, and well-preserved sedimentary features permit the age and paleoenvironments of rock units to be determined in detail uncommon in the New England portion of the mountain belt. The importance of the area is enhanced because of the presence of major eugeosynclinal lithofacies that may be traced along the mountain belt into the well-studied complexly deformed and metamorphosed terrain of southern New England. The

impact of studies in northern Maine on our understanding of the history of the northern Appalachians is clearly evident in the recent "Billings volume" (Zen, et al., 1968).

In the development of the New England portion of the Appalachian geosyncline, the Silurian was a period of significant change in the paleogeography of its eugeosynclinal portion. In many places, regionally extensive lithofacies of the Ordovician gave way to more variable lithofacies containing detritus "cannibalized" from newly emerged nearby land areas. Over much of southern New England, however, the limits of the Silurian basins and their internal stratigraphic variations have been largely obscured by metamorphism and deformation. In the metamorphic areas stratigraphic correlations must be based largely on lithologic similarities, commonly including inferences concerning the original character of the rocks; these correlations are enhanced only locally by fossil localities. Definitely established Silurian rocks in southern New England form lithofacies that may be correlated, in a general way, with lithofacies of similar age in northern Maine (Boucot and Thompson, 1963; Naylor and Boucot, 1965; Boucot, 1968; Ayrton, 1969).

Figure 1: A generalized geologic map of a portion of northeastern Aroostook County, Maine. Principal tectonic features are shown, and the area of this study is outlined. The Spragueville Formation forms the synclinal infold of Silurian rocks in the Fort Fairfield area. Only the Late Silurian (Ludlovian-Predolian) is present in the Fish River-Big Machias Lakes area.



In northeastern Aroostook County, a stratigraphic record of almost the entire Silurian has been documented, and there is evidence that the complete system is represented. A study of this Silurian in the area shown in Figure 1 was undertaken to determine the lithology, extent, and sedimentology of the lithofacies that comprise the system and to relate these lithofacies to a changing paleogeography. The results of the study provide a detailed account of the history of Silurian sedimentation in a large area of the geosynclinal interior, which may ultimately serve as a model for unraveling similar, though metamorphosed lithofacies, in structurally more difficult terrains.

#### PREVIOUS AND CONCURRENT WORK

Geologic investigations in northeastern Aroostook county have been stimulated largely by two important aspects of the area: the fossiliferous nature of many of the exposures and the presence of sedimentary banded ironstones with manganese enrichment. During the nineteenth century, the area was visited only briefly. In 1836 the state legislature authorized a three-year topographic and scientific survey of portions of northern Maine with Charles T. Jackson in charge. Outcrops along streams, rivers, and main roads were briefly described, and a

preliminary study of the ironstones of Wade Township was made (Jackson, 1838). In 1861, the state initiated a second scientific survey in which the geologic investigations were made principally by Charles H. Hitchcock. Hitchcock (1861, 1863) summarized the geological work of that survey as well as work by the Canadian Survey in northern Maine.

During 1897 and 1898, Henry S. Williams and Herbert E. Gregory of Yale University, under the auspices of the U. S. Geological Survey, conducted a study "...for the purpose of ascertaining the facts regarding the local modification of the Devonian and Silurian faunas in the eastern province of North America." Williams described the fauna and Gregory studied the rocks in Aroostook and Somerset counties; their reports (Gregory, 1899; Williams and Gregory, 1900; Williams, 1915) constitute the first systematic presentations of the geology of northeastern Maine.

In 1928 W. H. Twenhofel visited the area shown in Figure 1 and visited many of the localities studied by Williams and Gregory (Twenhofel, 1941). Twenhofel re-ordered the succession of rock units as established by Williams and Gregory and assigned different ages to some of the units.

During World War II, the strategic importance of iron and manganese prompted both the federal and state surveys to make systematic studies of the manganiferous ironstones in northern Maine. In 1941 and 1942 Walter S. White and Preston E. Cloud, Jr. for the Federal Survey and Paul F. Eckstrom for the State Survey examined in some detail the several prospects in the area of Figure 1 as well as farther south in the vicinity of Houlton, Maine. They also mapped the terrain around these prospects, modifying and expanding the previously established stratigraphic framework. In the course of the work, Cloud described and collected from many new, as well as previously known, fossil localities. White (1943) reported the results, incorporating information from the Manganese Ore Company, which had drilled two of the prospects.

A continuation of the above study was made by Ralph L. Miller during the summer of 1943 and a few weeks in 1944 (Miller, 1947). Miller used the regional stratigraphy established by White (1943) but presented a somewhat more extensive account of the local stratigraphy, mineralogy, and geochemistry of the various deposits.

The development of the modern stratigraphic framework in the region of the present study began with investigations, during the period 1959 to 1962, in the Presque Isle quadrangle by students under the supervision

of Arthur J. Boucot, then of MIT, and Louis Pavlides of the U. S. Geological Survey (Boucot, et al, 1964a). Reconnaissance mapping in the Ashland quadrangle by Richard S. Naylor (Naylor, unpublished data) and in the Caribou and Stockholm quadrangles by Douglas Smith (Smith, unpublished data) in 1962 provided support for many of the stratigraphic interpretations made by Boucot, et al. and confirmed that the units could be mapped over a large area.

In the summer of 1962, a mapping program was begun by Ely Mencher and his students. The work of this project was concentrated for the most part in the western half of the area shown in Figure 1. The writer joined this program in 1963 and did reconnaissance mapping in the Greenlaw, Winterville, and Ashland quadrangles. The study described here was begun in 1964, with 17 months of field work done during the summers of 1964-1966 and 1969. Concurrently, Mencher, the writer, and a succession of undergraduate and graduate students from MIT did reconnaissance and locally detailed mapping over much of the region and the present study area. Hamilton-Smith (1969) and Horodyski (1968), both working on the MIT project, studied the Siegas, New Brunswick and Fish River-Big Machias Lakes areas, respectively (Figure 1).



Many of the fossil localities in the study area have been the subjects of, or included in, several important paleontologic papers (Williams and Gregory, 1900; Clarke, 1908, 1909; Williams, 1915; Ruedemann and Smith, 1935; Ruedemann, 1947; Berry, 1960a; Pavlides, et al., 1961; Neuman, 1963; Berry, 1964; Boucot, et al., 1964a; Schopf, 1964; Pavlides, and Berry, 1966; Schopf, et al., 1966; Pavlides, 1968; Neuman, 1968). In the past, Olaf Nylander, and currently William Forbes, local naturalists, have made important contributions to our understanding of the paleontology of the area. Nylander found, and collected from, many of the localities later studied by Williams, Clarke, and Twenhofel; his descriptions of many of the collections were privately published and are not generally available. Forbes has been similarly active in helping more recent workers, including the author, and in conducting studies of his own.

Several unpublished MIT Bachelor's theses on portions of the area shown in Figure 1 have been produced by students working under Ely Mencher (Coskren and Lluria, 1963; Friedberg and Peterson, 1964; Hayes and Nalbandian, 1963; Laux and Warner, 1966; and Parr and Zidle, 1963). Boone (1959), in connection with his study of the Deboullie Stock, mapped Ordovician, Silurian, and

Devonian rocks along the northwest flank of the Pennington Mountain Anticlinorium between St. Froid Lake and Fish River Lake.

Pavrides (1962) discusses aspects of the manganiferous ironstone deposits of the study area in connection with his detailed study of the Maple Mountain and Hovey Mountain prospects further south. Pavrides, et al. (1964) discuss the principal stratigraphic and tectonic features of northeastern Maine, and Pavrides (1968), in a regional synthesis on the Carys Mills Formation and its stratigraphic relationships, reviews and updates the stratigraphy of the Presque Isle quadrangle. Several recent regional syntheses present aspects of the geology of the area (Naylor and Boucot, 1965; Ayrton, et al., 1969; several papers in Zen, et al., 1968). Boucot, et al. (1964b) presented a brief geologic summary accompanying a geologic and aeromagnetic map of northern Maine which includes most of the area shown in Figure 1. Early map data of the MIT group was included in the recently published geologic map of Maine (Doyle, 1967).

#### STRATIGRAPHIC NOMENCLATURE.

Development of the stratigraphic framework and nomenclature of the study area is depicted graphically in Figure 2. The "tie-lines" indicate the changes in

Figure 2: The development of stratigraphic relationships and nomenclature in northeastern Aroostook County Maine. Tie-lines indicate correlations of approximately equivalent rock units. In this work, the Perham Formation of Boucot, et al. (1964a) has been elevated to group rank and its upper and lower members are designated the Jemtland and New Sweden formations, respectively. The Fogelin Hill, Aroostook River, and Madawaska Lake formations described herein have no precursors in previous published formulations.

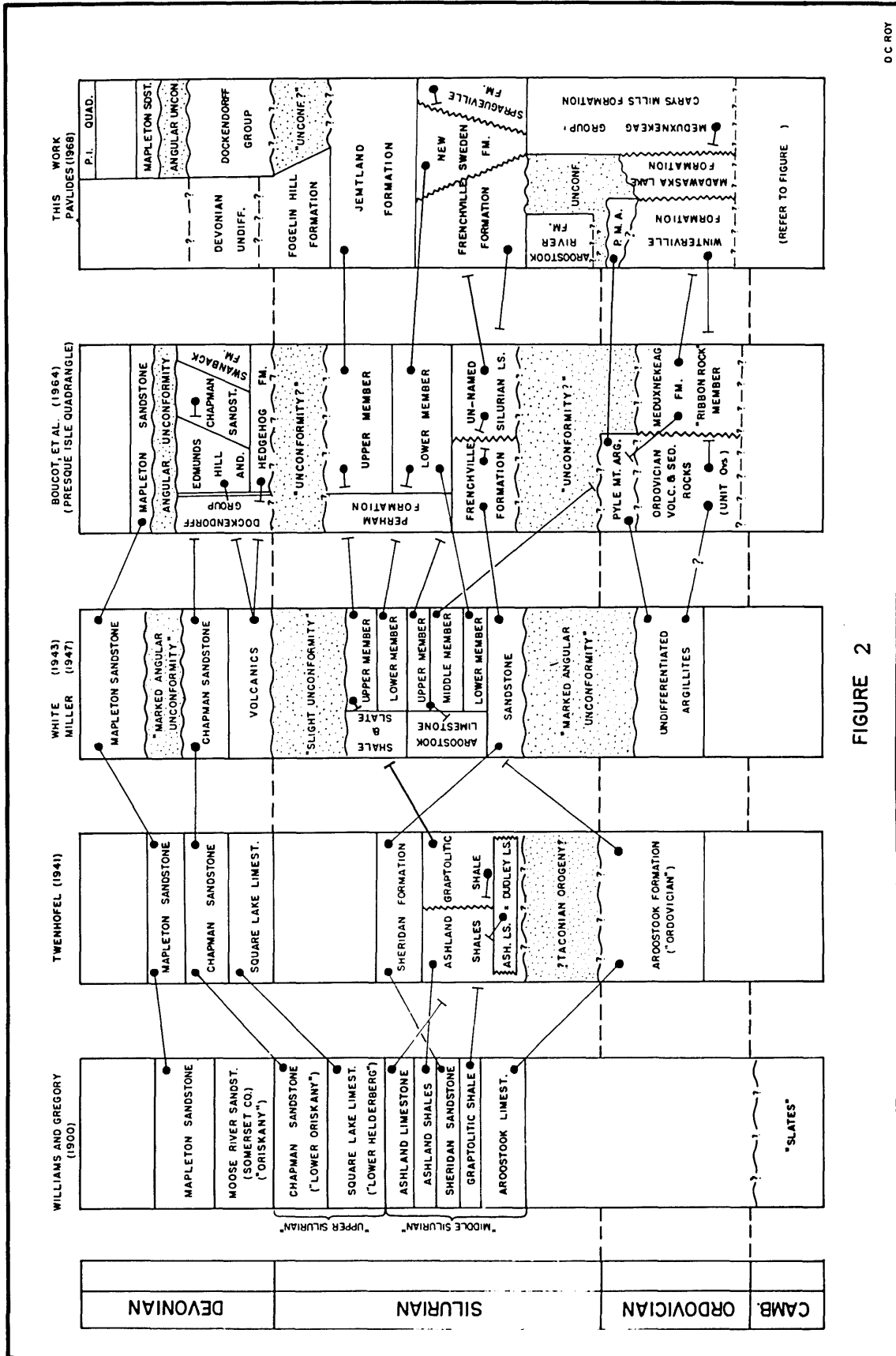


FIGURE 2

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stratigraphic position, name, and age of roughly equivalent rock units. The units of Williams and Gregory, and Twenhofel, with the exception of the "Aroostook Limestone (Formation)", were not specifically shown on maps; therefore, equivalencies between their units and those defined by later workers are approximate.

White (1943), with P. E. Cloud, was the first to define rock units in the Presque Isle and Caribou quadrangles as mappable entities in the conventional sense. In their investigation, most of the stratigraphic elements of the northern half of the Presque Isle quadrangle were isolated and extended, in part, into the Caribou quadrangle. White (1943) clearly indicates uncertainties in his stratigraphic sequencing shown in Figure 2. He points out, for example, that the calcareous and noncalcareous slates assigned to the "lower member" of the "Aroostook Limestone" may be equivalent to the slates and argillites in the "lower member" of the overlying "shale and slate" unit, a conclusion ultimately accepted by Boucot, et al. (1964a) when they placed both of White's slate sequences into the lower member of the Perham Formation. Boucot, et al. (1964a) and Pavlides (1968) discuss the variations in usages of the terms "Aroostook Limestone" and "Aroostook Formation" and conclude that they should be abandoned.

Although the volcanic rocks now assigned to the Winterville Formation and Dockendorff Group were examined and discussed by Williams and Gregory (1900), it was White (1943) and, more particularly, Boucot, et al. (1964a) who placed these rocks in their proper stratigraphic positions. Boucot, and others, also recognized that the Frenchville Formation ("Sheridan Sandstone" and "Sandstone" of previous workers) and the "unnamed Silurian Limestone" (Spragueville Formation of Pavlides, 1968) were, in part at least, temporal equivalents. The present investigation has produced abundant evidence indicating that the lower member of the Perham Formation forms a medial facies between the Frenchville and Spragueville formations; Pavlides (1968), using regional stratigraphic arguments, concurrently reached a similar conclusion.

The "Square Lake Limestone" refers to a single exposure on the west shore of Square Lake and is not yet established as a mappable unit. The "Ashland Limestone," now shown to be Lower Devonian, was thought to be equivalent to the "Dudley Limestone" (Lower Ludlovian) by Williams and Gregory, and Twenhofel; this was the prime assumption involved in Twenhofel's correlation of the "Ashland shales" and the "graptolitic shales." Twenhofel included strata belonging to the Aroostook River Formation (of this report) with the "Ashland Shales" and

used their structural relationship to the "Sheridan Sandstone" in the vicinity of Frenchville as the basis for concluding that the shales underlie the sandstones.

The Madawaska Lake, Aroostook River, and Fogelin Hill formations of this report have no precursors in the stratigraphy as proposed by previous workers. The Perham Formation of Boucot, et al. (1964a) has been elevated to group rank and its upper and lower members are here designated the Jemtland and New Sweden formations, respectively.

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## GENERAL GEOLOGY

### REGIONAL SETTING

The relationships of the major tectonic elements of the New England and Maritime Appalachian fold belt to those of the study area (Figure 1) are shown in Figure 3. These tectonic elements, generally ascribed to the Acadian orogeny, are internally complex but may be traced for great distances (Cady, 1960; Zen, 1968). East of the persistent Connecticut Valley-Gaspe Synclinorium the tectonic elements become more widely spaced and, with few exceptions, are less easily traced as single entities when carried northeastward into Maine and New Brunswick; the Bronson Hill-Boundary Mountain Anticlinorium, for example, loses its identity as a single element in western Maine (Albee, 1961; Hall, 1964).

Coincident with the northeastward broadening of the fold belt is the rapid decrease in the grade of regional metamorphism. Figure 3 shows the distribution, in New England, of terrane containing rocks of metamorphic grade higher than the greenschist facies (Thompson and Norton, 1968). Contact metamorphism around intrusive rocks in eastern and northern Maine is not shown. Most of Maine, except the southwestern part, is underlain by rocks which have been regionally metamorphosed no higher than the greenschist facies.

Figure 3: Principal tectonic features of the Northern Appalachians in New England, Eastern Quebec, and New Brunswick. The tectonic features of northeastern Maine contain rocks similar in many respects to those of like ages found in the Bronson Hill-Boundary Mountain Anticlinorium and Merrimac Synclinorium to the southwest. The decrease in regional metamorphic grade with the north-eastward broadening of the fold belt is shown by the chlorite isograd (after Thompson and Norton, 1968). Contact metamorphism associated with intrusive rocks is not shown.

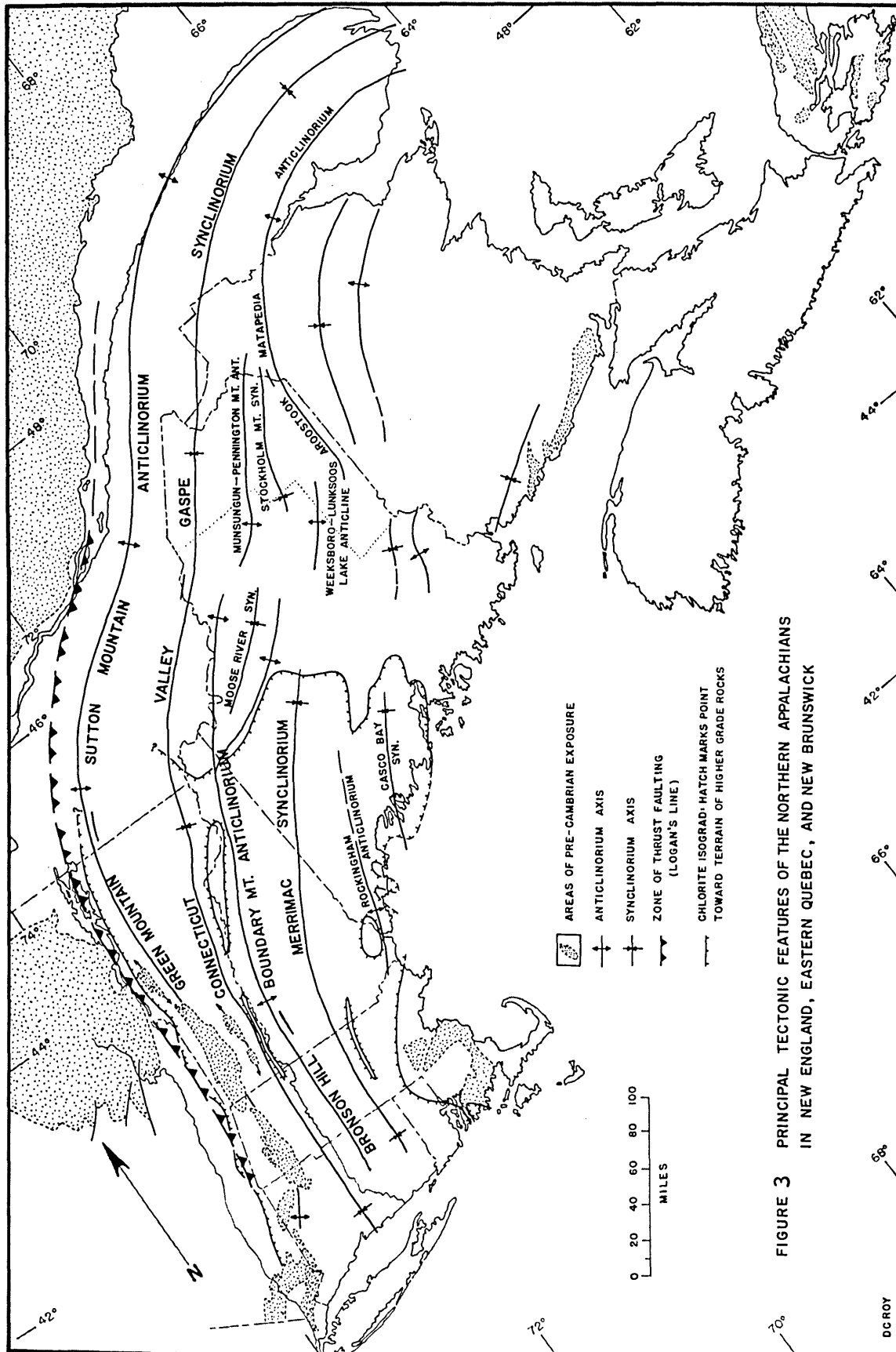


FIGURE 3 PRINCIPAL TECTONIC FEATURES OF THE NORTHERN APPALACHIANS IN NEW ENGLAND, EASTERN QUEBEC, AND NEW BRUNSWICK

DC ROY

Much of the area of Figure 1 has been shown as containing "sub-chlorite zone" rocks (Doyle, 1967). Coombs, et al. (1970) report Ordovician and Devonian rocks containing mineral assemblages characteristic of the prehnite-pumpellyite facies of regional metamorphism from the vicinity of Big Machias Lake. Pavlides (1965a) also reported the presence of prehnite in veinlets and vesicles in greenstones from Collins Ridge, Bridgewater quadrangle, but concluded that most of the rocks of that quadrangle belong to the greenschist facies. The distribution, in northern Maine, of rocks containing the prehnite-pumpellyite assemblage is incompletely known, but the presence, at least locally, of the zeolite assemblage suggests that the grade of regional metamorphism is not great and may be near the boundary between the zeolite and greenschist facies.

The Munsungun-Pennington Mountain Anticlinorium of northeastern Maine occupies the same tectonic position relative to the Connecticut Valley-Gaspe Synclinorium as the Bronson Hill Anticlinorium farther southeast (Hall, 1964); northeastward, in New Brunswick, the Aroostook-Matapedia Anticlinorium of Pavlides, et al. (1964) occupies this tectonic position. In southern New England, anticlinoria generally have Precambrian and/or Ordovician cores, whereas the synclinoria are formed mainly of

Siluro-Devonian rocks (Zen, 1968; Green and Guidotti, 1968). The same relationships are characteristic of similar tectonic features in northeastern Maine (Hall, 1964; Pavlides, et al., 1964) except that the oldest rocks exposed are of probable Cambrian age in the Weeksboro-Lunksoos Lake Anticline (Neuman, 1962, 1964) and Munsungun Anticlinorium (Hall, 1964). As shown in Figure 1, synclinal in-folds of Silurian and Devonian rocks are present in the anticlinoria, and Ordovician rocks may appear along anticlinal axes or as fault blocks within synclinoria. These occurrences reflect higher orders of folding superimposed on the first-order anticlinorial and synclinorial features.

Studies of the distribution of major Ordovician through Early Devonian lithofacies in the northern Appalachians have shown that facies boundaries tend to be parallel or subparallel to the major tectonic features (Naylor and Boucot, 1965; Berry, 1968; Boucot, 1968; Cady, 1968; Naylor, 1968; Ayrton, et al., 1969). This may be related to the apparent tendencies of some of the anticlinorial features to be superimposed upon geanticlinal areas or portions of such areas which were elevated periodically during the history of the geosyncline (Cady, 1968; Boucot, 1961; Naylor and Boucot, 1965; Boucot, 1968).



These geanticlinal elements produced tectonic islands and more or less linear land masses that contributed detritus to neighboring basinal areas.

The trend of the Bronson Hill-Boundary Mountain Anticlinorium and its probable continuations in northeastern Maine are roughly coincident in space with a belt of Early to Middle Ordovician volcanic rocks and associated slates, graywackes, cherts, and pyroclastic rocks (Kay, 1951; Green, 1964; Hall, 1964; Green and Guidotti, 1968; Naylor, 1968). Uplift of this belt along much of its length as part of a major geanticlinal development (Appalachia) during the interval of Late-Middle Ordovician to Late-Early Silurian was a principal feature of the Taconic orogeny (Pavlides, et al., 1968). Angular and disconformable relationships between Ordovician rocks and those of the Silurian and Early Devonian mark the existence and extent of the land mass formed. Regional considerations of major Silurian lithofacies indicate that this period brought gradual transgression of the seas onto the land area until, in the Early Ludlovian stage of the Late Silurian, only a thin, more or less linear land area existed along the present Green Mountain-Sutton Mountain Anticlinorium, and isolated islands and shallow marine shelves remained along the

general trend of the present Bronson Hill-Boundary Mountain Anticlinorium (Boucot, 1968; Naylor and Boucot, 1965).

#### STRATIGRAPHY

Sedimentary and volcanic rocks representing the Middle Ordovician to Late Middle Devonian time occur in and near the area of this study (Figure 1). Rocks of Cambrian (?) and Early Ordovician age, though not known in the immediate vicinity, are present to the south (Neuman, 1967) and southwest (Hall, 1964).

Preserved in the Stockholm Mountain Synclinorium is a complex assemblage of Early Silurian to Early Devonian (?) sedimentary rocks approximately 10,500 feet (3,200 m) thick. In addition, Lower Devonian slates, of unknown thickness, probably overlie this sequence between Ashland and Portage. The adjacent Pennington and Aroostook-Matapedia anticlinoria (henceforth referred to as the "western" and "eastern" anticlinoria, respectively) contain extensive Ordovician and Ordovician-to-Early Silurian rock units as well as younger Silurian and Devonian rocks preserved in fault blocks and synclinal infolds. Figure 4 shows the distribution of the major rock units as shown in more detail in Plate I.

Figure 4: Geologic map showing the distribution of Ordovician and Silurian units in the Stockholm Mountain Synclinorium. Formation symbols shown on Plate II. Sources of information are indicated in Figure 1.

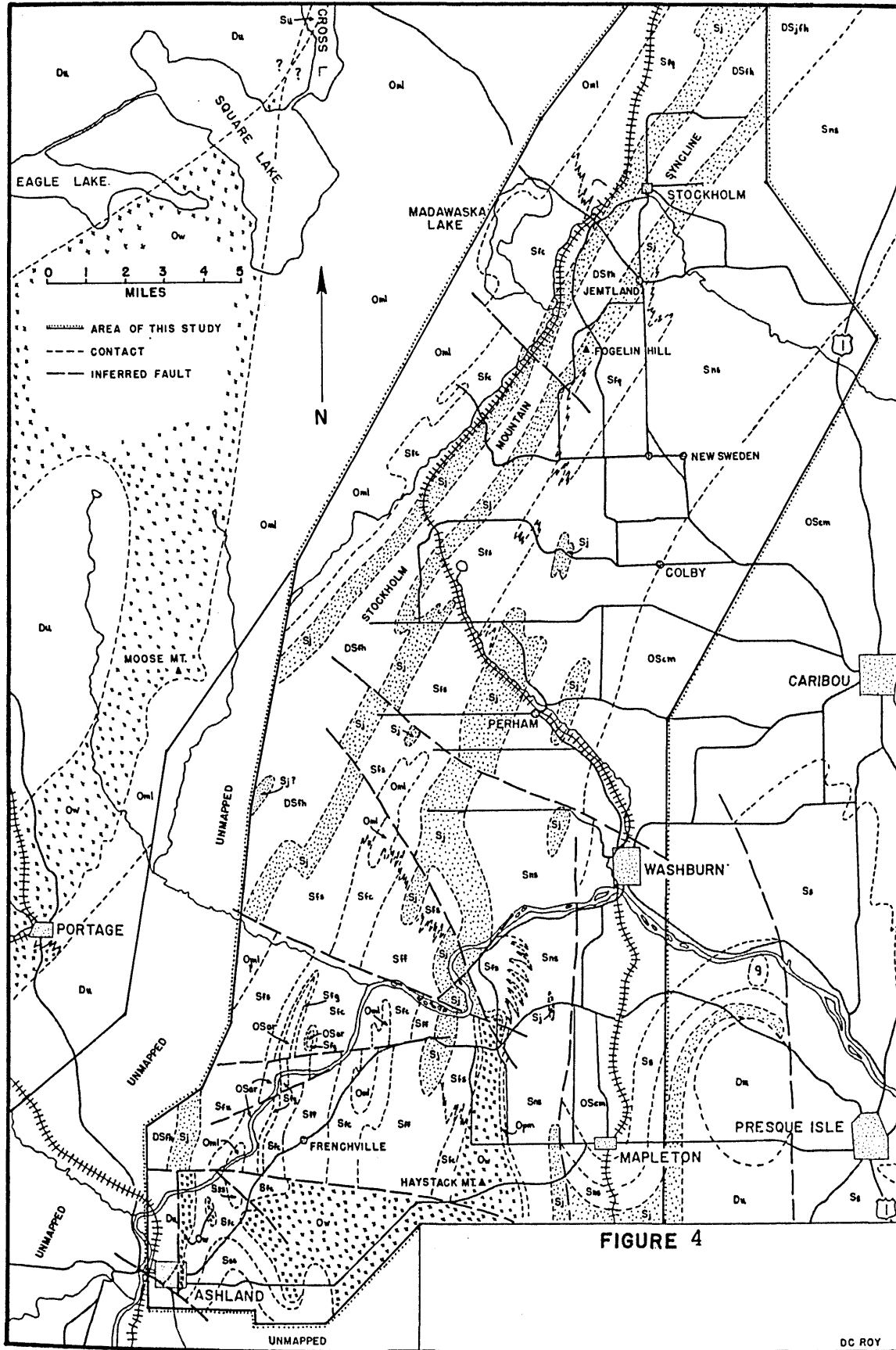


Figure 5 gives the stratigraphic relationships of units as developed in this paper, and the positions and age range of fossil localities. A detailed discussion of the paleontologic data used in this paper is given in the Appendix. The Standard European Section will be used in this paper. Ordovician and Silurian age assignments based upon brachiopods are referred to the Standard European Section for these systems, since the faunas found in northeastern Maine are more closely comparable to those in Europe than to those in the American Standard Section (Boucot, et al., 1964a; Pavlides and Berry, 1966; Neuman, 1963). Silurian graptolite assemblages are similarly referred to the European section (Pavlides and Berry, 1966) using the zonation established by Elles and Wood (1901) and Davis (1961). Ordovician graptolites are zoned according to a sequence established by Berry (1960b) for the Marathon region of Texas. Pavlides, et al. (1968) and Berry and Boucot (in press) give the latest correlations between the European and American standard sections.

Three distinct lithofacies can now be recognized in the Ordovician rocks: (1) greenstone-slate-graywacke-tuff-chert; (2) slate with minor arenite and graywacke; and (3) thin-bedded limestone and slate with lesser graywacke.

Figure 5: Ordovician and Silurian correlation chart  
for northeastern Aroostook County, Maine.



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Figure 5 on page 46 is missing from original thesis submitted by author.

The first facies, forming the Winterville and Machias River formations, is found principally in the western anticlinorium; however, it is also present as far east as Ashland and the Castle Hill Anticline. The western and eastern occurrences are separated by a broad and incompletely mapped area of younger rocks; thus, continuity of these exposure areas in the subsurface has not been established. As mapped in Plate I, the unit contains rocks ranging in age from graptolite zone 11 to zone 15 of the Ordovician.

The Madawaska Lake Formation constitutes the second and, in general, medial facies. This formation forms much of the core of the western anticlinorium between Portage and Madawaska Lake and constitutes the entire core from Madawaska Lake to the St. John River and into New Brunswick. There are three anticlinal exposures of the formation within the synclinorium (Figure 4). North of approximately the latitude of Washburn, the Madawaska Lake forms a facies between the Winterville and Carys Mills formations; however, to the south the Winterville of the Castle Hill Anticline intervenes, as shown diagrammatically in Figure 5. It is possible, though not demonstrable, that a sequence such as the Madawaska Lake Formation lies between the core rocks of the Castle Hill Anticline and the Carys Mills of the Mapleton Anticline



to the east. Limited paleontologic data suggest a possible age range of graptolite zone 11 to zone 15 for the unit.

The third and easternmost Ordovician facies is found in the lower portion of the Carys Mills Formation of Pavlides (1968). The exposure belt of this formation in northeastern Maine and northwestern New Brunswick defines the eastern anticlinorium (Pavlides, et al., 1964). The formation is known to range in age from at least graptolite zone 13 of the Ordovician to zone 19 of the Silurian (see Pavlides, 1968; Figure 5, this report), but it is not known what proportion of its section is Ordovician.

Boucot, et al. (1964a) recognized a Late Ordovician unit, the Pyle Mountain Argillite, as overlying the Winterville Formation in the Castle Hill Anticline. This slate and argillite unit is approximately 600 feet (183 m) thick and contains an Ashgillian fauna (Boucot, et al., 1964a). As defined by Boucot, et al. (1964a), the Pyle Mountain appears to be restricted to the vicinity of the Castle Hill Anticline.

The Taconic orogeny has long been known to have affected northeastern Maine (Twenhofel, 1941; White, 1943; Boucot, et al., 1964a; Hall, 1964; Pavlides, et al., 1964, 1968). Recent work indicates further that the deformation affected some areas while adjacent regions received

continuous sedimentation (Pavlidis, et al., 1964; Pavlidis, et al., 1968). In northeastern Maine, the terrane underlain by Ordovician volcanic rocks was principally affected; the main effect appears to have been moderate folding and uplift, with little or no metamorphism.

In the Ashland area, and along the western flank of the synclinorium, the Taconic event is indicated, in part, by the absence of Early Llandovery strata and the nature of subsequent Silurian sedimentation; west of the longitude of Ashland in Figure 1 the hiatus spans graptolite zones 14 to 32; that is, rocks of Late Ordovician, Llandoveryan, and Wenlockian age have not been identified.

The Aroostook River Formation, defined in this paper, is present in the core of an anticline north of Ashland, but has not been observed beyond the limits of that structure. The contact between the Aroostook River Formation and the overlying Frenchville Formation along the eastern flank of the anticline is gradational. Paleontologic information dates the unit as Ashgillian to Early Llandoveryan; however, stratigraphic relationship to the overlying Frenchville suggests that an Early Llandoveryan age is the more likely. The Aroostook River Formation is interpreted to be a lateral equivalent of the upper Carys Mills and to have formed during the early phase of the Taconian uplift.

Overlying the Aroostook River is a sandstone, conglomerate, and slate unit (Frenchville Formation) which interfingers eastward with a largely slate sequence (New Sweden Formation). The Frenchville and New Sweden formations comprise the Middle Llandoveryan-Early Wenlockian of the synclinorium; however, to the east the New Sweden is replaced by the Spragueville Formation, which is a calcareous mudstone and limestone unit.

The Jemtland Formation is a widespread thin-bedded, of flysch-type sequence/Late Wenlockian-Early Ludlovian age. It conformably overlies the Frenchville, New Sweden, and Spragueville formations and is abundantly graptolitic.

The Fogelin Hill Formation is the youngest phase of the Silurian. This slate-rich flysch-like unit is restricted to the core of the Stockholm Mountain Syncline. The Fogelin Hill spans the Early Ludlovian to Siegenian (?) and thus may contain the Siluro-Devonian boundary, as suggested in Figure 5.

East of Ashland there is a poorly understood, unnamed Late Silurian unit of sandstone, conglomeratic mudstone, argillite, and slate which is a temporal equivalent of the Jemtland and/or Fogelin Hill formations. This unit overlies both the Frenchville and Winterville formations and may be more extensive to the south of its occurrence near Ashland.

In the Presque Isle quadrangle, Boucot, et al. (1964a) found that middle and upper Helderbergian volcanic and sedimentary rocks (Dockendorf Group) overlie the Jemtland Formation (upper Member of the Perham Formation of their report; see Figure 2). The seeming absence of upper Ludlovian, Pridolian, and lower Helderbergian rocks led them to postulate a disconformity. Thus far, no evidence of the Fogelin Hill Formation has been found in the Presque Isle area, and its absence is consistent with the interpretation of Boucot, and others.

Rocks of Devonian age outside of the Presque Isle quadrangle consist predominantly of slate, with less fine sandstone. Locally, as in the village of Ashland, limestone conglomerate beds occur at or near the base of the slate sequence; similar rocks, as well as conglomerates of local derivation, are the lowest Devonian strata overlying the Winterville Formation of the western anticlinorium (Pavrides, et al., 1964; Horodyski, 1968; Roy, unpublished data). The slaty rocks of the Devonian section outside the Presque Isle quadrangle have many similarities to the Seboomook Formation (Pavrides, et al., 1964), and portions of the Devonian terrane in the western part of Figure 1 have been so assigned by Boone (1962), Doyle (1967), and Horodyski (1968).

The units discussed above constitute the pre-Acadian sequence. Apparently associated with the Acadian Orogeny, but clearly younger than most of the folding, was the intrusion of granite, syenite, and monzonite as small stocks and associated dikes (Williams and Gregory, 1900; Boone, 1962; Boucot, et al., 1964a; Pavlides, et al., 1964); dikes of teschenite (see Plate I) are present just east of Mapleton, where they intrude rocks of the Perham Group (Williams and Gregory, 1900; Boucot, et al., 1964a). Pavlides (1965a) reports a variety of dikes and sill-like intrusives of uncertain age in the Bridgewater quadrangle (southeast of the Presque Isle quadrangle); Mencher and Roy (unpublished data) have observed a thin mafic dike intrusive into the Spragueville Formation north of Fort Fairfield.

The upper Middle Devonian (Givetian) Mapleton Sandstone is the only post-Acadian Paleozoic sedimentary unit in the region shown in Figures 1 and 4 (Boucot, et al., 1964a). It is limited in distribution to a small area just west of Presque Isle. Red, roundstone pebble and cobble conglomerates, fine to coarse sandstones, and siltstones compose this sequence, which is estimated to be 2200 feet (670 meters) or more thick (Boucot, et al., 1964a). The abundant and well preserved plants that are present within the section form the primary basis for the

age assignment (Boucot, et al., 1964a; Schopf, 1964). The Mapleton, little deformed, is preserved in a shallow synclinal basin superimposed on the Acadian Chapman Syncline (Boucot, et al., 1964a) and overlies rocks of the Perham and Dockendorf groups with angular unconformity.

#### STRUCTURAL GEOLOGY

The first-order folds consist of the synclinorium and adjacent anticlinoria (Figure 1). Second-order folds form the numerous anticlines and synclines with wavelengths generally less than 5 miles (8.km). There is third-order folding along the flanks and at plunges of the second-order folds. Folds of even higher order are common, especially in areas underlain by slate-rich formations (particularly the Madawaska Lake, New Sweden, and Carys Mills formations).

The characteristics of the terrain and the resulting low outcrop density make the mapping of third-order (or higher) folds very difficult. Third-order folds shown in Plate I are based on the internal structure of the second-order folds and do not represent the tracing of contacts. Where internal structuring of second-order folds is absent or insufficiently known, these folds are shown with simple, smooth plunges.

With one exception, no marker beds of areal significance have been observed which would aid in structural

mapping. The exception is an aquagene tuff sequence, approximately 60 feet (18 m) thick, in the Jemtland Formation. This tuff has been traced discontinuously over a distance of about 5 miles (8 km) on the west flank of the Stockholm Mountain Syncline where its straight course indicates an absence of higher order folding.

Over much of the area the basal contact of the Jemtland Formation has been critical in defining the second-order folding. The generally distinctive lithologic contrasts across the contact make it relatively easy to locate, and it appears to be an approximately isochronous surface, as shown in Figure 5.

It has generally been observed in northeastern Maine that variations in the style of folding are caused in large part by the distribution of the Ordovician volcanic terrane or the presence of other relatively thick, competent rock units (Pavrides, et al., 1964; Boucot, et al., 1964a; Pavrides, 1965a). Variation in the competency of the stratigraphic sections played an important part in the structural styles of the study area.

North of the latitude of Washburn the pre-Silurian consists of slate-rich sequences (Madawaska Lake and Carys Mills formations), and much of the younger rock section

is also slate (New Sweden and Fogelin Hill formations and eastern phases of the Jemtland Formation). These incompetent argillaceous rocks were folded into parallel, appressed, steeply plunging, and similar folds, trending N35E. A major exception to this pattern is the Stockholm Mountain Syncline, which can be traced as a single, exceptionally simple structural feature for 16 miles (25 km) from northeast of Stockholm to just northwest of Perham (Figure 4). To the northeast and southwest important higher order folding developed. The presence of 3500-4000 feet (1100-1200 m) of sandstone and conglomerate (Frenchville Formation) is inferred to be the cause of the relative simplicity of this structure. Higher order folding within the structure correlates approximately with the distribution of the more slate-rich members of the Frenchville and the New Sweden Formation.

South of the latitude of Washburn and east of Mapleton the competent Winterville Formation and the thick overlying Frenchville section have caused the folding to be more open and faulting to be characteristic. Also, the fold axes trend in a more northerly direction, a feature of the folding observed in the northern half of the Presque Isle quadrangle (Boucot, et al., 1964a).



Cleavage is a pervasive deformational feature of the area. It commonly parallels the fold trends in strike and varies about the vertical in dip (usually within 10 degrees). As observed by Pavlides (1965a) in the Bridgewater quadrangle, most of the cleavage is best described as fracture cleavage; that is, there is little alignment of the constituent minerals parallel to the cleavage direction. This type of cleavage is typical in the Madawaska Lake and Aroostook River formations, much of the Jentland and Spragueville Formations, and noncalcareous slates of the New Sweden Formation. The common expression of this cleavage is as closely spaced fractures that divide the rock into irregular lenticular fragments and, less commonly, into more planar sheets.

Flow cleavage is present in the calcareous slates which form most of the New Sweden Formation; it is also commonly observed in the Carys Mills Formation. This type of cleavage is evidenced by alignment of the clay and micaceous constituents parallel to the cleavage direction producing a pronounced "sheen." This cleavage cuts thin limestone beds in many exposures; and the resulting segments of limestone fragments are commonly drawn out into lenses parallel to the cleavage.

Faults are very difficult to identify directly and must be inferred from contact or fold discontinuities. The nature and extent of fault movements are similarly difficult to define. The faults indicated in Figure 4 and Plate I consist of two sets: north-south faults in the Ashland-Presque Isle area that are parallel to the fold trends, and cross faults which cut the fold axes at approximately  $90^{\circ}$ .

The three parallel faults may be either normal or reverse. In each case the upthrown block is to the east. The Ashland fault brings fossiliferous Late Silurian and Early Devonian rocks into contact with Winterville rocks forming the core of an anticlinal structure; overlying the Winterville on the east flank of the fold is a thick section of Frenchville conglomerate (see Section D-D', Plate III). The fault west of Mapleton truncates the west flank of the Mapleton Anticline; it is indicated by the termination of the New Sweden and Spragueville Formations just west of Mapleton and by eastward facing directions in the Carys Mills where the fault crosses the Aroostook River. Pavlides (1968) mapped the eastern parallel fault near Presque Isle on the basis of apparently truncated structures in the Spragueville Formation and the presence of brecciated

rocks of the formation in a core taken from a drill-hole near the fault.

The cross faults are inferred primarily from offset contacts and fold axes, or the complete truncation of structures (Plate I). These transverse faults therefore show strike slip movements; normal or reverse components to the movements are less certain. In the cases of the east-west fault south of Frenchville (Alder Brook Fault) and the complex faulting at the north end of the Castle Hill Anticline, vertical movements are evident. The block south of the Alder Brook Fault is inferred to have been upthrown and displaced right-laterally with respect to the northern block. Right-lateral displacements are characteristic of all but one of the transverse faults north of the Alder Brook Fault.

The faulting clearly postdates the principal Acadian folding, since the folds are offset or truncated. If the north-south faults are considered to be high-angle reverse faults, the parallel and transverse sets combine to form a consistent kinematic system. In the Ashland-Presque Isle area, this system and the fold pattern are both compatible with east-west principal compression; thus, the faulting could be viewed as a late phase of the deformation that produced the folds. Alternatively, if the parallel set consists of normal faults, they could have been formed much later than the Acadian Orogeny under a different stress system.

## SANDSTONE AND CONGLOMERATE PETROGRAPHY

### OBJECTIVES

Medium- and coarse-grained sandstones have proven to be optimum for petrographic analyses (Dott, 1964). Since such rocks are abundant in the Silurian of the study area, a petrographic investigation of sandstones was undertaken to determine their provenance and lithologic variability. Suites of samples representative of the exposed rocks of the Aroostook River, Frenchville, New Sweden, and Jemtland formations were analyzed. Emphasis in this study was placed on the Frenchville Formation, in which variations in sandstone composition were observed in the field and used as a basis for distinguishing five members.

### PREPARATION

Samples were sectioned perpendicular to bedding and standard 40 X 24 mm thin sections were prepared. Large thin sections (43 X 50 mm) were also made from very coarse sandstones and conglomerates of the Conglomerate Member of the Frenchville so that larger lithic clasts could be compared with those in the finer sandstones.

Plagioclase and potassium feldspars in most of the standard thin sections were stained following procedures outlined by Rosenblum (1956) and Bailey and Stevens (1960). The HF-etched plagioclase feldspars were stained dark

brick-red following barium-for-calcium exchange and reaction with 0.25 weight-percent potassium rhodizonate. A light yellow stain on potassium feldspar grains resulted from the sodium cobaltinitrate treatment. Etch periods of 20-30 seconds over room-temperature concentrated hydrofluoric acid were found sufficient. Commonly, however, two etch periods were required, one preliminary to the sodium cobaltinitrate treatment and a second (after complete drying) preceding the barium chloride and rhodizonate treatment.

Argillaceous matrix and carbonate areas of some slides were weakly tinted red or pink. In the case of the carbonate, barium from the barium chloride treatment apparently exchanged with calcium on the etched surface. Barium absorbed on the etched surfaces of chlorite and sericite as well as the possible presence of finely divided feldspar may account for the red tint imparted to the argillaceous matrix. This staining did not produce identification difficulties.

#### MODAL COMPONENTS AND COUNTING PROCEDURE

Proper selection of modal components is critical in objective and reproducible modal analysis. The purpose of the analyses done in this study is to define the compositions of the sandstones so that lateral and vertical variations in provenance, if present, can be determined.

Since the analyses are to be compared, it was important that they be done in the same fashion and that the modal components be standardized.

The sandstones examined in this study have three detrital sand-size (and finer) populations:

(1) Grains of single mineral species such as quartz, plagioclase feldspar, pyroxene, etc.

(2) Fine-grained and very fine-grained rock fragments of igneous and sedimentary origin.

(3) Composite detrital grains of quartz-feldspar, feldspar-feldspar, micrographic or myrmekitic quartz-feldspar, and much less common quartz-feldspar-biotite grains.

In addition, an intergranular argillaceous matrix of chlorite-sericite with less and variable quartz, feldspar (?), sphene (?), and carbonate is ubiquitous. Secondary carbonate (mostly calcite) and opaques (pyrite, magnetite, and ilmenite?) are usually present in small amounts. Secondary carbonate is, however, commonly very abundant in the sandstones (and siltstones) of the Jemtland, Fogelin Hill, and Aroostook River Formations. Detrital carbonate and fossil fragments are present in some of the sandstones.

A recent study by Boggs (1968) of the preservation of textural and compositional features in debris from crushed

"parent" rocks indicates that fine-grained (0.02 mm and less) source rocks (e.g. andesites, slates, basalts, limestone, etc.) are readily identified in sand-size deposits. Coarse-grained parent rocks such as granite, diorite, gabbro, gneiss, etc. were reduced to fragments of two to five crystallites in sand-size material with consequent loss of defining textural and compositional indicators in most of the fragments. The composite grains of plutonic rocks in sandstones, though commonly difficult to unequivocally relate to specific parent rock-types, are important indicators of both provenance and compositional immaturity, and probably represent first-cycle detrital debris (Blatt, 1967). In order to avoid parent-rock implications during the analyses, composite grains of the third population indicated above were tabulated separately, and are so presented in the data tables.

Definition of original detrital grain outlines in some of the sandstones is obscured by secondary enlargement of quartz and feldspar, particularly in those rocks with low argillaceous matrix content. This alteration, though generally minor, is commonly sufficient to make difficult the separation of detrital grains of the first and third populations described above. In order to produce compositional data with maximum operator consistency, and at the same time to estimate the abundance of composite grains of

various types, a "side-count" method for tabulating these grains (excluding the easily identified micrographic/myrmekitic grains) was used. This procedure involved counting as quartz, plagioclase, or potassium feldspar any such grain from populations one and three regardless of whether it appeared to be a single grain or part of a composite grain. If the grain in question was "judged" to be linked to an adjacent grain, then the appropriate "composite grain component" was side-counted. Operator consistency is considered high for the "primary count," i.e. quartz, plagioclase, or potassium feldspar, because these minerals are easily distinguished, especially in stained thin sections; operator consistency involved in the composite-grain judgments is unknown but is probably lower.

The results of this analytical procedure are displayed in the data tables of this report in two parts. The "primary count" is presented first, and totals 100.0 percent; the composite grains are excluded. The composite grains are reported separately as "Composite Qtz-Feld", "Composite Feld-Qtz", "Composite Feldspar", and "Composite Quartz"; the distinction between the first two categories is based on where the composite grain is included in the primary count, i.e. "Qtz-Feld" grains are in the primary quartz total and the "Feld-Qtz" grains are included in the



plagioclase-plus-potassium feldspar total. A single feldspar value is given in analyses of unstained thin sections.

The following components are used in the "primary count" modes on sandstones and conglomerates reported in this paper:

(1) Quartz (C1): Includes single-crystal and composite quartz grains, and quartz crystals of composite quartz-feldspar grains.

(2) Plagioclase Feldspar (C2): Includes single-crystal grains and plagioclase crystals of composite plagioclase-quartz, plagioclase-plagioclase, and plagioclase-potassium feldspar grains. Much of the plagioclase is untwinned and is variably saussuritized. Most plagioclase grains have a cloudy or dusty appearance due to minute inclusions.

(3) Potassium Feldspar (C3): Includes single-crystal grains and potassium feldspar crystals of composite potassium feldspar-quartz, composite potassium feldspar, and potassium feldspar-plagioclase grains. Potassium feldspar constitutes a minor proportion of most of the sandstones but is relatively abundant in a few. Staining reveals that many of the grains contain "patches" and inclusions of plagioclase.

(4) Detrital Mica (C4): Includes muscovite, biotite, and composite detrital chlorite grains larger than approximately 0.02 mm in greatest dimension.

(5) Pyroxene (C5): Single and composite grains of augite and pigeonite (?).

(6) Sphene (?) (C6): Scattered through the argillaceous matrix and forming rare grains of approximately 0.02 mm size is a colorless, high-relief mineral with extreme birefringence, which is probably sphene. Optical determinations are not possible on these grains.

(7) Argillaceous Matrix (C7): Intergranular chlorite and sericite with lesser very fine-grained quartz, feldspar (?), sphene (?), carbonate, and opaques is included in this component. This material is generally less than 0.02 mm in grain size and is interpreted as recrystallized clay.

(8) Secondary Carbonate (C8): Mostly secondary "matrix" calcite. Secondary carbonate replacing matrix argillaceous material, volcanic rock fragments and feldspar is present in highly variable amounts. Carbonate clearly replacing rock fragments and feldspar grains is not included in this component.

(9) Opaque (C9): Largely secondary pyrite, magnetite, ilmenite, and hematite (limonite). Also includes carbonaceous material and opaque detrital grains of uncertain composition in some rocks.

(10) Micrographic Quartz-Feldspar (C10): Micrographic and myrmekitic quartz-plagioclase and quartz-potassium feldspar grains.

(11) Fine-grained Mafic Rocks (C11): Consists of fine-grained volcanic and hypabyssal igneous rocks with intersertal, pilotaxitic, felted, trachytic, and pyroclastic textures. Phenocrysts of plagioclase and pyroxene are infrequently observed in these lithic fragments in sandstones, but are common in larger clasts of similar rocks in the conglomerates.

(12) Fine-grained Felsic Rocks (C12): Consists of felsophyric volcanic and hypabyssal rocks which commonly display variolitic, spherulitic, and micropoikilitic textures. Phenocrysts of quartz (commonly embayed) and angular plagioclase are common in larger clasts present in the conglomerates. In sandstone analyses, separation of this component from C13 is very difficult; the presence of feldspar in the fragments (made visible by staining) was taken to indicate felsite.

(13) Chert and Cherty rocks (C13): Consists of micro- and cryptocrystalline quartz with less intergranular chlorite and white mica. Rounded, quartz-filled bodies up to 0.4 mm in diameter and inferred to be radiolarians occur in some clasts. Red, green, and black varieties are present, but gray and green-gray types are much more abundant.

(14) Sericitic Fragments (C14): Clasts of fine-grained parallel-oriented sericite and white mica. Some of the fragments contain quartz and plagioclase and others

may be highly saussuritized plagioclase grains. Many of these fragments display / undulatory extinction.

(15) Pelite<sup>1</sup> Fragments (C15): Fragments of pelite, calcareous siltstone, and argillaceous siltstone.

(16) Sandstone (C16): Consists of fragments of quartzite and fine-grained graywacke.

(17) Detrital Carbonate (C17): Fragments of single-crystal and polycrystal carbonate. Commonly these clasts have overgrowths of secondary carbonate.

(18) Fossil Fragments (C18): Commonly coral, brachiopod and crinoid fragments.

(19) Miscellaneous (C24) and unidentified (C23): Very few rocks had constituents tallied as miscellaneous, but "chert" matrix has been so counted in one or two slides. Detrital fragments of obscure character are included in the "unidentified" category.

Side-counted composite grains as discussed above form the composite quartz-feldspar (C19), composite feldspar-quartz (C20), composite feldspar (C21), and composite quartz (C22) modal components.

Modal analyses of approximately 500 counts (range 495 to 557 counts) were done on all sections. Point spacing was chosen to minimize replicate counting of

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<sup>1</sup>The term "pelite" is used in this paper to refer to argillaceous material without regard to presence of cleavage (slate) or bedding fissility (shale). The term is used for both argillaceous fragments in clastic rocks and argillaceous beds.

individual grains; in the case of sandstones, spacings of 0.3 mm to 1 mm were generally used. Analyses were done using 80X magnification; however, lower and higher powers were used when necessary for proper identification.

#### CONGLOMERATE PETROGRAPHY (FIELD ANALYSES)

Exposures of conglomerate suitable for outcrop modal analysis are rare. An outcrop was considered suitable if it presented several square feet of relatively flat surface perpendicular to bedding (or nearly so) and was free of lichen and moss cover. Three or four square-foot areas were divided into grids of two-inch squares using chalk. The modal component under each intersection of the grid was tallied. Analyses of 169 and 133 counts were thus obtained.

#### SANDSTONE CLASSIFICATION

A sandstone classification following that suggested by Gilbert (Williams, et al., 1954) and Dott (1964) is used in this paper. The term "sandstone" is used to refer to the general class of clastic rocks with greater than 60 percent sand-size detrital particles. Sandstones are subdivided into arenites (less than 10 percent recrystallized argillaceous matrix, C7) and graywackes (greater than 10 percent recrystallized argillaceous matrix, C7).

Sandstone classifications are generally referenced to a triangular plot of the "principal detrital components." The various classifications differ as to which detrital components should be included in each "pole" of the diagram (e.g. Pettijohn, 1957, Folk, 1954; Dott, 1964), even though many authors designate the poles as "Quartz," "Feldspar," and "Rocks Fragments."

Composite grains of quartz-feldspar and feldspar-feldspar, distinguishable in many sandstones (Folk, 1965), are rarely discussed in reference to these polar components. Fine-grained rock fragments of igneous, metamorphic, and sedimentary origin are usually specifically included in the rock-fragment pole. Pettijohn (1957, p. 130) precludes the possibility that coarser grained parent rocks, both igneous and metamorphic, could appear as detrital grains in medium-grained clastic sediments, yet "plutonic rock fragments" are frequently reported in graywackes of that grain size (Dzulyuski and Walton, 1965). Folk (1954) places "plutonic" composite grains in a "Feldspar and all igneous-rock fragments" pole and similar grains of metamorphic origin in a "mica, metamorphic-rock fragments and metaquartzite" pole; even if one assumes that composite grains of these two types could be uniquely separated, Folk's classification becomes inconvenient for sandstones which contain little or no metamorphic source contribution.

Though the classification proposed by Gilbert and modified slightly by Dott (1964) is flexible and based on the measurement of relatively objective parameters, no specific provision has been made by these authors for the composite grains. The "rock fragments" pole of Williams, et al. (1954) is called "unstable fine-grained rock fragments" and Dott terms it simply "labile fragments." These designations suggest that composite grains, if present, are to be included in the feldspar and quartz poles. In the analyses of this paper, this is accomplished by simply plotting the primary count data and disregarding the composite grains (see Table 1). Chert (Cl3) is here included with the rock fragments.

The lithic and feldspathic sandstone fields as defined by Dott (1964) are subdivided to indicate quartz contents in excess of 50 percent as shown in Figure 6.

An indication of the compositional stability of the sandstones is given by the DEF diagram as defined in Table 1. This plot differs from the ABC diagram in the inclusion of the composite grains (except composite quartz) in the rock-fragment pole.

The principal source analysis (plot GHI, Table 1) is discussed in a later section.

POLE OF

<u>ANALYSIS</u>	<u>TRIANGULAR DIAGRAM</u>	<u>DETRITAL COMPONENTS</u>
Primary Count	A	C1
(Classification)	B	C2+C3
	C	C10+C11+C12+C13+C14+C15+C16+C17
	D	C1-C19
Compositional Maturity	E	C2+C3-C20-C21
	F	C10+C11+C12+C13+C14+C15+C16+C17+C19+C20+C21
	G	C1-C19
Principal Source	H	C10+C19+C20+C21
	I	11+C12+C13+C14+C15+C16+C17

TABLE 1

Modal components assigned to the poles of triangular composition diagrams used in this paper. Detrital components are discussed in the text.



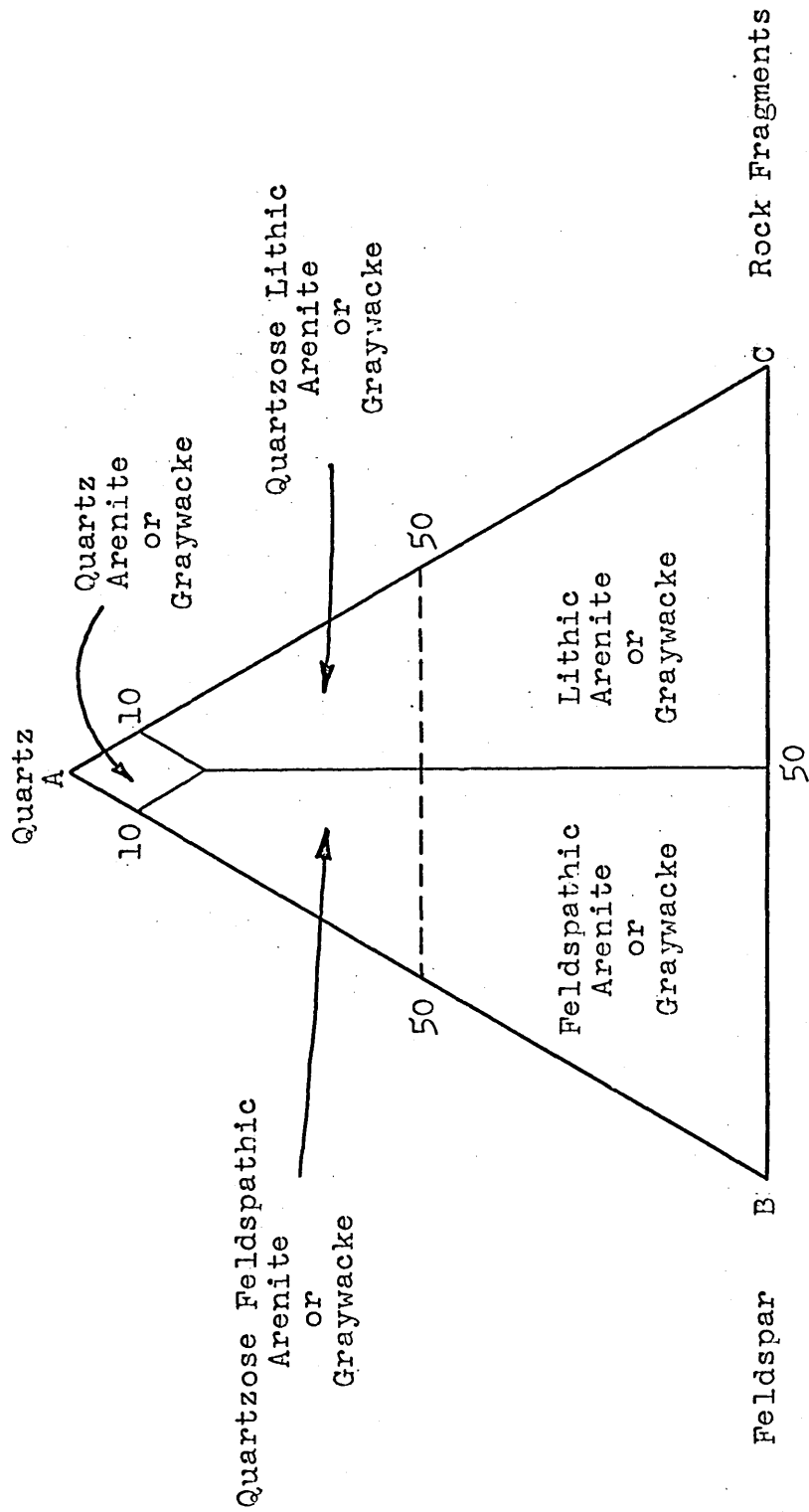


Figure 6 : Classification of sandstones used in this paper. Arenites contain less than 10 percent argillaceous matrix; graywackes contain greater than 10 percent argillaceous matrix. (after Williams, Turner, and Gilbert, 1954; Dott, 1964)

## ROCKS OF ORDOVICIAN AND EARLIEST SILURIAN AGE

### WINTERVILLE FORMATION

#### Name and Distribution

Boone (1959) applied the name "Winterville Volcanics" to a complex of andesitic and basaltic rocks underlying the Upper Silurian and Lower Devonian between St. Froid Lake and Fish River Lake. The name is taken from the Winterville Township in the north-central part of the Winterville quadrangle. The term "Winterville Formation" has been used by the MIT research group because the complex contains a variety of sedimentary rocks inter-layered with the volcanics. The formation has not been formally established, and is used informally in this paper.

As shown in Figure 1, the Winterville is widely present in and to the west of the study area. As yet, no type section or type area has been proposed. The most detailed petrographic analysis of the unit, however, is that of Horodyski (1968) in the Fish River-Big Machias Lakes area; the lithologic discussion that follows is based largely on Horodyski's study and observations by the writer.

#### Lithology

The Winterville Formation is a complex assemblage of mafic and felsitic extrusive rocks (with associated

sills (?) and dikes), tuffs and tuffaceous clastic sedimentary rocks, and minor black slate, red and green cherts, graywacke, and conglomerate. Horodyski (1968) has estimated the relative abundances of the principal rock types, based on their frequency of exposure, as follows: 61% andesite, 9% basalt, 5% quartz keratophyre, 10% water-laid tuffs, 2% tuffaceous mudstone, 10% sandstone and conglomerate, and 3% black slate. In the area of his study, Horodyski found areal variations in the abundances of the sedimentary rocks and established members based upon these variations.

The distinction between andesite and basalt cannot usually be made in the field. Exposures are generally highly fractured, and a 2 to 4 mm brown weathering rind is common. Calcite and quartz veins are common. "Fresh" surfaces are gray to green-gray in color.

Horodyski estimated that approximately ninety percent of the mafic volcanic rocks are andesites and differ from the basalts primarily in feldspar composition. The andesites and basalts are composed of plagioclase, chlorite, and commonly augite; quartz, sphene, leucosene, ilmenite, pyrite, white mica, and carbonate are present in much smaller amounts. Chlorite, sericite, and carbonate replace the plagioclase to varying degrees in all samples. Prehnite and pumpellyite have been observed by Coombs,

et al. (1970) in some of these mafic rocks as veins and vesicle fillings, as replacements of plagioclase and augite, and in association with intersertal chlorite. Albitization of originally more calcic plagioclase, producing cloudy albite ( $An_{0-4}$ ) is apparently widespread (Coombs, et al., 1970). Many of the andesites may be spilitic derivatives of originally more basaltic rocks.

Quartz keratophyres, as distinguished by Horodyski, are rather easily recognized in the field. They are light brown and light gray to light greenish gray in color and very fine grained. A cherty appearance and brecciated fabric are common. Dark-gray and black "stringers" are visible in many hand specimens.

Phenocrysts of quartz and plagioclase in a microcrystalline matrix of quartz, feldspar, and intersertal chlorite characterize the keratophyres. The quartz phenocrysts commonly are corroded, producing rounded and embayed crystals. The groundmass consists of microcrystalline (0.05 mm) anhedral quartz and plagioclase (albite?). Micropoikilitic enclosure of feldspar laths in quartz is commonly observed in the groundmass.

Fine-grained water-laid tuffs displaying a subvitreous luster and subconchoidal fracture constitute about ten percent of the Winterville. These rocks form much of what is termed "chert" in the field. A light-brown or white weathering rind is indicative of a rela-

tively high feldspar content. Fresh surfaces are usually shades of gray or green-gray in color, but bright-green and reddish-brown varieties are present. In sawed specimens Horodyski has observed lamination and cross-lamination; graded bedding and micro-load-casting are important but less common features.

Petrographically these tuffs consist of a microcrystalline matrix containing varying amounts of silt-size and sand-size angular quartz and feldspar grains. The microcrystalline matrix is similar to that observed in the keratophyres but, in the main, finer grained (0.002 to 0.02 mm). Fragments composed of microcrystalline quartz-albite (?) -chlorite present in some of these rocks were interpreted by Horodyski to be recrystallized glass fragments. The matrix is considered to be recrystallized vitric ash.

Spherical bodies filled with fibroradiating quartz or microcrystalline mosaic quartz that are inferred to be recrystallized and filled radiolarian tests are in some of these tuffs; small, rod-shaped fragments consisting of microcrystalline quartz in these same rocks may represent radiolarian spines.

Similar to the water-laid tuffs in many respects are the "tuffaceous mudstones." A complete gradation probably exists between nontuffaceous silicified

mudstone and the water-laid tuffs. These rocks are all cherty in appearance and are very siliceous. It is not clear in many cases whether the silicification is due to recrystallization of vitric material or to the introduction of silica by percolating deuteric solutions.

The tuffaceous mudstones as described by Horodyski are generally gray to black. More "tuffaceous" varieties display a poorly developed cleavage. In thin section, microcrystalline and cryptocrystalline quartz with varying amounts of intergranular chlorite characterize these rocks; bedding-oriented mica is present in some samples. Red or maroon varieties which owe their color to finely divided hematite are present locally. Green and green-gray types seem to be colored by their chlorite content. Graptolites and radiolarians were observed by Horodyski in these mudstones at two localities.

Black slates are locally very important in the Winterville sequence. Although comprising only 3 percent or so of the unit where studied by Horodyski, this lithology is seemingly more abundant in the Portage-Moose Mountain area (Mencher, unpublished data). These dark slates are commonly pyritiferous, and ocher-stained on cleavage and fracture surfaces. Laminae and thin beds of siltstone (light gray) are present in the slate

in some exposures. At a number of localities, rocks of this lithology contain graptolites which provide most of the age information on the Winterville Formation.

Tuffaceous sandstones and conglomerates locally form up to 20 percent of the Winterville. These coarse clastic rocks are poorly to moderately sorted and contain fragments of quartz, plagioclase, recrystallized glass, quartz keratophyre, andesite, and tuff. A matrix of microcrystalline quartz and feldspar with varying amounts of chlorite, white mica, and carbonate is a typical feature. Horodyski interprets these rocks to be deposits that formed contemporaneously with active (explosive) volcanism.

Unit "Ovs" of Boucot, et al. (1964a) in the Castle Hill Anticline is here assigned to the Winterville Formation. This assignment is based on lithologic similarity and common age. The Winterville of the Castle Hill Anticline has been extended westward into the Ashland area (Figure 4).

Williams and Gregory (1900) have described a variety of felsitic rocks on Haystack and Pyle mountains, many of which show a micropoikilitic groundmass in which feldspar laths are enclosed in quartz. These authors and Boucot, et al. (1964a) also report vesicular and amygdaloidal andesites, pillowed flow rocks, tuff,

chert and black slate as forming the remaining core rocks of the Castle Hill Anticline.

In, and just north of, the village of Ashland, black and olive green slates, pebbly argillites,<sup>and</sup> chert, together with mafic volcanic rocks comprise the Winterville, which is overlain by the Frenchville Formation. Between Ashland and the Castle Hill Anticline, approximately 90 percent of the Winterville exposures are of mafic volcanic rocks (andesites?); fossiliferous tuffaceous sandstones associated with the volcanics have been described by Neuman (1963) at fossil locality 3 (Plate I).

#### Lower Contact

The lower contact of the Winterville has not been recognized in the area.

#### Thickness

Horodyski (1968) estimated a minimum thickness of 5000 feet (1.5 km) but considered the formation to be much thicker. Since the lower contact has not been observed and the formation is unconformably overlain by younger rocks, thickness estimates are very uncertain.

#### Age

Direct paleontological data on the age of the Winterville Formation is summarized in Table 2 and shown diagrammatically in Figure 5. The data indicate



Table 2: Fossil localities from the Winterville (Ow) and Madawaska Lake (Oml) formations. All graptolites identified by W. B. N. Berry. Brachiopods of locality 1 identified by A. J. Boucot (personal communication, October, 1966) and Neuman (1968). Data for locality 3 are from Neuman (1963, 1968). Locality 14 is from Boucot, et al. (1964a, locality C-6). Localities 4, 7, 11, 12, and 13 are from west of the area shown in Plate I. Precise locations of all localities cited in this paper are given in the Appendix. The following ages are assigned to the collections: locality 1, Ashgillian (zone 15); locality 2, Caradocian (zone 12-13); locality 3, Caradocian (approx. zones 12-13); localities 4, 5, 6, and 7, Caradocian (zone 12); locality 9, Caradocian (probably zone 12; localities 8, 10, 11, and 13, Caradocian (zones 11-12); locality 14, Caradocian (zone 13); locality 15, Caradocian-Ashgillian (in the span of zones 11-15, but probably in the range of zones 11-13); locality 16, Caradocian-Ashgillian (probably zone 13).



that the formation is of Caradocian and Ashgillian age.

Most of the age information is based on graptolite collections made from the black slate rock type; however, two brachiopod-rich localities (numbers 1 and 3) have been significant in the dating of the formation in the Ashland area. With the exception of locality 1, the fossils indicate ages within the Caradocian stage of the Ordovician (span of zones 11-13); no faunas representing the Late Caradocian (zone 14) have been documented.

Locality 1 is in the village of Ashland; the exposure was in the basement excavation for a house built in 1966 by Mr. Carlton Jimmo on what is known locally as "Cottage Hill." The excavation, no longer available for examination, exposed the contact between the Winterville and Frenchville formations. The graptolites came from black and olive-green, pyritiferous, ocher-weathering slate about 5 feet (1.5 m) stratigraphically below the contact. Berry (personal communication, February, 1967) assigns the graptolites to the span of zones 12-15. Brachiopods were collected from an olive-green pebbly argillite continuous with the graptolitic strata and 0-2 feet (0-0.6 m) below the contact. Boucot (personal communication, October, 1966) and Neuman (1968) indicate that the brachiopods are

probably Ashgillian in age, but the possibility of an Early Llandoveryan age cannot be ruled out.

The age ranges of the graptolite and brachiopod assemblages therefore suggest an Ashgillian age for the Winterville Formation at locality 1. Alternatively, since the graptolites come from a stratigraphically lower level it is possible to consider the graptolite assemblage to be Late Ordovician (Caradocian-Ashgillian) in age and the brachiopods to be Early Llandoveryan. An Ashgillian age is favored for the entire sequence, since no evidence of a stratigraphic break has been observed between the two collected horizons, and Boucot and Neuman have assessed the brachiopod assemblage to be more characteristic of the Ashgillian than the Early Silurian.

#### MACHIAS RIVER FORMATION

Horodyski (1968) defined and briefly described a new unit, the Machias River Formation, which he mapped in a small area southeast of Big Machias Lake (Figure 1). Like the Winterville Formation, this new formation has not been formally proposed. Since it is not present in the area of this investigation it will not be discussed at length here.

Horodyski estimated the Machias River to consist of approximately 75 percent black slate, 17 percent

graywacke, 5 percent andesite, and 2 percent calcareous mudstone. The Machias River is inferred to overlie the Winterville Formation, but direct stratigraphic and paleontologic evidence for this relationship is lacking. It is possible that these slates are equivalent to portions of the Winterville as mapped elsewhere in the region, and to the Bluffer Pond Formation of Hall (1964) discussed below.

#### ORDOVICIAN ROCKS OF THE SPIDER LAKE AREA

The Ordovician rocks in the Spider Lake quadrangle, as described by Hall (1964) and generalized in Figure 7, are lithologically very similar to those in the Winterville Formation. Hall has, however, been able to divide the Spider Lake Ordovician into four formational units with an aggregate estimated thickness of about 20,000 feet (6200 m). He was able to recognize the base of the section and inferred an angular unconformity between the Cambrian (?) Chase Brook Formation and the overlying Middle Ordovician Chase Lake Formation.

The oldest fossil collection in Hall's Ordovician section is from the Conglomerate and Graywacke Member of the Chase Lake Formation; the age is in the span of zones 11-12, probably correlating with the Late Porterfield of the American Standard Section. Hall considered this locality to define the early age limit of the Ordovician sequence.

Figure 7: Generalized Ordovician section in the Spider Lake area as established by Hall (1964).

GRAPTOLITE ZONES		FORMATION	LITHOLOGY
ORDOVICIAN	13 (as young as Zone 15?)	Blind Brook Formation (6,000'-7,000'?)	Gray pyritiferous slate, minor tuffs and tuffaceous slate, minor volcanic rocks.
	12-13	Munsungun Lake Formation (6,000'+)	Dolerite, rhyolitic pyroclastic rocks, red chert and slate, mafic volcanic breccia.  <u>Reed Pond Member (&lt;1,000')</u> : mafic volcanic breccia
	12	Bluffer Pond Formation (4,000'-7,000')	Predominantly basalt, pillow basalt, dolerite, mafic tuff, and minor rhyolitic rocks.  <u>Ragged Mt. Rhyolite Member (&lt;1,000')</u>
	11-13	Chase Lake Formation (~2,000')	<u>Slate - graywacke Member</u>  <u>Conglomerate - graywacke Member</u>
CAMBRIAN (?)		Chase Brook Formation ~? ~? ~? ~? ~?	Slate, lesser graywacke

Figure: 7 From Hall (1964)

Hall's youngest Ordovician unit, the Blind Brook Formation, is assigned by him to zone 13 of the Middle Ordovician (Caradocian) but his paleontologic data indicates that some of the formation could be as young as Ashgillian, zone 15 (Hall, 1964).

#### MADAWASKA LAKE FORMATION

##### Name and Distribution

The term "Madawaska Lake Formation" is here applied to an extensive, largely slate, unit which forms all or part of the core of the western anticlinorium from Portage to the St. John River and into New Brunswick (Figure 1). The writer has also found this unit to underlie the Frenchville Formation in small anticlines in the north-central part of the Ashland quadrangle, and the southeastern portion of the Portage quadrangle. Although not as yet formally proposed, the formation as defined here has been used extensively by Ely Mencher and his students, Hamilton-Smith (1969), and the writer.

No type section that gives complete exposure of the formation can be designated for the Madawaska Lake. Typical rock types of the unit are found in exposures along the north shore of Madawaska Lake itself, along Maine Route 161, and along lumbering roads just north of the lake. The vicinity of the north shore of the lake is here designated the type area. The formation



is also extensively exposed along easily accessible lumbering roads west of Blackstone Siding in the northeast corner of the Portage quadrangle, and along similar roads in the northwest corner of the Stockholm Township, Stockholm quadrangle.

### Lithology

A quarry approximately 300 feet (90 m) southwest of Maine Route 161 at a distance of 0.85 miles (1.4 km) north of Madawaska Lake presents the most extensive exposure of the formation. Green-gray to light olive-green, very fine-grained brittle slate with thin beds, generally less than one inch (2.5 cm) thick, and laminae of light-gray, orange-weathering siltstone constitute an estimated 95 percent of quarry section. The thin siltstone beds commonly display cross-lamination and ripple morphology. Beds of the siltstone up to 6 inches (15 cm) thick showing highly contorted lamination are observed locally elsewhere. Widely spaced, thin, rust-weathering, dark-gray, argillaceous, aphanitic limestone beds are a distinctive minor lithology. These limestone beds are both continuous and lenticular.

A brown or ocher staining is ubiquitous on fracture and cleavage surfaces. A pronounced bedding parting is usually observed in large exposures. The intersection of the cleavage and this bedding parting commonly produce "pencil-shaped" fragments.

Except for the presence of the limestone beds, the rock types just described are typical of those seen in most exposures of the formation. Locally, however, there are graded graywacke beds (see Figure 8), massive sandstone and conglomerate, and red, maroon, and (rarely) purple slates. The distributions of these minor rock types in the Madawaska Lake Formation are not known. The red and maroon slates have been commonly observed near the contact of the formation with the overlying Frenchville Formation, but this apparent coincidence may be due to the greater amount of mapping along this contact than elsewhere.

#### Lower Contact

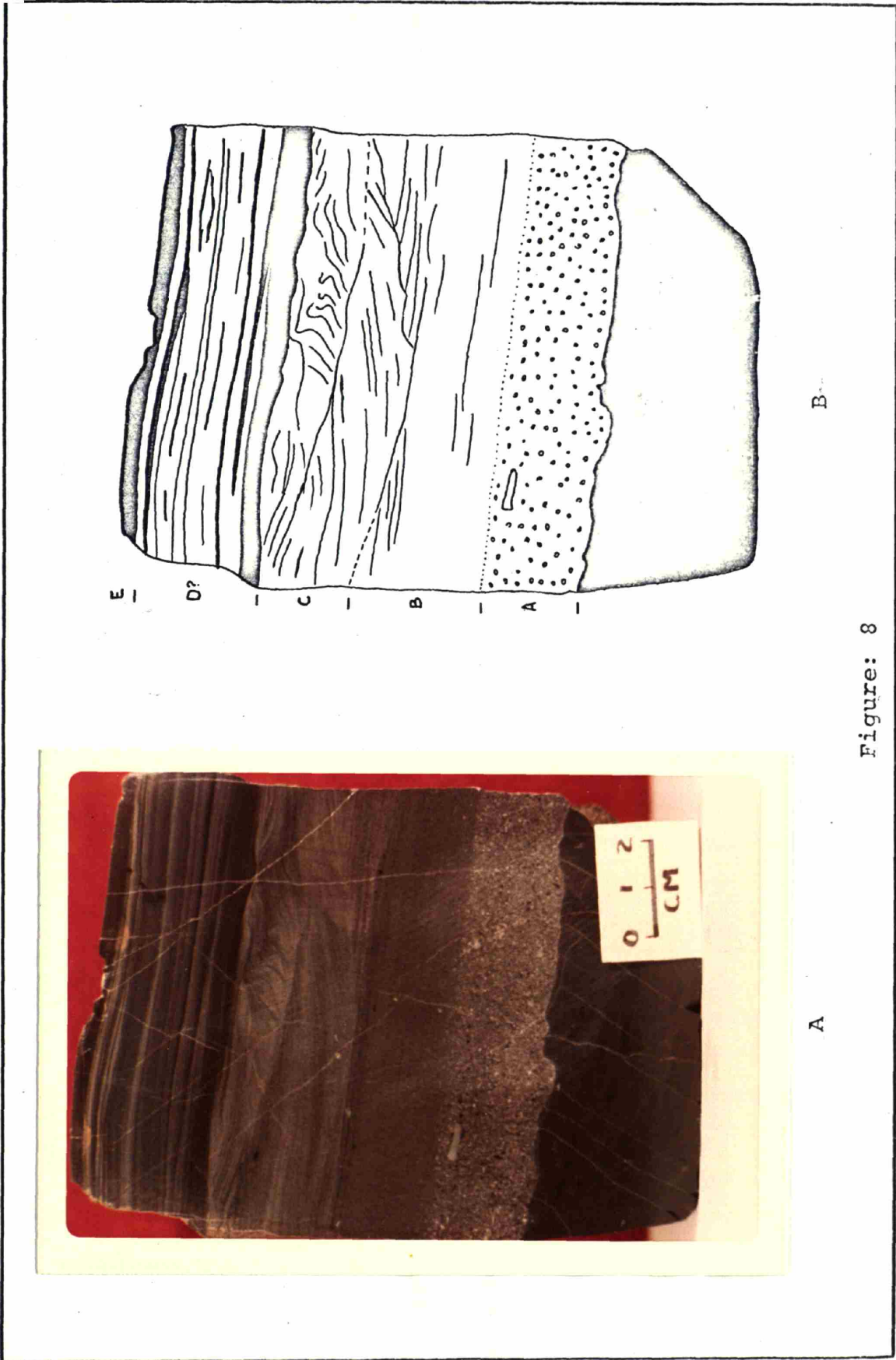
The lower contact of the Madawaska Lake has not been recognized.

#### Thickness

As yet no reliable thickness estimates are possible for the Madawaska Lake Formation. The formation is unconformably overlain by the Frenchville Formation along most of the southeastern flank of the western anticlinorium; the base of the unit has not been defined. Much of the area underlain by the formation has not been mapped sufficiently to establish the geometry of the folding or to eliminate the possibility of synclinal infolds of younger rocks. Hamilton-Smith (1969) was able to document the presence of at least 1950 feet

Figure 8: (A) Sawed specimen of a graded graywacke bed from the Madawaska Lake Formation. Internal structures described by Bouma (1962) as characteristic of a complete turbidite bed are clearly visible.

(B) Bouma's subdivisions of a "complete turbidite" are illustrated in this interpretive sketch; A = graded interval; B = lower interval of lamination; C = interval of current rippling and convolution; D? = upper interval of lamination; E = pelitic or interturbidite interval. Note the erosional contact between the B and C intervals. Interval D, consisting of the interlamination of fine silt and pelitic material, is commonly difficult to separate from interval E (Walker, 1967).



(600 m) of Madawaska Lake section in the Siegas, New Brunswick, area, but the formation is probably much thicker.

#### Age

Very limited paleontologic information has been obtained from the Madawaska Lake. The results of collections from the two localities found so far are shown in Table 2 (Localities 15 and 16). Locality 15, found by Gary Laux and Richard Warner near Collins Siding northeast of Stockholm, has produced the best preserved graptolite faunas. Berry (personal communication, 1970) concludes that the forms present are of Ordovician age (in the interval of zones 11-15). The poorly preserved forms have characteristics that suggest they probably represent the span of zones 11-13 (Caradocian), but a slightly younger age cannot be ruled out. Locality 16, found by Hamilton-Smith (1969) in the Siegas, New Brunswick area, produced a species of Diplograptus which Berry (personal communication, 1970) identified as "...a slender Diplograptus which appears to me to be most similar to D. mohawkensis (Ruedemann). Many specimens are present....but all are very badly distorted --most of them are stretched along the central axis of the rhabdosome. This stretching makes positive identification impossible." Berry states that the form indicates a Late Ordovician age and he suggests that a zone 13 age is probable.

Hamilton-Smith (1969) presented convincing evidence from the Van Buren area that the Carys Mills Formation there conformably overlies the Madawaska Lake. Locality 24 (see Table 3) of Early or Middle Llandoveryan age from the Carys Mills near the contact indicates that the Madawaska Lake Formation could be as young as Ashgillian or Early Llandoveryan.

The Madawaska Lake Formation is therefore considered to range from at least the Caradocian to the Ashgillian, with a possibility that its youngest phases may locally be of Early Llandoveryan age.

#### PYLE MOUNTAIN ARGILLITE

##### Name and Distribution

The Pyle Mountain Argillite was defined and mapped by Boucot, et al. (1964a). It is restricted to the flanks of the Castle Hill Anticline, where it overlies the Winterville Formation and underlies the Frenchville and New Sweden formations. The unit is not well exposed but has produced four important fossil localities.

Fossiliferous exposures along an east-west road near its intersection with Turner Road (north slope of Pyle Mountain; vicinity of locality 17) have been designated as the type localities (Boucot, et al., 1964a).

##### Lithology

In the type exposures, the Pyle Mountain consists of a poorly cleaved, tan- to brown-weathering silty

argillite. Exposures in the fields just south of the type exposures, including fossil locality 18, show olive-green, poorly to well cleaved, silty slate which in some exposures breaks into splinters. These olive-green slates apparently overlie the brown-weathering silty argillite.

Where the Pyle Mountain outcrop belt crosses Maine Route 163, about 1.0 miles (1.6 km) south of the type exposures, a similar sequence of lithologies is exposed. The brown-weathering silty argillite is exposed in the highway ditches when these ditches have been cleaned by maintenance crews. This exposure is cited by Boucot, et al. (1964a, Appendix III) as a fossil locality, but no fossils are listed and the locality is not discussed in the text. Just north of the highway and apparently stratigraphically above the road-ditch exposure is an outcrop of green, lenticularly cleaved, silty slate.

At fossil locality 19 on the steep west face of Castle Hill is a large exposure of medium-gray and green-gray, lenticularly cleaved, silty slate that weathers brown. Thin, contorted, and seemingly lenticular, orange-weathering limestone beds are present sparsely in the slate.

#### Lower Contact

As discussed by Boucot, et al. (1964a), the Pyle Mountain Argillite overlies the Winterville Formation

(their unit Ovs) of the Castle Hill Anticline. Where the contact can be closely approached, no structural discontinuity is evident. No evidence of contemporaneous volcanism (e.g. silicified sedimentary rocks, sulfide mineralization, or interbedded volcanic rocks) has been observed, suggesting that the Pyle Mountain postdates the volcanic activity in the Castle Hill-Haystack Mountain area and probably rests on the older rocks disconformably.

#### Thickness

Boucot, et al. (1964a) estimated the thickness of the Pyle Mountain to be approximately 600 feet (90 m). On the west flank of the anticline, the argillite is inferred to wedge out; exposure of the unit along that flank is very poor, and it is possible that it exists farther south than the termination shown.

#### Age

Table 3 gives the paleontologic data for the Pyle Mountain Argillite (localities 17, 18, 19, 20). The trilobite fauna of localities 17, 18, and 19 establishes an Ashgillian age for the unit; the brachiopod assemblage is consistent with this age but dates the rocks no closer than Late Ordovician (Boucot, et al., 1964a).

#### CARYS MILL FORMATION

#### Name and Distribution

Pavliides (1968) has summarized the stratigraphic



Table 3: Fossil localities from the Pyle Mountain Argillite (Opm), Carys Mills Formation (OScm), and Aroostook River Formation (OSar). Graptolites identified by W. B. N. Berry; trilobites identified by H. B. Whittington; ostracods identified by Jean Berdan; conodonts identified by J. Huddle; brachiopods from localities 17, 18, 19, and 20 identified by R. B. Neuman and cited in Boucot, et al. (1964a); brachiopods from locality 26 identified by A. J. Boucot. Locality 23 is the "Colby locality" of Boucot, et al. (1964a) and locality 1 of Pavlides (1968). Locality 25 is reported by Hamilton-Smith (1969) from near Siegas, New Brunswick and is not plotted on Plate I. Locality 22 is locality 6 of Pavlides (1968). The following ages are assigned: localities 17, 18, 19, and 20, Ashgillian; locality 21, Early Llandoveryan (zone 18); locality 22, probably Ashgillian (zone 15); locality 23, Caradocian (zone 13); locality 24, Early-Middle Llandoveryan; locality 25, Late Ordovician-Early Silurian; locality 25, Ashgillian-Early Llandoveryan.



and facies relationships of the Carys Mills Formation. The Carys Mills is one of three formations comprising the Meduxnekeag Group. The formation is underlain by the Chandler Ridge Formation (slate and graywacke) and is overlain by the Burnt Brook Formation (slate) (Pavrides, 1965b, 1968). Of these three units, only the Carys Mills Formation has been recognized north of the Bridgewater quadrangle.

Pavrides (1968) designated the vicinity of the community of Carys Mills (Houlton quadrangle) as the type area of the formation.

#### Lithology

Pavrides (1965a) describes the unit as consisting of a variety of rock types, but indicates that

"...it is chiefly buff-weathered, gray to blue limestone irregularly interlayered with gray to gray-green slate. On weathered outcrops and in outcrops in stream beds, the limestone layers are commonly more deeply eroded than the slate interbeds. This differential erosion imparts a pronounced ribbed appearance to such outcrops; hence they have been variously described as 'ribbon rock' and 'ribbon limestone'. Calcite, locally derived from the limy rocks during deformation, commonly is present in irregular veinlets or sometimes along cleavage. The slate interbeds generally have few, if any, of these

calcite veinlets because the slate was more plastic during deformation (slate intruded cleavage in limestone layers at several places) and less prone to open fracturing than the more brittle limestone layers ....Thin, intricately contorted, nearly pure calcite veinlets that crosscut bedding are also present.... Ribbon rock can be classed as thin bedded or thick bedded, depending upon the thickness of individual layers of limestone and slate. Thus, thin-bedded ribbon rock is composed of limy layers 0.5 to 1.0 inch thick which are commonly separated by slate layers 0.5 inch thick or less. Thick-bedded ribbon rock consists of limy layers 0.5 foot thick or more, separated by slate layers several inches or more thick. There are all gradations of ribbon rock between thick-bedded and thin-bedded varieties and such gradational types make up the bulk of this lithology."

Pavliades further notes that the limestone beds may be divided into two types: quartzose limestone and quartz-free limestone. In the former type, the quartz is concentrated in silty laminae which stand out in higher relief upon weathering. Cross-lamination and convolute lamination are frequently observed in these quartz-rich beds. The relatively quartz-free type of limestone "...occurs as massive and dense gray-blue layers that have slate

interbeds; such ribbon rock is commonly thick bedded rather than thin bedded. The limy beds may be calcareous argillite, argillaceous limestone, or limestone. Some of the more dense limy rocks break with a subconchoidal fracture" (Pavrides, 1965a). In fresh exposure the two limestone types are difficult to distinguish, but even moderate weathering is sufficient to delineate the silty laminations.

Pavrides has mapped lenticular slate and slate-graywacke bodies which appear to be within the Carys Mills or near the top of the formation in the Bridgewater quadrangle. Such lenses have not yet been mapped in the region of Plate I, but the graywacke-slate-limestone sequence at fossil locality 23 along Maine Route 161 near Colby may represent part of such a lens.

#### Lower Contact

The lower contact of the Carys Mills has not been recognized in the area of this study, but Pavrides (1965a) has mapped the contact with the underlying Chandler Ridge Formation in the Bridgewater quadrangle.

#### Thickness

In the Bridgewater quadrangle, Pavrides (1965a) found the Carys Mills to vary considerably in thickness. He estimated that in the eastern part of the quadrangle the formation is at least 12,000 feet (3800 m) thick, but in the northwestern part of the quadrangle, where it

overlies the Chandler Ridge Formation, a minimum thickness of 1500 feet (470 m) is present. No reliable basis for estimating the thickness in the region of Figure 1 is thus far available, but the unit is presumed to be thick (Boucot, et al., 1964a).

### Age

The reader is referred to Pavlides (1968) for a detailed discussion of Carys Mills relationships. Table 3 (localities 21, 22, 23, and 25) gives the paleontologic data available from the region of Plate I and from the vicinity of Siegas, New Brunswick.

As summarized by Pavlides, the paleontologic data indicate that the Carys Mills ranges from Caradocian (zone 13) of the Ordovician to Early Llandoverian (zone 19) of the Silurian. Rocks of zone 19 age have been documented in the formation near Smyrna Mills in the Houlton quadrangle (Pavlides, 1968); the youngest dated Carys Mills in the area of this study is at locality 21, from which the writer collected a graptolite that W. B. N. Berry (personal communication, 1965) places in zone 18 of the Early Llandoverian.

## AROOSTOOK RIVER FORMATION

### Name and Distribution

The name Aroostook River Formation is here proposed for a sequence of slate and sandstone in the core of an unnamed anticline north of Ashland. Strata assigned to

this unit have been previously included in the "Sheridan Sandstone" of Williams and Gregory (1900) and the "Ashland Shales" as defined by Twenhofel (1941).

Outcroppings of the formation along the Aroostook River between the mouths of Alder and Brown brooks are designated as type exposures (Figure 9). No complete section is exposed, but extensive exposures of the unit are present at DR 796, DR 798, and fossil locality 26 (Figure 9); the first is a high cliff exposure just below the mouth of Alder Brook, and the last two are river-bank outcrops that are visible only at low water. Exposures at DR 798 and locality 26 show the gradational contact between the Aroostook River and Frenchville formations.

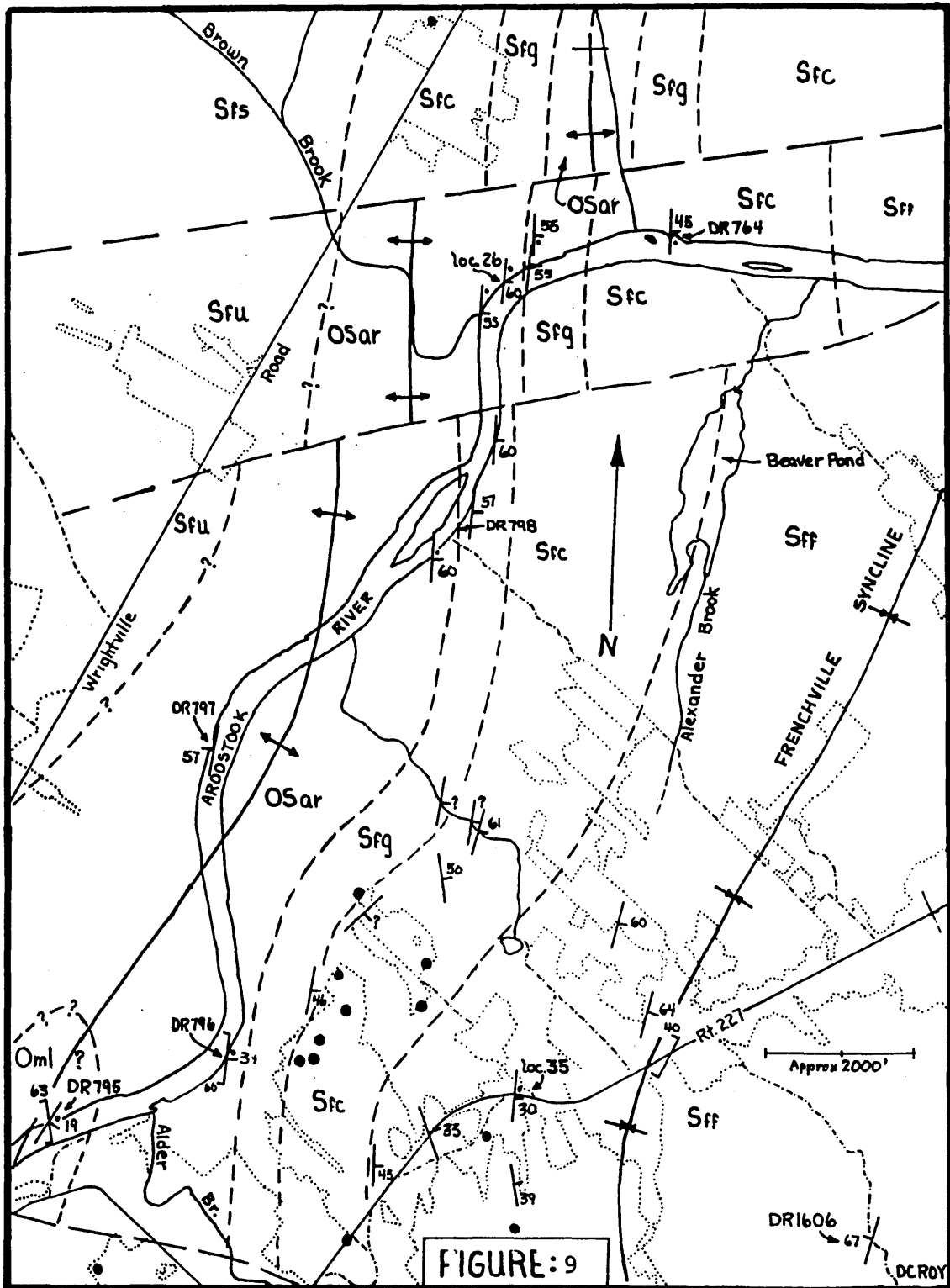
#### Lithology

Most of the Aroostook River Formation consists of dark-gray to green-gray, fracture-cleaved, calcareous slate that is thinly interbedded with fine calcareous sandstone and coarse siltstone. Interbedded with these rock types is medium to coarse sandstone; beds of this coarser sandstone are from 1 inch (2.5 cm) to 12 inches (30 cm) thick and may form up to 50 percent of the section locally.

Slate. The slate is very fine grained; it consists of a chlorite-sericite-carbonate "matrix" in which angular silt-size quartz, feldspar, and white mica are

Figure 9: Geologic map of the area around and north of Frenchville. This region is designated as the type area for the Aroostook River Formation and the graywacke, conglomerate, and feldspathic sandstone members of the Frenchville Formation. Dotted lines outline cleared areas and dot-dash lines are farm or lumbering roads. Geologic symbols are shown in Plate II.





widely disseminated. Only a faint orientation of the matrix argillaceous material parallel to bedding is observed; commonly near the larger detrital grains a thin zone of this material is oriented parallel to the grain boundaries. The silt-size mica flakes are oriented parallel or subparallel to bedding. The macroscopic fracture cleavage is evident microscopically as curvilinear, anastomosing zones (0.003 mm wide) of oriented argillaceous material. These zones cross the bedding at a high angle.

The slate may have no macroscopic bedding features, or may contain persistent and discontinuous quartz-carbonate fine siltstone laminae less than 1 mm thick, as shown in Figure 10.

The upper contact of the Aroostook River with the overlying graywacke member of the Frenchville Formation is placed above the highest slate bed at fossil locality 26 and DR 798.

Fine Sandstone and Siltstone. Figure 10 illustrates typical macroscopic features observed in the fine sandstone and siltstone beds. These beds are commonly less than 1.5 inches (4 cm) thick, are light gray or "salt-and-pepper" in color, and are thinly laminated. The tops of many beds display a ripple morphology with simple foreset or "chevron" lamination. The parallel-laminated phase of these beds is of fine sand or coarse silt size;

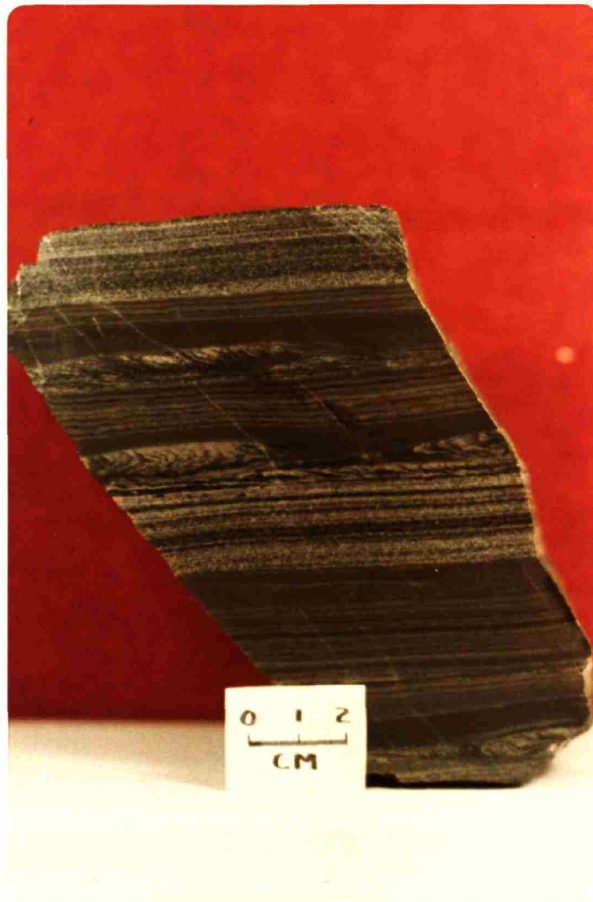


Figure 10: Sawed specimen of typical slate and fine sandstone of the Aroostook River Formation. Note the silty laminations in the pelitic phases and the ripple morphology of the upper part of the largely parallel-laminated fine sandstone bed.

the upper rippled phase commonly consists of fine to medium silt material. Some of these beds are complexly rippled throughout; one such bed with ripple-drift lamination is shown in Figure 11. Complex bed morphology, of uncertain origin, characterizes some of the beds that are entirely siltstone.

A modal analysis of the fine sandstone bed in the middle of the specimen shown in Figure 10 is given in Table 4 (analysis 3). This bed is essentially composed of quartz, argillaceous material, and carbonate. The argillaceous component is concentrated in the dark laminae and is compositionally very similar to the argillaceous phase of the slate interbeds.

Medium and Coarse Sandstone. Medium and coarse calcareous sandstone beds interlayered with the rock types just discussed are commonly graded and many display internal layering which may be classified according to Bouma's turbidite model (see Figure 8). Parallel lamination ("interval B"), with and without observable grading, characterizes most of the beds seen by the writer. A thin "massive" A interval, commonly containing a high proportion of pelite clasts, is seen in many of the beds below the interval of lamination. A C interval of cross-lamination is commonly present but generally poorly defined. The upper portion of interval B is typically fine sandstone, and interval C is entirely silt-size or finer.

Component	Analysis Number		
	1	2	3
Quartz	24.1	38.0	21.1
Plagioclase Feldspar	6.2	7.4	7.6
Potassium Feldspar		-	
Detrital Mica	0.2	-	1.0
Pyroxene	-	-	Tr
Sphene (?)	.6	-	-
Argillaceous Matrix	12.3	15.2	39.5
Secondary Carbonate	12.7	16.4	22.8
Opaque	1.6	2.6	3.8
Micrographic Qtz-Feld	.4	-	-
Fine-grained Mafic Rocks	13.8	7.2	3.2
Fine-grained Felsic Rocks	6.8	6.4	0.8
Chert and "Cherty" Rocks	4.3	3.8	-
Sericitic Fragments	2.0	1.0	-
Pelite Fragments	9.8	0.6	-
Sandstone	0.8	-	-
Detrital Carbonate	2.6	0.2	-
Fossil Fragments	-	-	-
Misc.	-	-	-
Unidentified	2.0	1.2	0.2
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	0.2	-	0.6
Composite Feld-Qtz	1.2	0.6	0.4
Composite Feldspar	-	0.4	0.2
Composite Quartz	3.5	5.0	0.8
<b>Calculated Parameters</b>			
A	34.2	58.8	64.6
B	8.8	11.5	23.2
C	57.0	29.7	12.2
D	33.9	58.8	62.8
E	7.1	9.9	21.3
F	59.0	31.3	15.9
G	36.5	65.3	79.8
H	2.7	1.7	4.7
I	60.7	33.0	15.5

TABLE 4

Modal Analyses of Sandstones from the  
Aroostook River Formation

Figure 11 shows an 8-inch (22-cm) bed of medium sandstone considered typical of the coarser sandstone. The angular pelite fragments at the base of the bed are macroscopically identical to the interlayered slate. These pelitic fragments suggest that erosion of the bottom took place during the formation of the sandstone bed, and that the underlying pelite had appreciable cohesive strength.

Analyses 1 and 2 of Table 4 are from the basal portions of two different sandstone beds. Argillaceous matrix content is appreciably lower in these samples than in the fine, laminated sandstone; this difference is consistent with the usual observation that the matrix content of graywackes varies inversely with median grain size (Dzulynski and Walton, 1965). Fine-grained mafic and felsic volcanic rocks and chert comprise the major portion of the rock fragments present in the sandstones, with pelite fragments also significant in analysis 1. The slate fragments are very similar microscopically to the slate interbedded with the sandstones.

At locality DR 797 on the west bank of the Aroostook River (see Figure 9) is a poorly exposed sequence that is included in the Aroostook River Formation. At low water, a poorly cleaved, highly jointed, sandy and pebbly slate with massive sandstone interbeds is visible. The



Figure 11: An 8-inch (22-cm) medium-grained sandstone bed, sawed perpendicular to the bedding, illustrates features common to most of the coarser sandstone beds observed in the Aroostook River Formation. Relatively large (1-2 cm) pelite fragments are present in a poorly stratified basal interval (A); a laminated interval (B) forms most of the bed; and an upper cross-laminated interval (C) with a poorly defined upper boundary is evident. A complexly rippled siltstone bed is shown at the right end of the specimen and stratigraphically below the sandstone bed.

sandstone beds are 1-4 feet (0.3-1.3 m) thick, and some appear to be offset along fractures parallel to the jointing. Other sandstone "masses" do not appear to be continuous beds, but are "rounded" and surrounded by the sandy and pebbly slate. The exposure is too poor to determine the exact geometry of these sandstone masses, and their relations to / more bedded sandstone remains obscure. The sandstones at DR 797 are similar to those found elsewhere in the Aroostook River Formation, but the sandy and pebbly slate is atypical.

#### Lower Contact

The base of the Aroostook River Formation has not been observed.

Approximately 2500 feet (760 m) upstream from locality DR 796 is a large exposure (DR 795) on the west bank of the river that is assigned on lithologic grounds to the Madawaska Lake Formation (Figure 9). Although there are a few similarities in appearance between the strata of the Madawaska Lake and Aroostook River formations, clear and fundamental distinctions allow them to be differentiated:

- (1) The Aroostook River Formation contains abundant medium and coarse sandstone, as described above, which shows characteristic lamination and compositional features not observed in the Madawaska Lake.



(2) The siltstone and fine sandstone of the Aroostook River Formation are typically more abundant, coarser grained, and display thicker lamination than similar beds in the Madawaska Lake Formation.

(3) The slate beds of the Aroostook River are calcareous, a property seldom observed in the Madawaska Lake.

The structural attitude and common east top-facing direction in the two exposures suggest that the Aroostook River overlies the Madawaska Lake. The possibility of faulting between the two exposures cannot be ruled out, but given the available data, the interpretation of superposition is the simplest, and is compatible with present paleontologic and regional stratigraphic information.

#### Thickness

If the inferred relationship of the Aroostook River to the Madawaska Lake Formation discussed above and shown in cross-section C-C' of Plate III is correct, then a thickness of 2000 feet (610 m) may approximate the total thickness of the formation.

#### Age

Locality 26 (Table 3) is the only exposure that has provided paleontologic data for the Aroostook River Formation. Boucot (personal communication, 1966) places the brachiopod assemblage in the age span of Ashgillian to Early Llandoveryan based on the presence of Plectothyrella

and Cryptothyrella and suggests that "...it is somewhat reminiscent of the Siegas material but, in the absence of stricklandid brachiopods one could not be sure of a Lower Llandovery assignment." The Siegas material referred to by Boucot is an MIT collection from the "Siegas Quarry" which has been described by him (Ayrton, et al., 1969) and to which he has assigned an Early Llandoveryian age.

The gradational contact of the Aroostook River Formation with the overlying Frenchville Formation suggests that an Early Llandoveryian age is likely.

#### STRATIGRAPHIC RELATIONSHIPS

The Winterville, Madawaska Lake, and lower Carys Mills formations are known to be coeval (Caradocian-Ashgillian). In the northern part of the area, the Winterville lies to the west (northwest) and the Carys Mills to the east (southeast) of the Madawaska Lake. To the south, between Ashland and Presque Isle, a complex distribution pattern is present and the relationships are largely obscured by younger rocks; however, with the possible exception of relations in the area between the Castle Hill and Mapleton anticlines (Plate I), the Madawaska Lake appears to remain in a position intermediate between the other two units.

The physical character of the transitions between these distinctive Ordovician lithofacies cannot be assessed

in detail, but some recent observations have bearing on the problem:

(1) In, and northeast of, Portage, E. Mencher (unpublished data) has observed the interlayering of Winterville-type volcanic breccias and slaty rocks typical of the Madawaska Lake Formation (Figure 4). At Moose Mountain, Mencher (personal communication, 1966) has also found evidence that volcanic rocks, graptolitic black slate, and chert of the Winterville Formation overlie the slates of the Madawaska Lake, which has led him to infer the interfingering of these units along the contact between Portage and Square Lake, although the possibility of a faulted relationship has not been ruled out.

(2) The presence of thin aphanitic limestone beds in the Madawaska Lake at one locality along the southeast margin of the western anticlinorium may represent westward extensions of the Carys Mills limestone lithotope.

(3) Hamilton-Smith (1969) reported the upward gradation of the Madawaska Lake into the Carys Mills Formation northwest of Van Buren, Maine, in the northeast corner of the Stockholm quadrangle (Plate I). Fossil locality 24 (Table 3), in the vicinity of the contact, indicates that the Carys Mills there is Early-Middle Llandoveryan in age and an overlap of that lithofacies onto the Madawaska Lake is indicated.

The relations of the Winterville and Carys Mills between the Castle Hill and Mapleton anticlines are concealed by an intervening syncline containing Silurian rocks (Figure 4). Much, if not all, of the Carys Mills in the core of the Mapleton Anticline is probably of Ashgillian-Early Llandoveryan age, as suggested by fossil localities 21 and 22, and is, therefore, largely younger than the Winterville of the Castle Hill Anticline. Thus, it is quite possible that the Madawaska Lake (or similar) facies is present, in the subsurface, between the Winterville and the lower Carys Mills, but direct evidence for its presence is lacking.

The Pyle Mountain Argillite (Ashgillian) of the Castle Hill Anticline is coeval with a portion of the Carys Mills to the east, and probably also with the youngest phases of the Winterville and Madawaska Lake. The lithologic similarity of slaty parts of the Pyle Mountain to the Madawaska Lake is further support for the correlation of these two units.

The Aroostook River Formation is inferred to overlie the Madawaska Lake Formation in the Frenchville area. The nature of the contact is unknown, but the gross lithologic similarities of the formations suggest that a gradational contact is present. The probable Early Llandoveryan age of the Aroostook River places it as an equivalent of both

the Carys Mills Formation and the Siegas Formation of Hamilton-Smith (1969). The Carys Mills and Aroostook River are separated, between Frenchville and Mapleton (Figure 4), by terrain in which Early Llandoverian strata are absent; these units may, however, interfinger in the subsurface between Frenchville and Perham to the northeast.

## ROCKS OF MIDDLE LLANDOVERIAN-EARLY WENLOCKIAN AGE

### FRENCHVILLE FORMATION

#### Name and Distribution

Boucot, et al. (1964a) applied the name "Frenchville Formation" to a sequence of sandstone and conglomerate that had previously been called the "Sheridan Sandstone" by Williams and Gregory (1900) and "Sandstone" by White (1943). Red, green, and gray slates have been reported by these previous workers as forming minor parts of the unit locally.

The present writer has divided the formation into five complexly interrelated members:

- (1) Graywacke member
- (2) Conglomerate member
- (3) Feldspathic sandstone member
- (4) Sandstone-slate member
- (5) Quartzose sandstone member

The distributions of these members is shown in Figure 4. The first three members comprise the formation in its type area (Boucot, et al., 1964a; see Figure 9) with the graywacke member at the base, overlain in succession by the conglomerate and feldspathic sandstone members. The conglomerate member comprises the entire formation along much of the western flank of the Stockholm Mountain Syncline. The quartzose sandstone member,

inferred to be a lateral equivalent of both the conglomerate and sandstone-slate members, is present along both flanks of the syncline in the vicinity of Stockholm. The sandstone-slate member is an extensive facies lying generally between the conglomerate and feldspathic sandstone members and the more eastern New Sweden Formation.

The type area for the graywacke, conglomerate, and feldspathic sandstone members is the area between Maine Route 127 and the Aroostook River near the village of Frenchville (Figure 9). The type area for the sandstone-slate member is between Castle Hill and the Aroostook River to the north (in the northward plunge of the Castle Hill Anticline), with fossil locality 43 providing the best exposure; west of the Story Hill Fire Tower and in the vicinity of fossil locality 44 are additional good exposures of the member. The quartzose sandstone member is best exposed along the railroad tracks in and north of the village of Stockholm, including fossil localities 37-41.

#### Lithology of the Graywacke Member

The best exposures of this member are at fossil locality 26 and DR 798 (Figure 9), where it conformably overlies the Aroostook River Formation. Thin- to thick-bedded<sup>2</sup>, green-gray to green, medium and coarse lithic

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<sup>2</sup>Laminae (1-3 mm); thin-bedded (0.3-30 cm); medium-bedded (30-100 cm); thick-bedded (excess of 1 meter).

graywackes form most of the unit. Much less thin- to medium-bedded pebble conglomerate is present locally. No pelitic beds have been observed.

Except for the conglomerate beds, compositional and textural variations within the unit are not great. It is not clear whether bedding planes seen in the larger exposures of the unit define separate sedimentation units or were developed subsequent to sedimentation. Within any given sandstone bed, the texture is macroscopically homogeneous; if present, granule- and pebble-size fragments are widely and randomly scattered throughout. Elongate pebbles in the conglomerates are commonly subparallel or parallel to the bedding. Microscopically, elongate detrital fragments in the sandstones tend to parallel bedding. Lamination or other internal structuring within the sandstone beds has not been observed.

Modal compositions of typical sandstones from the graywacke member are shown in Table 5 and plotted in the triangular diagrams of Figure 12. The sandstones are lithic graywackes of limited compositional variation. Modal quartz ranges from 12 to 25 percent; plagioclase feldspar varies between 15 and 20 percent, with potassium feldspar absent. Felsic rock fragments are consistently more abundant than mafic varieties; composite grains form between 7 and 14 percent of the rocks and are



Component	Analysis Number			
	4	5	6	7
Quartz	12.6	20.7	23.2	13.4
Plagioclase Feldspar	20.6	15.8	19.5	18.8
Potassium Feldspar	-	-	-	-
Detrital Mica	0.6	1.4	0.6	2.2
Pyroxene	-	-	Tr	-
Sphene (?)	-	-	-	-
Argillaceous Matrix	30.4	21.9	16.3	30.6
Secondary Carbonate	0.2	3.6	1.2	-
Opaque	6.4	3.8	2.0	1.0
Micrographic Qtz-Feld	0.2	5.6	0.6	0.2
Fine-grained Mafic Rocks	9.6	2.6	5.8	11.2
Fine-grained Felsic Rocks	10.8	3.6	12.4	14.2
Chert and "Cherty" Rocks	2.8	12.2	8.4	1.8
Sericitic Fragments	4.8	-	4.4	5.8
Pelite Fragments	-	5.0	2.6	-
Sandstone	-	-	-	-
Detrital Carbonate	-	0.2	-	-
Fossil Fragment	-	-	-	-
Misc.	-	-	-	-
Unidentified	1.0	3.6	3.0	0.8
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	1.6	2.6	1.0	2.2
Composite Feld-Qtz	2.8	1.8	2.2	3.0
Composite Feldspar	1.6	1.0	1.8	2.4
Composite Quartz	1.0	3.2	4.0	1.8
<b>Calculated Parameters</b>				
A	20.5	31.6	30.3	20.5
B	33.6	24.0	25.3	28.7
C	45.9	44.4	44.4	50.8
D	17.9	27.7	29.0	14.1
E	26.4	19.8	20.1	20.5
F	55.7	52.6	50.9	52.4
G	24.3	34.5	36.3	21.5
H	13.7	20.8	9.1	15.0
I	61.9	44.7	54.6	63.5

TABLE 5

Modal Analyses of Sandstones from the  
Graywacke Member of the Frenchville Formation

Component	Analysis Number			
	8	9	$\bar{X}$	$\sigma$
Quartz	21.3	24.0	19.2	5.0
Plagioclase Feldspar	18.5	19.6	18.8	1.6
Potassium Feldspar	-	-	-	-
Detrital Mica	0.8	1.6	1.2	0.6
Pyroxene	-	Tr	-	-
Sphene (?)	-	-	-	-
Argillaceous Matrix	27.4	17.4	24.0	6.4
Secondary Carbonate	0.8	1.8	1.3	1.3
Opaque	2.8	0.4	2.7	2.2
Micrographic Qtz-Feld	1.6	2.8	1.8	2.1
Fine-grained Mafic Rocks	5.6	8.2	7.2	3.1
Fine-grained Felsic Rocks	9.8	9.0	10.0	3.6
Chert and "Cherty" Rocks	6.6	7.6	6.6	3.8
Sericitic Fragments	-	-	2.5	2.8
Pelite Fragments	2.8	4.2	2.4	2.1
Sandstone	-	-	-	-
Detrital Carbonate	-	-	-	0.1
Fossil Fragments	-	-	-	-
Misc.	-	-	-	-
Unidentified	2.0	3.4	2.3	1.2
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	
Composite Qtz-Feld	1.0	1.6	1.7	0.6
Composite Feld-Qtz	2.0	3.2	2.5	0.6
Composite Feldspar	1.2	3.6	1.9	1.0
Composite Quartz	3.0	5.0	3.0	1.4
<b>Calculated Parameters</b>				
A	32.2	31.8	28.0	
B	27.9	26.0	27.4	
C	39.9	42.2	44.5	
D	30.7	29.7	25.5	
E	23.1	17.0	21.0	
F	46.2	53.3	53.4	
G	39.9	35.8	32.3	
H	11.4	17.9	14.6	
I	48.7	46.3	53.0	

TABLE 5 (Cont)

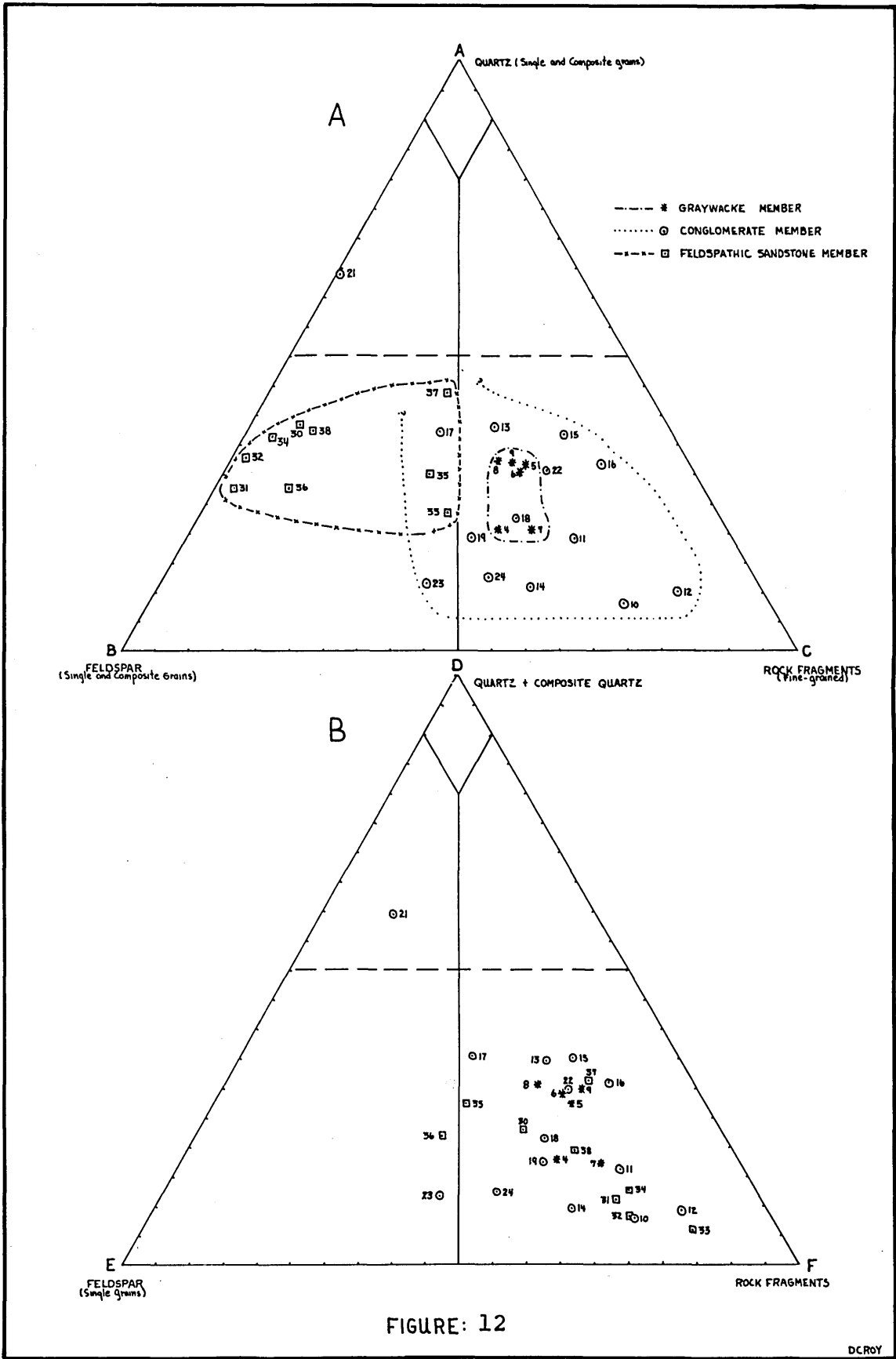
subordinate in abundance to the fine-grained igneous rocks. Abundant argillaceous matrix (16-31 percent) and relatively abundant slate and sericitic fragments are distinctive features of these sandstones. Except for scattered trace occurrences in sandstones of the overlying conglomerate member, the sericitic fragments appear to be restricted to this member.

#### Lithology of the Conglomerate Member

Overlying the graywacke member on the flanks of the anticline west of Frenchville is a succession of sandstones and pebble conglomerates. This sequence is here designated the conglomerate member of the Frenchville. The best exposures of this member are found in the area shown in Figure 9, but numerous outcrops of the unit may be found between Ashland and Frenchville in the fields and woods along Maine Route 227.

In the vicinity of Frenchville the exposed section of the member consists of approximately 75-80 percent conglomerate, 20-25 percent sandstone, with slate and pebbly slate comprising no more than one or two percent. These figures are about correct for the Ashland area except that the conglomerate proportion may be slightly higher. Along the western flank of the Stockholm Mountain Syncline the outcrop population within the member suggests that the section may be closer to 50

Figure 12: Triangular composition diagrams for the graywacke, conglomerate, and feldspathic sandstone members of the Frenchville Formation. Components included at each pole of the diagrams are shown in Table 1. The ABC diagram is used to determine rock names used in the text.



percent sandstone. The small size of many of the exposures and their nonuniform distribution make these estimates crude at best; the resistant character of the conglomerate beds probably results in an overestimate of their abundance at the expense of sandstone. Slate may be much more abundant, but only a few exposures of this rock type have been seen. Near the inferred zone of interfingering of the conglomerate member with the sandstone-slate member, an increase in both slate and sandstone content may occur.

Conglomerate. The best exposure of the conglomerate rock type is at DR 764 on the Aroostook River (Figure 9). There, medium to massive beds of pebble roundstone conglomerate are interlayered with much less medium and coarse lithic sandstone. The contacts between the conglomerate and sandstone beds are commonly gradational. Apparent graded bedding<sup>3</sup> is present in two beds; one of these and the base of second is pictured in Figure 13. The two graded beds are separated by a sharp erosional (?) interface.

Aside from the grading observed at DR 764, the only other fabric features of the conglomerates in the member are pebble orientations parallel or subparallel to bedding and variations of the pebble/matrix ratio producing internal stratification in some beds. No imbrication, cross-stratification or channeling has been observed.

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<sup>3</sup>All determinations of internal and external structures of sandstone and conglomerate beds reported here are based on field observations unless otherwise indicated.



Figure 13: Apparently graded beds in the conglomerate sequence at DR 764 (Figure 9). Hammer is 12.5 inches (31.3 cm) long.

Field estimates of the composition of the conglomerate at DR 764 are shown in Table 6 (DR 764-I and DR 764-II). Two important features of the pebble conglomerates are illustrated:

(1) A matrix of sandstone (graywacke) forms a large part of the beds. At DR 764, about 40 percent of the rock is matrix sandstone; similar analyses from other exposures (Table 6) suggests that the matrix content of the conglomerates may approach 60 percent. The conglomerates, therefore, range from orthoconglomerates (intact frameworks; 50 percent or less matrix) to paraconglomerates (disrupted frameworks; 50 percent or more matrix) in the classification of Pettijohn (1957).

(2) A dominance of fine-grained igneous (volcanic) rocks and chert is found in the pebbles. All of the field analyses as well as visual estimates from other outcrops suggest a preponderance of felsic rocks comprising the volcanic pebbles (felsic/mafic ratio in the field analysis is 1.2-7.7).

Four thin-section analyses of conglomerate beds are given in Table 7. These analyses are not strictly comparable to the field analyses since sand-size matrix between the pebbles is not differentiated. In addition, these thin-section results cannot be considered fully representative of the sampled beds because the size of the sections is small relative to the grain sizes present.



<u>Component</u>	<u>Analysis</u>			
	<u>DR 764-I</u>	<u>DR 764-II</u>	<u>DR 1866</u>	<u>DR 1851</u>
Graywacke Matrix	42.2	39.6	34.6	54.5
Fine-grained Felsic Rocks	34.0	34.9	21.6	23.1
Fine-grained Mafic Rocks	13.5	10.7	18.6	3.0
Chert	2.8	6.5	15.6	15.4
Slate	---	0.6	0.6	---
Plutonic Rocks	4.5	1.8	---	---
Quartz Pebbles	T	T	1.2	3.0
Aphanitic Limestone	T	T	---	---
Unidentified Rocks	<u>3.0</u>	<u>5.9</u>	<u>7.8</u>	<u>1.2</u>
TOTAL	100.0	100.0	100.0	100.0

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TABLE 6

Field modal analyses of pebble conglomerates from the conglomerate member of the Frenchville Formation. Matrix is medium-grained lithic graywacke. Plutonic rocks are fine-phaneritic quartz-feldspar pebbles. Unidentified rocks are granule and fine-pebble sized particles of probable volcanic origin.

Component	Analysis Number			
	25	26	27	28
Quartz	5.8	4.4	18.8	5.8
Plagioclase Feldspar	11.4	1.4	1.8	9.4
Potassium Feldspar				
Detrital Mica	-	-	-	0.2
Pyroxene	-	-	-	Tr
Sphene (?)	-	-	-	0.2
Argillaceous Matrix	13.6	2.8	10.8	10.6
Secondary Carbonate	1.8	0.2	-	-
Opaque	2.6	0.2	0.4	0.4
Micrographic Qtz-Feld	0.2	0.6	0.1	1.0
Fine-grained Mafic Rocks	22.8	24.6	31.7	53.2
Fine-grained Felsic Rocks	30.2	47.4	26.2	17.0
Chert and "Cherty" Rocks	7.2	16.0	9.0	0.2
Sericitic Fragments	-	-	-	-
Pelite Fragments	1.4	2.2	-	1.8
Sandstone	-	-	-	-
Detrital Carbonate	2.6	-	-	-
Fossil Fragments	0.2	0.2	-	-
Misc.	-	-	-	-
Unidentified	0.2	-	1.2	0.2
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	0.4	0.2	0.2	2.8
Composite Feld-Qtz	0.4	-	-	-
Composite Feldspar	0.4	0.4	-	-
Composite Quartz	2.8	2.6	11.0	1.8
<b>Calculated Parameters</b>				
G	7.6	4.4	21.7	3.5
H	2.0	1.3	0.4	11.3
I	90.4	94.4	77.9	85.1

TABLE 7

Modal Analyses of Conglomerates from the  
Frenchville Formation

Analyses 25, 26, 27, and 28 are from the conglomerate member and analysis 29 is from the quartzose sandstone member. Averages and standard deviations apply to conglomerate member samples.

Component	Analysis Number		
	$\bar{X}$	$\sigma$	29
Quartz	8.8	6.8	26.8
Plagioclase Feldspar	6.0	5.1	14.4
Potassium Feldspar			
Detrital Mica	-	0.1	0.4
Pyroxene	-	-	-
Sphene (?)	-	0.1	0.2
Argillaceous Matrix	9.4	4.6	8.8
Secondary Carbonate	0.5	0.9	1.2
Opaque	0.9	1.1	-
Micrographic Qtz-Feld	0.5	0.4	4.4
Fine-grained Mafic Rocks	33.1	14.0	29.0
Fine-grained Felsic Rocks	30.3	12.7	11.8
Chert and "Cherty" Rocks	8.1	6.5	0.8
Sericitic Fragments	-	-	-
Pelite Fragments	1.3	1.0	0.6
Sandstone	-	-	-
Detrital Carbonate	0.6	1.3	1.2
Fossil Fragments	0.1	0.1	-
Misc.	-	-	-
Unidentified	0.4	0.5	0.4
<b>TOTAL</b>	<b>100.0</b>		<b>100.0</b>
Composite Qtz-Feld	0.9	1.3	5.8
Composite Feld-Qtz	1.5	2.8	7.2
Composite Feldspar	0.2	0.2	0.2
Composite Quartz	4.5	4.3	2.2
Calculated Parameters			
G			25.6
H			21.5
I			52.9

TABLE 7 (Cont)

The thin-section results are presented to give a rough approximation of the conglomerate composition, which can be compared with the results for sandstones presented below.

The thin-section results are in general agreement with the field analyses of Table 6. An abundance of volcanic rock fragments and chert is a principal feature, with composite grains low in amount. The felsic/mafic ratio ranges from 0.32 to 1.92. These lower ratios reflect the inclusion of lithic fragments from the sand-sized matrix; interbedded sandstones of the conglomerate member generally have a preponderance of mafic fragments (see below).

Limestone fragments are not commonly abundant in the conglomerates. Isolated pebbles and cobbles of aphanitic limestone and coarser grained, commonly crinoidal, limestone are seen in some exposures. The conglomerates exposed at fossil locality 31, and in other outcrops nearby, are exceptionally rich in light-gray, coarsely crystalline, limestone fragments. Coral fragments, crinoid columnals, and shell fragments are also mixed with the volcanic rocks and chert.

Conglomerates of markedly different aspect are also present at two places along the western flank of the Stockholm Mountain Syncline northeast of Madawaska Lake. The first is the exposure at fossil locality 32 near

Madawaska Lake; the second is a series of exposures interpreted to represent a lenticular conglomerate body near Collins Siding northeast of the lake (see Plate I).

At fossil locality 31, beds of pebble and cobble conglomerate composed of abundant limestone and slate fragments are interlayered in a sequence of pebbly lithic graywacke. The limestone fragments are dark gray, brown weathering, finely crystalline, and argillaceous. Light-gray and white, more coarsely crystalline limestone clasts are also present. The limestone pebbles and cobbles are angular, commonly tabular and oriented parallel or nearly parallel to the bedding plane. Olive-green slate, green and green-gray chert, rounded fine-grained felsitic and mafic rocks, siltstone, and fine sandstone pebbles are mixed with the limestone. The olive-green slate clasts of cobble size are cleaved, and one fragment was observed to have light-gray, rusty-weathering siltstone laminations; these slate fragments and those of limestone are lithologically very similar to the rock types of the Madawaska Lake Formation exposed in the quarry just north of Madawaska Lake itself (see discussion on page 88 ).

The lenticular (?) body of the conglomerate member within the quartzose sandstone member just northeast of Collins Siding (Plate I) is best exposed along the crest of the northeast-trending ridge immediately southeast of the railroad tracks. In these conglomerates cream-colored

quartz-feldspar-biotite pebbles form up to 25 percent of the clasts; the remaining volcanic and chert pebbles are typical of those found in other Frenchville conglomerates. The light-colored fragments are composed of single and polycrystalline phenocrysts of plagioclase and altered biotite in a dominant fine-grained matrix of micrographically intergrown quartz and potassium feldspar. These fragments have the general texture and composition of granophyre.

The matrix in the conglomerates near Collins Siding consists of medium-grained, quartzose lithic graywacke containing rounded quartz and granophyre grains.

Sandstone. Sandstones of the conglomerate member are poorly sorted, compositionally immature, lithic graywackes and, less commonly, lithic arenites. Feldspathic graywacke and quartzose feldspathic arenite have been observed but appear to be minor in abundance.

Texturally, sandstones from the conglomerate member are medium- to coarse-grained and of homogeneous appearance. A bedding fabric caused by orientation of pelite and other lithic fragments or variations in lithic fragment concentration is present at some exposures. Most of the sandstones are poorly sorted, and there is a continuous spectrum from lithic through pebbly sandstone to pebble conglomerate.

Modal analysis of typical sandstones from this member are given in Table 8. Though the sandstones are quite variable in composition, some general features are evident:

(1) Most of the sandstones are lithic graywackes with maximum matrix "clay" content of about 31 percent.

(2) With one exception (analysis 15), mafic volcanic rock fragments exceed those of felsic composition; the felsic/mafic ratio varies from zero to 1.7 and averages 0.19.

(3) Side-counted composite grains constitute less than 11 percent of the rocks. Micrographic quartz-feldspar is, however, important in two of the sandstones analyzed; a few of these micrographic grains contain biotite crystallites.

(4) Potassium feldspar is absent, or is present in only trace amounts.

With the exception of analysis 21, the compositions of the sandstones fall into a broad, but well defined, field in the ABC plot of Figure 12A. The analyses of the underlying graywacke member form a small field near the center of the distribution for the conglomerate member. It is possible that the field of the conglomerate member extends into the quartzose feldspathic sandstone area of the diagram as suggested by analysis 21, but thus far quartzose sandstones have proven to be very scarce in the member.

Component	Analysis Number			
	10	11	12	13
Quartz	5.9	14.4	8.0	25.3
Plagioclase Feldspar	15.9	15.8	10.2	16.9
Potassium Feldspar	-	1.8	-	-
Detrital Mica	-	-	0.4	1.0
Pyroxene	2.9	2.2	-	Tr
Sphene (?)	-	-	-	-
Argillaceous Matrix	20.4	20.4	14.2	30.4
Secondary Carbonate	1.8	-	3.4	1.0
Opaque	0.2	0.4	0.8	0.8
Micrographic Qtz-Feld	8.1	8.2	1.8	0.6
Fine-grained Mafic Rocks	37.1	23.3	40.4	15.1
Fine-grained Felsic Rocks	-	10.1	5.0	4.6
Chert and "Cherty" Rocks	6.1	1.8	12.6	0.6
Sericitic Fragments	-	-	-	2.3
Pelite Fragments	0.2	0.2	2.4	0.8
Sandstone	-	-	-	-
Detrital Carbonate	-	-	-	0.2
Fossil Fragments	-	-	0.2	-
Misc.	-	-	-	-
Unidentified	1.4	1.4	0.6	0.4
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	0.2	2.2	0.6	2.3
Composite Feld-Qtz	0.2	2.2	-	2.3
Composite Feldspar	0.8	1.6	-	1.4
Composite Quartz	2.6	NC	0.8	3.2
<b>Calculated Parameters</b>				
A	8.0	19.0	10.0	38.1
B	21.7	23.2	12.7	25.5
C	70.3	57.7	77.4	36.4
D	7.8	16.1	9.2	34.6
E	20.3	18.2	12.7	19.9
F	71.9	65.7	78.1	45.5
G	9.8	19.7	10.5	43.2
H	15.9	22.9	3.4	12.4
I	74.3	57.4	86.0	44.4

TABLE 8

Modal Analyses of Sandstones from the  
Conglomerate Member of the Frenchville Formation



Component	Analysis Number			
	14	15	16	17
Quartz	8.5	25.7	25.3	32.9
Plagioclase Feldspar	27.0	11.2	10.4	30.1
Potassium Feldspar	-	-	-	-
Detrital Mica	0.2	1.6	0.2	-
Pyroxene	-	-	0.2	1.2
Sphene (?)	-	-	-	-
Argillaceous Matrix	5.5	18.3	14.2	7.6
Secondary Carbonate	2.2	1.4	3.4	-
Opaque	2.2	6.8	0.2	0.4
Micrographic Qtz-Feld	8.1	1.4	1.1	3.8
Fine-grained Mafic Rocks	39.0	4.4	6.6	7.8
Fine-grained Felsic Rocks	2.0	7.6	6.4	2.6
Chert and "Cherty" Rocks	1.6	9.0	15.0	8.8
Sericitic Fragments	-	-	-	-
Pelite Fragments	1.2	8.8	10.2	1.4
Sandstone	-	0.4	1.6	1.2
Detrital Carbonate	-	1.4	3.4	-
Fossil Fragments	-	-	-	-
Misc.	0.2	-	-	-
Unidentified	0.4	2.0	1.8	2.2
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	1.0	1.2	0.6	1.4
Composite Feld-Qtz	1.6	0.2	0.2	1.2
Composite Feldspar	2.8	-	0.2	2.2
Composite Quartz	0.4	4.4	5.0	1.6
<b>Calculated Parameters</b>				
A	10.7	36.7	31.7	37.1
B	34.0	16.0	13.0	34.0
C	55.2	47.3	55.3	28.9
D	9.5	35.0	31.0	35.6
E	28.5	15.8	12.5	30.1
F	62.0	49.3	56.6	34.3
G	13.2	41.5	35.4	50.9
H	9.5	4.8	3.0	13.9
I	77.2	53.7	61.6	35.2

TABLE 8 (Cont)

Component	Analysis Number			
	18	19	21	22
Quartz	16.6	15.6	54.8	22.4
Plagioclase Feldspar	22.2	31.0	30.7	15.6
Potassium Feldspar	--	--	--	--
Detrital Mica	--	--	--	0.6
Pyroxene	1.0	0.4	--	--
Sphene (?)	--	--	--	--
Argillaceous Matrix	22.8	7.0	9.3	20.8
Secondary Carbonate	1.4	2.8	2.8	2.6
Opaque	0.4	7.2	1.6	2.2
Micrographic Qtz-Feld	2.0	1.4	0.6	2.8
Fine-grained Mafic Rocks	23.0	26.6	--	17.8
Fine-grained Felsic Rocks	4.8	3.6	--	3.8
Chert and "Cherty" Rocks	4.8	2.8	--	2.4
Sericitic Fragments	--	--	--	--
Pelite Fragments	0.4	0.2	--	7.2
Sandstone	--	--	--	0.8
Detrital Carbonate	--	--	--	--
Fossil Fragments	--	--	--	--
Misc.	--	--	--	--
Unidentified	0.6	1.4	0.2	1.0
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	1.0	1.6	3.6	0.8
Composite Feld-Qtz	1.0	2.2	4.0	1.0
Composite Feldspar	1.4	5.4	1.0	0.6
Composite Quartz	3.2	3.8	2.0	3.0
<b>Calculated Parameters</b>				
A	22.5	19.2	63.7	30.8
B	30.1	38.2	35.6	21.4
C	47.4	42.6	0.7	47.8
D	21.1	17.2	59.5	29.7
E	26.8	28.8	29.8	19.2
F	52.0	53.9	10.7	51.1
G	28.9	24.2	84.8	36.7
H	10.0	18.3	15.2	8.8
I	61.1	57.4	0.0	54.4

TABLE 8 (Cont)

Component	Analysis Number			
	23	24	$\bar{X}$	$\sigma$
Quartz	8.4	8.6	19.5	13.2
Plagioclase Feldspar	35.5	26.6	21.4	8.7
Potassium Feldspar	0.2	--	0.1	0.5
Detrital Mica	--	0.2	0.3	0.5
Pyroxene	--	Tr	0.6	0.9
Sphene (?)	--	--	--	--
Argillaceous Matrix	18.4	30.8	17.8	7.3
Secondary Carbonate	7.6	Tr	2.2	2.0
Opaque	0.4	0.4	1.7	2.3
Micrographic Qtz-Feld	1.2	0.2	2.4	2.6
Fine-grained Mafic Rocks	25.1	28.2	21.0	13.0
Fine-grained Felsic Rocks	0.4	4.2	3.9	2.9
Chert and "Cherty" Rocks	1.8	0.2	4.8	4.8
Sericitic Fragments	--	--	0.2	0.6
Pelite Fragments	0.4	--	2.4	3.6
Sandstone	--	--	0.3	0.5
Detrital Carbonate	--	--	0.4	1.0
Fossil Fragments	--	--	--	0.1
Misc.	--	--	--	0.1
Unidentified	0.6	0.6	1.0	0.7
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	
Composite Qtz-Feld	--	0.4	1.2	1.0
Composite Feld-Qtz	0.4	0.4	1.2	1.1
Composite Feldspar	1.0	0.2	1.3	1.4
Composite Quartz	0.4	0.2	2.2	1.7
<b>Calculated Parameters</b>				
A	11.5	12.6	25.5	
B	48.9	39.1	28.1	
C	39.6	48.2	46.3	
D	11.5	12.1	24.0	
E	47.0	38.2	24.9	
F	41.5	49.7	51.2	
G	21.7	19.5	31.9	
H	6.7	2.9	10.6	
I	71.6	77.6	57.5	

TABLE 8 (Cont)

Slate and Pebbly Slate. Red and green slate assigned to the conglomerate member is present in the well exposed plunge of a small anticline on the east bank of the Aroostook River 1.45 miles upstream from the mouth of Alder Brook. Williams and Gregory (1900, p. 132) cited this exposure as part of the "Sheridan Sandstone" and noted the presence of thin beds of "greenish gray calcareous material" that weathers more readily than the slate and contains abundant crinoid columnals. The writer has observed similar material at the exposure forming discontinuous beds (approximately one foot thick) within the slate; the material is light-gray coarsely crystalline limestone containing "floating," angular, gray and light-green chert, and fine-grained volcanic rock fragments as well as the crinoid columnals.

Red slate is also found in the bed of a small drainage near its confluence with the Aroostook River 0.86 miles down-river from the cliff labeled "Pudding Rock" north of Frenchville (Plate I). Slate exposures near fossil locality 31 east of Ashland are interpreted to be interbedded with the conglomerates.

Pebbly slate (argillite) is present at fossil localities 28 and 29 along Route 227 near Alder Brook. The poorly cleaved slate consists of silty, gray pelite containing fragments of brachiopods, corals, crinoids, and gastropods and pebbles of chert and volcanic rocks.

These pebbly slates are interbedded with more resistant sandstone and pebble conglomerate.

#### Lithology of the Feldspathic Sandstone Member

Overlying the conglomerate member in the vicinity of Frenchville is a sequence of medium- to massive-bedded feldspathic graywacke and arenite. The absence of conglomerates, and the prevalence of feldspar-rich sandstones with low volcanic and chert rock-fragment content distinguish the member. Red slates are present as a minor rock type locally.

Sandstone. Fossil locality 35, along Maine Route 227 in the village of Frenchville, provides an extensive exposure of sandstones typical of the member (Figure 9). Approximately 145 feet (44.2 m) of section is provided by the roadcut. The principal features of the sequence are shown in Figure 14.

Massive, light-gray, rust-weathering feldspathic graywacke composes most of the section. A uniform texture, subconchoidal fracture and widely spaced pelite fragments characterize these sandstones. Beds of this rock type up to 15 feet thick (4.6 m) show no internal features to suggest they are multiple sedimentation units, and "bedding" planes separating them, as at 76.5 and 91.5 feet, have no noticeable compositional or grain-size differences across them. These surfaces contain slickensides, and the bed overlying the interface at

Figure 14: Measured stratigraphic section at fossil locality 35. Features of the section are discussed in the text.

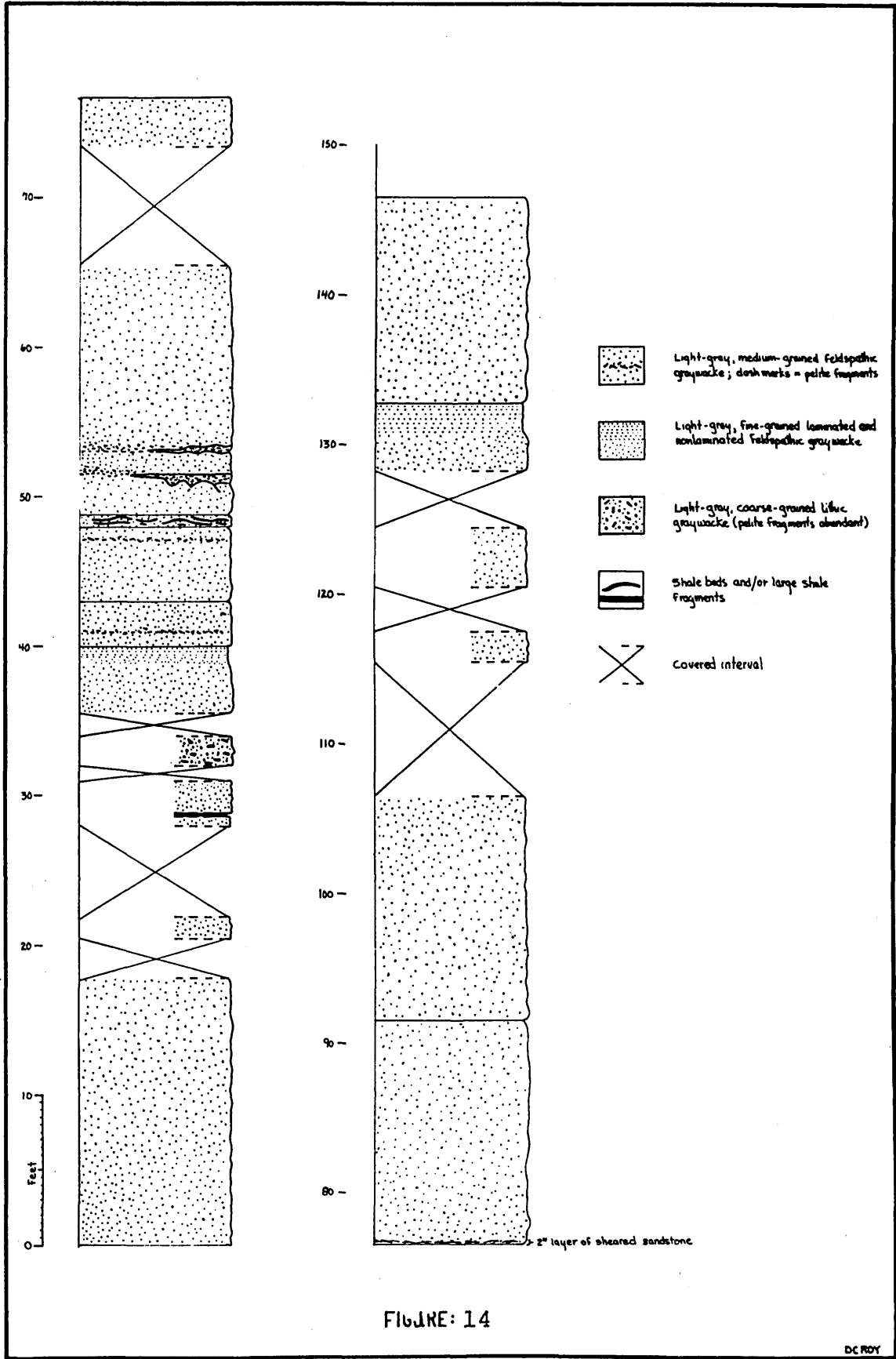


FIGURE: 14

the 76.5 foot level has a two-inch sheared zone at its base. These features indicate that at least some of the bedding planes were kinematically active during folding.

A one inch (2 cm) shale seam separates two of these sandstone beds near the 30 foot level. Just below the 50 foot mark, thin sandstone and shale beds (?) are complexly deformed; it is not clear in the available exposure whether the shale portions of this interval were originally thin beds or large clasts.

Fine-grained, commonly laminated, feldspathic graywacke is present at the tops of some of the massive beds. The sharp contact between these fine sandstone phases and the overlying medium sandstone beds is inferred to represent the separation of two sedimentation units.

The basal portions of two sedimentation episodes are represented by the coarse pelite-rich sandstone phases just above the 50 foot mark. These basal phases are separated from the medium sandstones underneath by sharp contacts; however, these phases along much of their exposed length were sheared during deformation (Figure 15). The coarse bottom interval, where not sheared, grades over a distance of 10 to 15 cm into the typical medium grained sandstone. The coarse-grained, pelite-rich sandstone bed just above the 30-foot mark may represent a basal phase of the next exposed sandstone interval above it.





Figure 15: Two thick-bedded feldspathic graywacke beds separated by an interval of sheared coarse-grained, pelite-rich, lithic sandstone.

(Hammer is 12.5 inches (13.3) cm) long.)

Other than the grading, lamination, and deformational features just discussed, the only fabric feature visible at locality 35 is the concentration of pelite fragments at widely spaced intervals. Elsewhere, parting lineation, lamination and lithic fragment concentrations are the only fabric features seen.

Modal analyses of sandstones from the feldspathic sandstone member are presented in Table 9. The following compositional characteristics are evident:

(1) Average quartz content is 26.0 percent ( $\sigma = 5.5$ ).

(2) Average plagioclase feldspar content is 37.9 percent ( $\sigma = 11.8$ ). This high abundance of feldspar is quite evident in hand specimens and outcrops, allowing separation of the sandstones from those of the underlying conglomerate member.

(3) Composite grains, particularly those including feldspar, are commonly very abundant.

(4) Volcanic and chert rock fragments are usually present but subordinate to the composite grains in abundance. With few exceptions the volcanic and chert fragments are not readily observed in the field except in the coarse sandstones.

(5) Potassium feldspar is present in nearly all of the analyses (up to 12.0 percent) but is not distinguishable in hand specimen or outcrop.

Component	Analysis Number			
	30	31	32	33
Quartz	30.2	18.4	23.8	19.2
Plagioclase Feldspar	42.5	36.0	47.8	24.5
Potassium Feldspar	0.4	10.8	--	7.9
Detrital Mica	Tr	0.4	--	0.7
Pyroxene	Tr	--	0.2	Tr
Sphene (?)	--	1.2	--	--
Argillaceous Matrix	15.5	15.8	25.0	11.9
Secondary Carbonate	0.0	15.2	--	2.6
Opaque	5.5	--	1.6	0.8
Micrographic Qtz-Feld	3.3	1.0	0.6	7.8
Fine-grained Mafic Rocks	1.4	--	0.8	15.8
Fine-grained Felsic Rocks	1.0	0.4	--	3.6
Chert and "Cherty" Rocks	0.2	0.6	0.2	2.8
Sericitic Fragments	--	--	--	--
Pelite Fragments	--	--	--	--
Sandstone	--	--	--	--
Detrital Carbonate	--	---	--	--
Fossil Fragments	--	--	--	--
Misc.	--	--	--	--
Unidentified	--	0.2	--	2.5
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	12.0	11.0	17.8	14.5
Composite Feld-Qtz	13.3	19.0	20.6	14.4
Composite Feldspar	6.7	13.4	12.0	7.7
Composite Quartz	1.8	0.6	--	NC
<b>Calculated Parameters</b>				
A	38.2	27.4	32.5	23.6
B	54.3	69.6	65.3	39.7
C	7.5	3.0	2.2	36.7
D	23.0	11.0	8.2	5.9
E	29.0	21.4	20.8	12.7
F	48.0	67.6	71.0	81.4
G	32.4	14.0	10.3	6.7
H	62.9	84.1	87.9	62.2
I	4.6	1.9	1.7	31.1

TABLE 9

Modal Analyses of Sandstones from the Feldspathic Sandstone Member of the Frenchville Formation

Component	Analysis Number			
	34	35	36	37
Quartz	32.6	23.6	23.6	29.9
Plagioclase Feldspar	53.6	30.2	51.4	20.2
Potassium Feldspar	0.2	0.4	0.8	--
Detrital Mica	Tr	--	1.6	Tr
Pyroxene	--	0.2	0.6	0.2
Sphene (?)	--	--	--	--
Argillaceous Matrix	9.6	17.0	9.2	20.9
Secondary Carbonate	9.0	1.2	1.0	Tr
Opaque	--	0.4	Tr	7.4
Micrographic Qtz-Feld	3.6	9.0	2.6	7.0
Fine-grained Mafic Rocks	--	5.4	2.0	3.7
Fine-grained Felsic Rocks	0.4	2.8	3.4	4.6
Chert and "Cherty" Rocks	--	6.8	1.4	2.8
Sericitic Fragments	--	--	--	--
Pelite Fragments	--	0.4	--	--
Sandstone	--	--	--	--
Detrital Carbonate	--	--	Tr	--
Fossil Fragments	--	--	--	--
Misc.	--	--	--	--
Unidentified	--	2.6	2.4	3.3
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	21.4	2.2	5.0	8.5
Composite Feld-Qtz	23.8	2.2	8.2	5.4
Composite Feldspar	13.0	0.8	8.6	4.4
Composite Quartz	1.6	3.2	1.8	4.4
<b>Calculated Parameters</b>				
A	36.1	30.0	27.7	13.8
B	59.5	39.0	61.3	29.7
C	4.4	31.0	11.0	26.6
D	12.4	27.2	21.8	31.3
E	18.8	35.2	41.5	15.3
F	68.8	37.6	36.6	53.5
G	15.3	42.0	37.3	36.9
H	84.2	27.8	49.0	43.8
I	0.5	30.2	13.7	19.2

TABLE 9 (Cont)

Component	Analysis Number		
	38	$\bar{X}$	$\sigma$
Quartz	33.0	26.1	5.5
Plagioclase Feldspar	35.0	38.1	11.8
Potassium Feldspar	12.0	3.6	5.1
Detrital Mica	Tr	0.3	0.5
Pyroxene	Tr	0.1	0.2
Sphene (?)	--	0.1	0.4
Argillaceous Matrix	10.8	15.2	5.4
Secondary Carbonate	--	2.0	5.0
Opaque	0.4	1.8	2.7
Micrographic Qtz-Feld	6.2	4.6	3.0
Fine-grained Mafic Rocks	0.4	3.3	5.4
Fine-grained Felsic Rocks	1.2	1.9	1.7
Chert and "Cherty" Rocks	0.8	1.7	2.2
Sericitic Fragments	--	--	--
Pelite Fragments	--	--	0.1
Sandstone	--	--	--
Detrital Carbonate	--	--	--
Fossil Fragments	--	--	--
Misc.	--	--	--
Unidentified	0.2	1.2	1.4
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	
Composite Qtz-Feld	15.8	12.0	6.1
Composite Feld-Qtz	20.6	14.2	7.6
Composite Feldspar	5.4	8.0	4.2
Composite Quartz	4.2	2.0	1.7
<b>Calculated Parameters</b>			
A	37.2	32.9	
B	53.0	52.5	
C	9.7	14.6	
D	19.4	17.7	
E	23.5	24.4	
F	57.1	57.8	
G	25.4	23.5	
H	71.1	65.0	
I	3.5	11.6	

TABLE 9 (Cont)

The sandstone analyses form a well defined field in the feldspathic sandstone area of Figure 12A, but are indistinguishable from the sandstones of the conglomerate member in the compositional maturity plot of Figure 12B. With two exceptions, the analyzed sandstones are graywackes; the exceptions (analyses 34 and 36) contain 9.6 and 9.2 percent argillaceous respectively.

Slate and Shale. Slate and shale form a very small proportion (2-3 percent) of the exposed section of this member. Aside from the thin shale seam observed at fossil locality 35, green slate is interbedded with thin feldspathic sandstones at DR 868 (Figure 9); green, red and black slate, abundantly manganese and iron stained, are present in an old test pit at DR 629. Miller (1947, p. 60) discussed the manganese and iron content of these pelitic rocks and similar ones exposed along the east side of Maine Route 227 just to the southwest. The strata at DR 869 and DR 629 appear to overlie the succession at fossil locality 35 with the rocks of DR 629 being the youngest.

Southeast of DR 629, at DR 1606 (see Figure 9), massive, orange-weathering feldspathic graywacke is interlayered with red slate containing zones of laminated mangiferous ironstone. Assuming a simple synclinal structure between the exposures at locality 35 and DR 1606, the mangiferous slates at the latter are at about the

same stratigraphic level as the sandstones of locality 35 or possibly slightly lower.

#### Lithology of the Sandstone-Slate Member

Along the eastern flank of the Stockholm Mountain Syncline from Fogelin Hill in the northeast to north of Ashland, sandstone interlayered with variable amounts of slate comprises the Frenchville Formation. The same interlayered sequence is found as far east as the west flank and north plunge of the Castle Hill Anticline, and extends northward along the west flank of the faulted syncline west of Perham (see Figure 4).

In the northward plunge of the Castle Hill Anticline, shown in Figure 16, the member is in a structurally complex setting involving an imperfectly understood fault pattern. The outcrops of the member form two groups: a southern group on Castle Hill, around fossil locality 42, that defines the northward plunge (approximately 35-40 degrees) of the anticline and represents the lower portion of the unit; and a northern group, around fossil locality 43, that is interpreted to form a small syncline and represent the upper part of the member. Both groups are separated from exposures of the Jemtland Formation in the river by inferred northwesterly and northeasterly trending faults.

Castle Hill Area. The stratigraphically lowest exposures of the member are two rubbly outcrops along

Figure 16: Geologic map of the Castle Hill area showing the plunge of the Castle Hill Anticline and the type area of the sandstone-slate member.



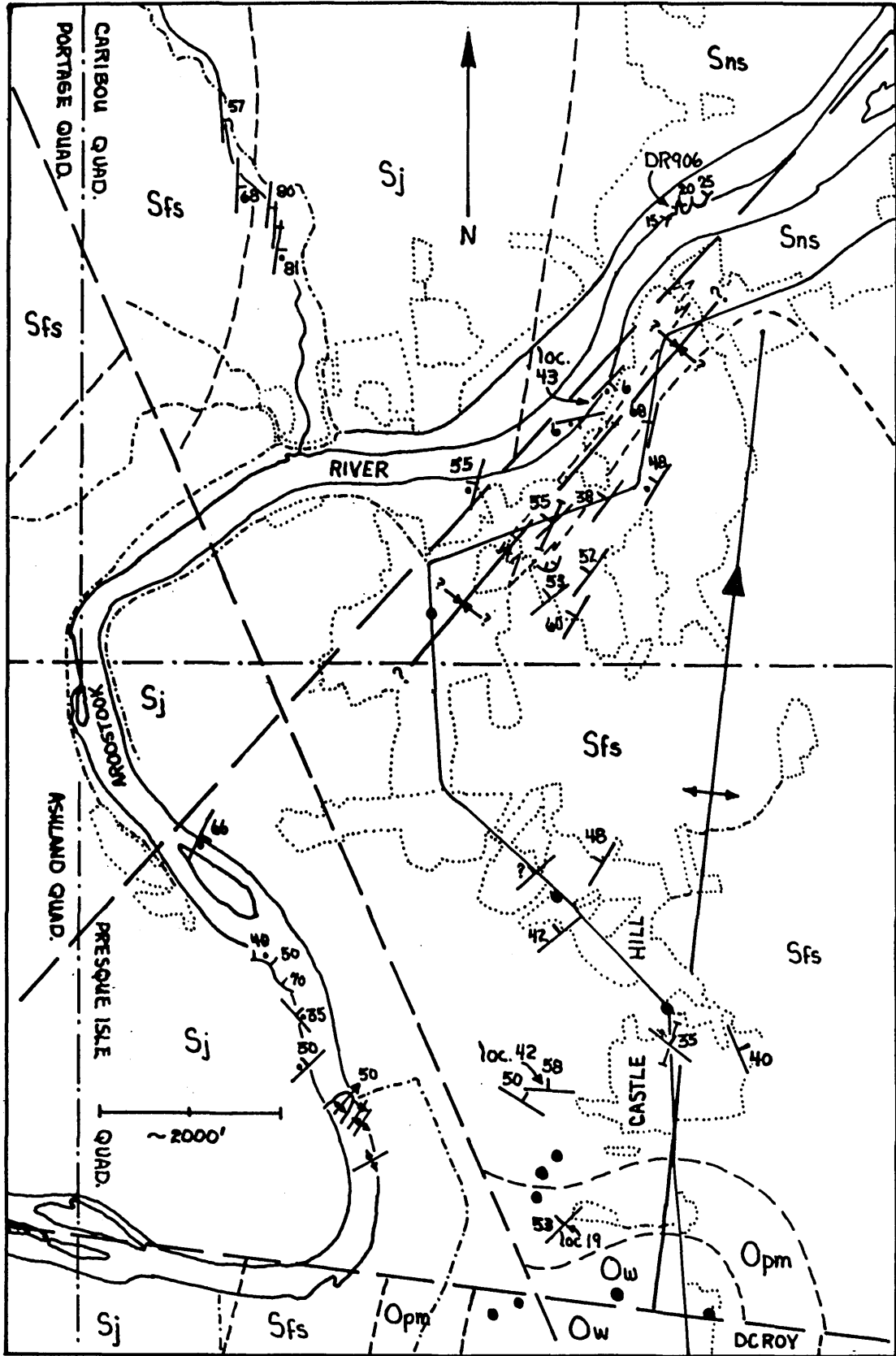


FIGURE: 16  
152

the top of the precipitous west face of Castle Hill just south of fossil locality 42. These consist of medium-grained, laminated and nonlaminated, gray lithic graywacke. The nature of the stratification and presence of inter-layered pelitic rocks is obscured by the rubbly and slumped character of the exposures.

Higher in the section, an interlayered sequence of gray calcareous slate, calcareous, laminated and cross-laminated siltstone, and calcareous lithic graywacke is present. The lithic graywacke occurs in beds from 2 inches to several feet thick; grading, from medium-grained at the base to fine-grained and laminated at the top, is common in the thinner beds. The entire sequence, including the graywacke beds, shows a fracture cleavage.

At fossil locality 42 there is cleaved, medium-grained, calcareous, pebbly, lithic graywacke with lenses or thin beds of fossiliferous limestone. The lithic graywacke contains irregular masses of pebbly, coarse lithic sandstone. Pebble conglomerate is interbedded with the lithic graywacke at the exposure just southwest of locality 42; the lithic fragment suite present in this conglomerate is the same as that observed in similar rocks of the conglomerate member.

In summary, the lower part of the member in the area shown in Figure 16 is inferred to consist primarily of a

fracture-cleaved sequence of calcareous lithic graywacke and lesser gray calcareous slate, pebble conglomerate, and pebbly graywacke. These highly calcareous and cleaved lithic graywackes are present only in the Frenchville section exposed at Castle Hill; they are overlain and underlain by much less calcareous and more massive lithic graywackes of similar composition.

Dark gray feldspathic arenites and graywackes are exposed north of locality 42 along the road and in adjacent fields (Figure 16). Texturally these rocks are very uniform, but a mottled dark gray and light green-gray appearance is common.

Section at Locality 43. The upper part of the sandstone-slate member is represented by the group of exposures along, and just southeast of, the Aroostook River in Figure 16. Fossil locality 43 presents the most extensive section (Figure 17) and illustrates many of the features considered typical of the member. Beds of gray, medium and fine lithic graywacke are interlayered with gray slate and aphanitic limestone.

The lithic graywacke beds are macroscopically unstructured or have structures which may be classified using the system established by Bouma (1962). Graded bedding (decrease of maximum grain size) is a common feature in these beds with multiple grading present in two of the thicker beds (beds 2 and 16). Gradual transition

Figure 17: Stratigraphic section exposed at fossil locality 43. This section was described graphically following a procedure proposed by Walker (1967).

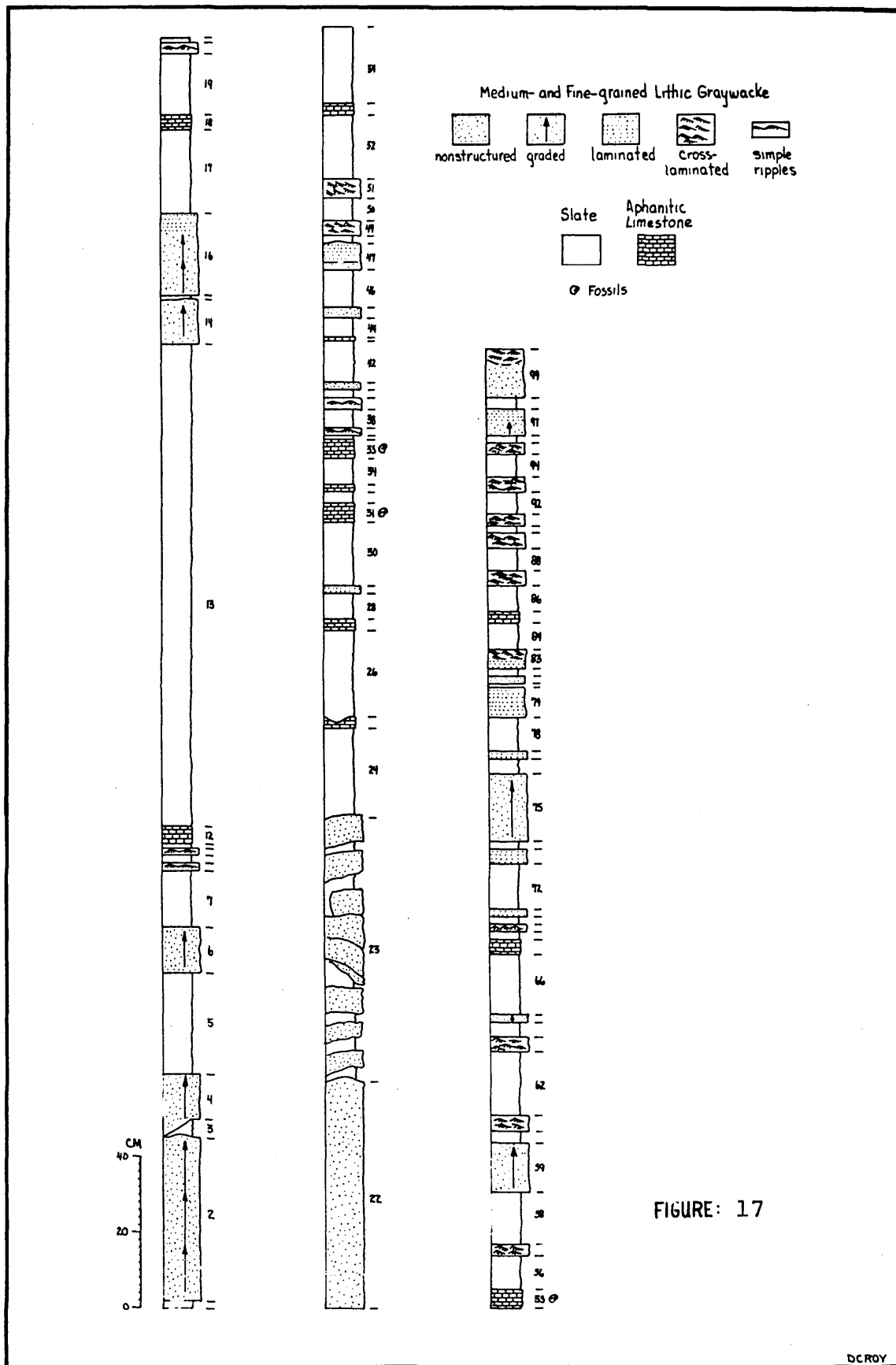


FIGURE: 17

from unstructured or graded lower parts (A interval) to intervals of parallel-laminated fine sandstone (B interval) is present in many of the beds; an abrupt change is present in bed 47. Complexly rippled fine sandstone (C interval) occurs as individual beds or as upper parts of beds containing other structural intervals; thin beds of fine sandstone consisting of simple ripples occur sparsely in the section. Sharp lower and upper contacts are characteristic of all sandstone beds observed.

Sandstone beds 14-22 are shown in Figure 18. The upper surface of bed 22 has an asymmetrical ripple morphology with amplitude of 6 inches (14 cm) and wavelength of about 38 inches (95 cm); pelite fragments occur locally along the bed at a level corresponding approximately to the base of the ripples. Internal foreset bedding within the large-scale ripples is not well displayed. The overlying slate and sandstone beds of interval 23 parallel the stoss slope and are parallel or truncated at the crests and along the foreslope of the ripples. Truncation of the overlying beds appears to be in part due to vertical intrusion of sandstone at the crests of the ripples.

Interval 23 contains beds of sandstone and slate which are discontinuous and deformed. The disruption of this interval may be due to slumping and differential compaction around the large ripples of bed 22.

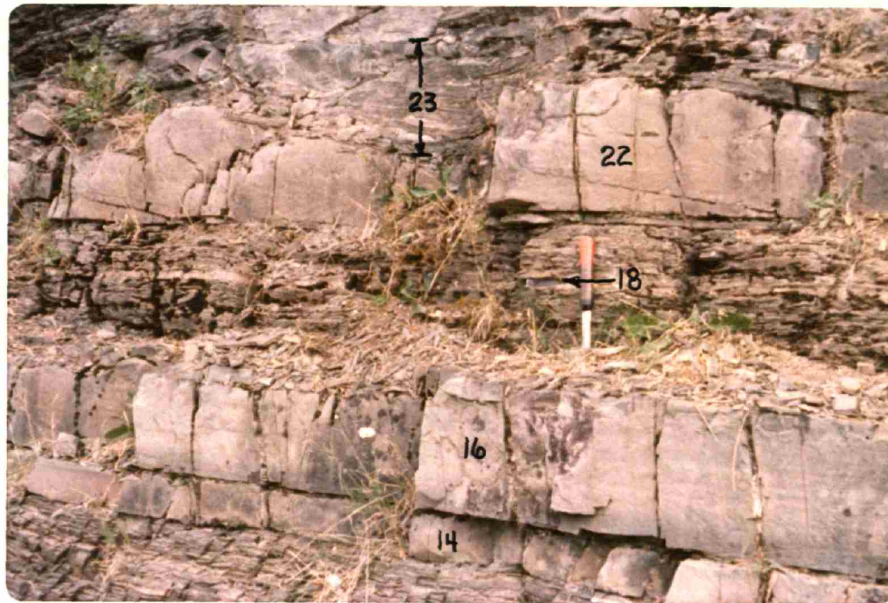


Figure 18: Beds 14 through 22 and interval 23 of the section at locality 43. Note the large-scale "ripple" morphology of bed 22 and the persistent orange-weathering limestone bed (bed 18).

Gray, orange-weathering aphanitic limestone in thin persistent and discontinuous beds forms an important minor rock type. Microfossils (conodonts and brachiopods), useful in dating the sequence, have been recovered from beds 31, 35, and 55. The discontinuous beds consist of nodular and lenticular segments along a given horizon within the section, whereas the persistent beds may be traced continuously across the face of the exposure.

The slate is green-gray in color and brittle. Though generally noncalcareous, some intervals are slightly calcareous and contain siltstone laminae with high carbonate content.

Story Hill Area. Along lumbering roads between Story Hill and Gardner Brook, west of Washburn, the sandstone-slate member is exposed at a number of small outcrops (Figure 19). There the member lies between the Madawaska Lake and Jemtland formations.

Green-gray to light-olive-green slate is interlayered with thin- to medium-bedded, commonly graded, lithic and feldspathic graywackes to form most of the exposed section. Light green, calcareous, finely cleaved slate with 0.75-inch to 6-inch (2 to 15 cm) beds of light gray, calcareous, laminated and cross-laminated siltstone occurs locally in the sequence but appears to be a minor phase.

Orange-weathering, light-gray, fine and medium feldspathic graywacke similar to that observed in the



Figure 19: Geologic map of the Story Hill area. Geologic symbols are shown in Plate II. Dotted lines outline cleared areas; dot-dash lines indicate farm or lumbering roads. Circles show trace of a conglomerate layer in the Jemtland Formation.

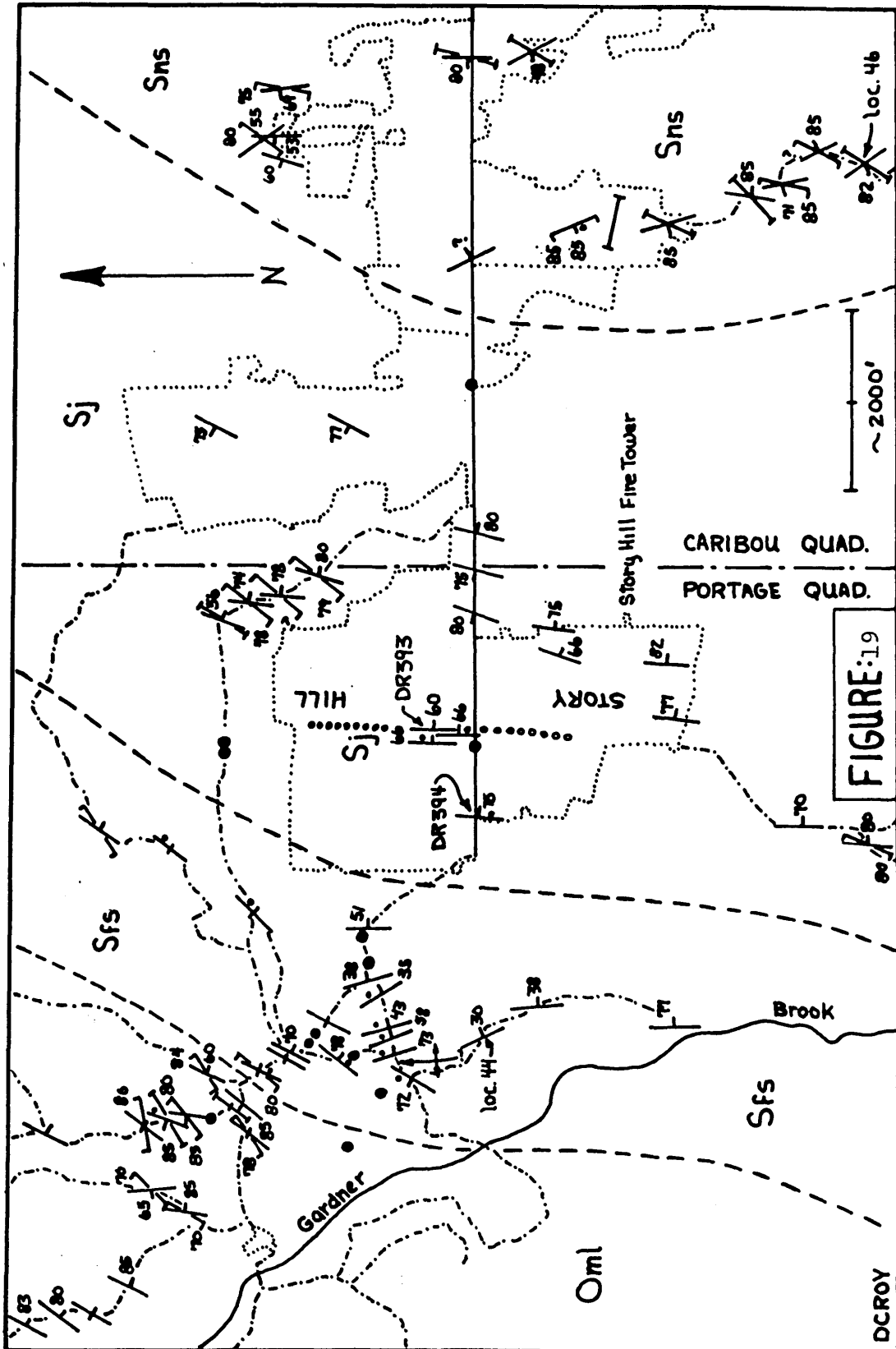


FIGURE 19

feldspathic sandstone member at fossil locality 35 (Figure 14) is present in the sequence west of Story Hill on the northwest flank of the small anticline just north of locality 44 (Figure 19). This sandstone occurs in thin beds separated by shale seams; grading is present in some of the beds.

Sandstone Composition. Modal analyses of a variety of sandstones from the member are presented in Table 10. Compositionally the sandstones are highly variable and include rocks comparable to those in both the conglomerate and feldspathic sandstone members, as shown by the principal component diagrams of Figure 20. It is thus not possible to distinguish the member on the basis of sandstone composition; this difficulty is compatible with the interpretation of the sandstone-slate member as the lateral equivalent of both the conglomerate and feldspathic sandstone members.

The distinctive features of the member are the relatively high abundance of slate and virtual absence of conglomerate. The slate phase is not always present in small outcrops of the member, but the assignment of such outcrops to the member can be made on the basis of stratigraphic relations to nearby slate-bearing exposures.

#### Lithology of the Quartzose Sandstone Member

In the Stockholm-Jemtland area, on both flanks of the Stockholm Mountain Syncline, the Frenchville is composed

Component	Analysis Number			
	39	40	41	42
Quartz	4.4	35.2	19.8	12.8
Plagioclase Feldspar	25.8	15.3	44.0	25.1
Potassium Feldspar	--	0.2	2.2	--
Detrital Mica	--	0.2	0.2	--
Pyroxene	--	0.6	0.4	0.4
Sphene (?)	--	--	--	--
Argillaceous Matrix	30.8	21.6	9.8	11.0
Secondary Carbonate	13.0	0.2	6.2	10.2
Opaque	3.8	--	Tr	0.2
Micrographic Qtz-Feld	--	12.7	8.6	2.6
Fine-grained Mafic Rocks	8.6	3.0	4.4	25.5
Fine-grained Felsic Rocks	8.8	3.0	--	8.6
Chert and "Cherty" Rocks	2.8	5.6	0.6	2.0
Sericitic Fragments	--	--	--	--
Pelite Fragments	0.2	1.6	--	--
Sandstone	--	--	--	--
Detrital Carbonate	--	--	--	--
Fossil Fragments	--	--	--	--
Misc.	--	--	--	--
Unidentified	1.8	0.8	3.8	1.6
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	0.8	7.7	16.2	1.4
Composite Feld-Qtz	1.6	2.8	8.2	0.6
Composite Feldspar	2.4	0.4	13.2	--
Composite Quartz	0.6	4.8	2.4	1.2
<b>Calculated Parameters</b>				
A	8.7	46.0	24.9	16.8
B	51.0	20.2	58.0	32.7
C	40.3	33.8	17.1	50.5
D	7.1	36.0	4.5	14.9
E	43.1	16.0	31.2	31.9
F	49.8	48.0	64.3	53.1
G	12.5	42.9	6.6	21.9
H	16.7	36.6	84.3	8.8
I	70.8	20.5	9.1	69.2

TABLE 10

Modal Analyses of Sandstones from the  
Sandstone-Slate Member of the Frenchville Formation

## Analysis Number

Component	43	44	45	46
Quartz	20.3	31.0	35.6	24.2
Plagioclase Feldspar	39.5	12.5	21.4	46.2
Potassium Feldspar	--	2.4	18.0	Tr
Detrital Mica	1.0	Tr	0.6	Tr
Pyroxene	--	--	Tr	0.2
Sphene (?)	--	--	--	--
Argillaceous Matrix	9.4	8.6	14.6	16.8
Secondary Carbonate	3.6	3.0	--	0.6
Opaque	6.4	1.7	1.2	1.4
Micrographic Qtz-Feld	4.8	6.0	5.0	8.8
Fine-grained Mafic Rocks	9.2	9.5	0.8	0.4
Fine-grained Felsic Rocks	3.2	4.8	0.8	--
Chert and "Cherty" Rocks	1.2	17.9	2.0	--
Sericitic Fragments	--	--	--	--
Pelite Fragments	--	0.7	--	--
Sandstone	--	--	--	--
Detrital Carbonate	0.2	Tr	--	--
Fossil Fragments	--	--	--	--
Misc.	--	--	--	--
Unidentified	1.2	1.9	--	1.4
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	4.8	4.1	8.2	11.6
Composite Feld-Qtz	3.2	4.1	9.4	18.8
Composite Feldspar	2.8	1.7	5.6	9.2
Composite Quartz	1.8	NC	3.2	2.0
<b>Calculated Parameters</b>				
A	25.9	36.6	42.6	30.4
B	50.4	17.6	47.1	58.0
C	23.7	45.8	10.3	11.6
D	19.7	31.8	32.8	15.8
E	42.8	10.7	29.2	22.9
F	37.5	57.5	38.0	61.3
G	34.5	35.6	46.3	20.5
H	34.7	21.0	47.6	78.8
I	30.7	43.4	6.1	0.7

TABLE 10 (Cont)

Component	Analysis Number			
	47	48	49	50
Quartz	40.5	11.2	9.4	20.6
Plagioclase Feldspar	21.7	20.8	33.2	38.2
Potassium Feldspar	--	--	--	--
Detrital Mica	Tr	--	0.4	0.6
Pyroxene	0.2	--	0.2	0.6
Sphene (?)	--	--	--	--
Argillaceous Matrix	4.9	8.4	20.4	15.4
Secondary Carbonate	7.9	15.0	1.0	0.4
Opaque	Tr	0.6	Tr	Tr
Micrographic Qtz-Feld	1.4	4.8	6.2	19.4
Fine-grained Mafic Rocks	8.7	26.2	22.2	2.2
Fine-grained Felsic Rocks	0.2	3.2	3.8	0.6
Chert and "Cherty" Rocks	9.5	2.6	2.0	1.2
Sericitic Fragments	--	--	--	--
Pelite Fragments	2.2	2.2	0.2	--
Sandstone	--	--	--	--
Detrital Carbonate	0.4	3.6	--	--
Fossil Fragments	--	0.2	--	--
Misc.	--	--	--	--
Unidentified	2.4	1.2	1.0	0.8
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	2.7	1.2	2.0	3.6
Composite Feld-Qtz	2.7	1.0	2.8	5.2
Composite Feldspar	1.2	2.2	4.0	2.6
Composite Quartz	5.9	1.0	1.0	0.4
<b>Calculated Parameters</b>				
A	47.9	15.0	12.2	25.1
B	25.7	27.9	43.1	46.5
C	26.5	57.1	44.7	28.5
D	44.7	13.4	9.6	20.7
E	21.0	23.6	34.3	37.0
F	34.3	63.0	56.1	42.3
G	56.6	17.5	14.6	32.8
H	12.0	16.1	29.6	59.5
I	31.4	66.3	55.7	7.7

TABLE 10 (Cont)

Component	Analysis Number			
	51	52	$\bar{X}$	$\sigma$
Quartz	22.8	14.6	21.6	10.8
Plagioclase Feldspar	30.8	50.2	30.4	11.9
Potassium Feldspar	--	--	1.6	4.8
Detrital Mica	0.4	--	0.2	0.3
Pyroxene	--	0.2	0.2	0.2
Sphene (?)	--	--	--	--
Argillaceous Matrix	12.0	14.8	14.2	6.7
Secondary Carbonate	--	--	4.4	5.2
Opaque	0.2	0.4	1.2	1.8
Micrographic Qtz-Feld	28.0	6.2	8.2	7.5
Fine-grained Mafic Rocks	3.0	0.4	8.9	9.2
Fine-grained Felsic Rocks	1.4	10.8	3.5	3.6
Chert and "Cherty" Rocks	0.6	0.8	3.5	4.8
Sericitic Fragments	--	--	--	--
Pelite Fragments	0.2	--	0.5	0.8
Sandstone	--	--	--	--
Detrital Carbonate	--	--	0.3	1.0
Fossil Fragments	--	--	--	0.1
Misc.	--	--	--	--
Unidentified	0.6	0.4	1.3	1.0
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	
Composite Qtz-Feld	4.8	5.4	5.3	4.4
Composite Feld-Qtz	4.8	6.4	5.1	4.7
Composite Feldspar	2.0	12.0	4.2	4.2
Composite Quartz	1.0	1.6	1.9	1.7
<b>Calculated Parameters</b>				
A	26.3	17.6	27.6	
B	35.5	60.5	40.7	
C	38.2	21.9	31.8	
D	20.7	11.1	20.8	
E	27.6	38.3	28.8	
F	51.6	50.6	50.4	
G	28.7	18.0	29.2	
H	63.1	58.6	40.9	
I	8.3	23.4	29.9	

TABLE 10 (Cont)

Figure 20: Triangular composition diagrams for the sandstone-slate and quartzose sandstone members of the Frenchville Formation. Components included at each pole of the diagrams are shown in Table 1. The ABC diagram is used to determine rock names used in the text.



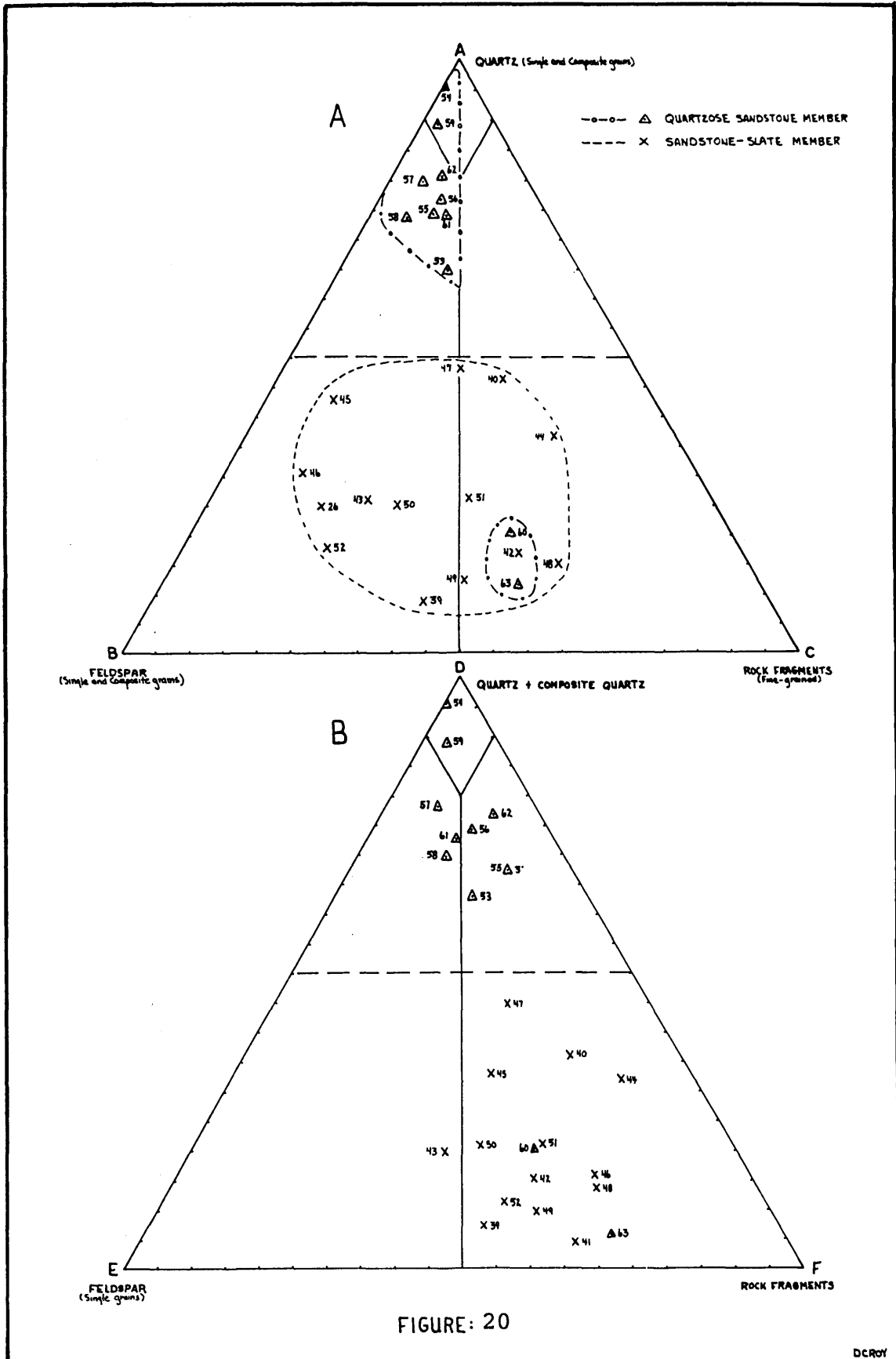


FIGURE: 20

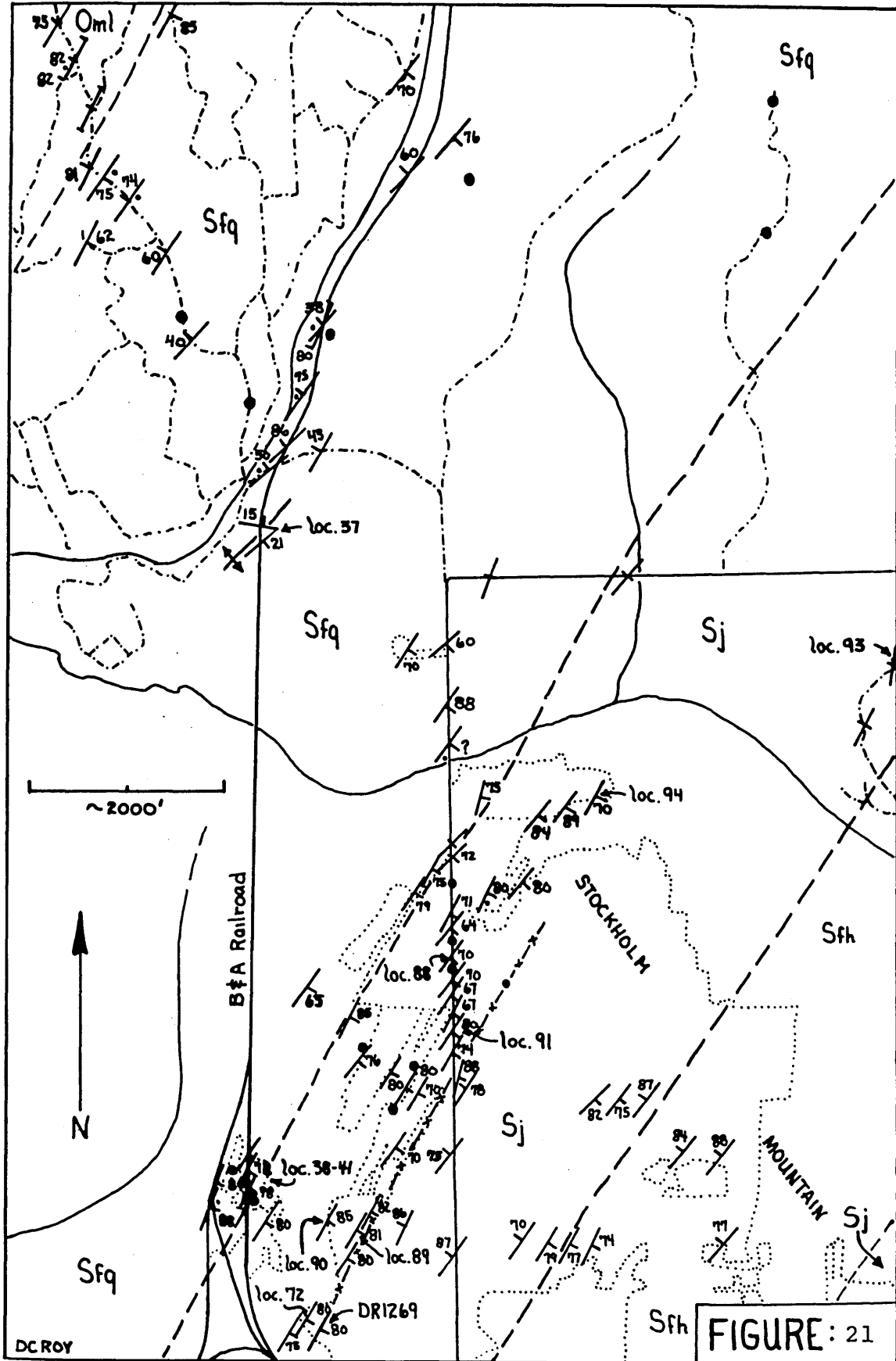
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of quartz arenite, quartzose feldspathic arenite and graywacke, and lithic graywacke interbedded with varying amounts of slate and minor conglomerate. The presence of abundant quartz-rich sandstone is the distinctive feature of the unit; no sandstone with quartz content in excess of 50 percent has been observed in the other Frenchville members except analyses 21 from the conglomerate member (Table 8). Lithic graywacke, compositionally and texturally similar to that present in the conglomerate member, is approximately equal in abundance to the quartz-rich varieties. Slate, though only locally well represented in outcrop, is probably an important rock type in the section.

Though inferred to form an extensive portion of the Frenchville terrane from the vicinity of Fogelin Hill northeastward to Martins Siding, the member is only locally well exposed. The largest area of exposure is along the west flank of the Stockholm Mountain Syncline just north of the village of Stockholm (Figure 21). There, the lower contact with the Madawaska Lake Formation and the upper contact with the Jemtland are well defined, and the variety of rock types composing the member may be observed. A second area of good exposure is the east side of Fogelin Hill on the east flank of the syncline.

Stockholm Area. Fossil locality 37, a railroad cut along the Bangor and Aroostook Railroad mainline north of

Figure 21: Geologic map of the Stockholm area. Geologic symbols are given in Plate II. Dotted lines outline cleared areas; dot-dash lines are farm or lumbering roads. Dash-x line shows the trace of an aquagene tuff sequence in the Jemtland Formation.

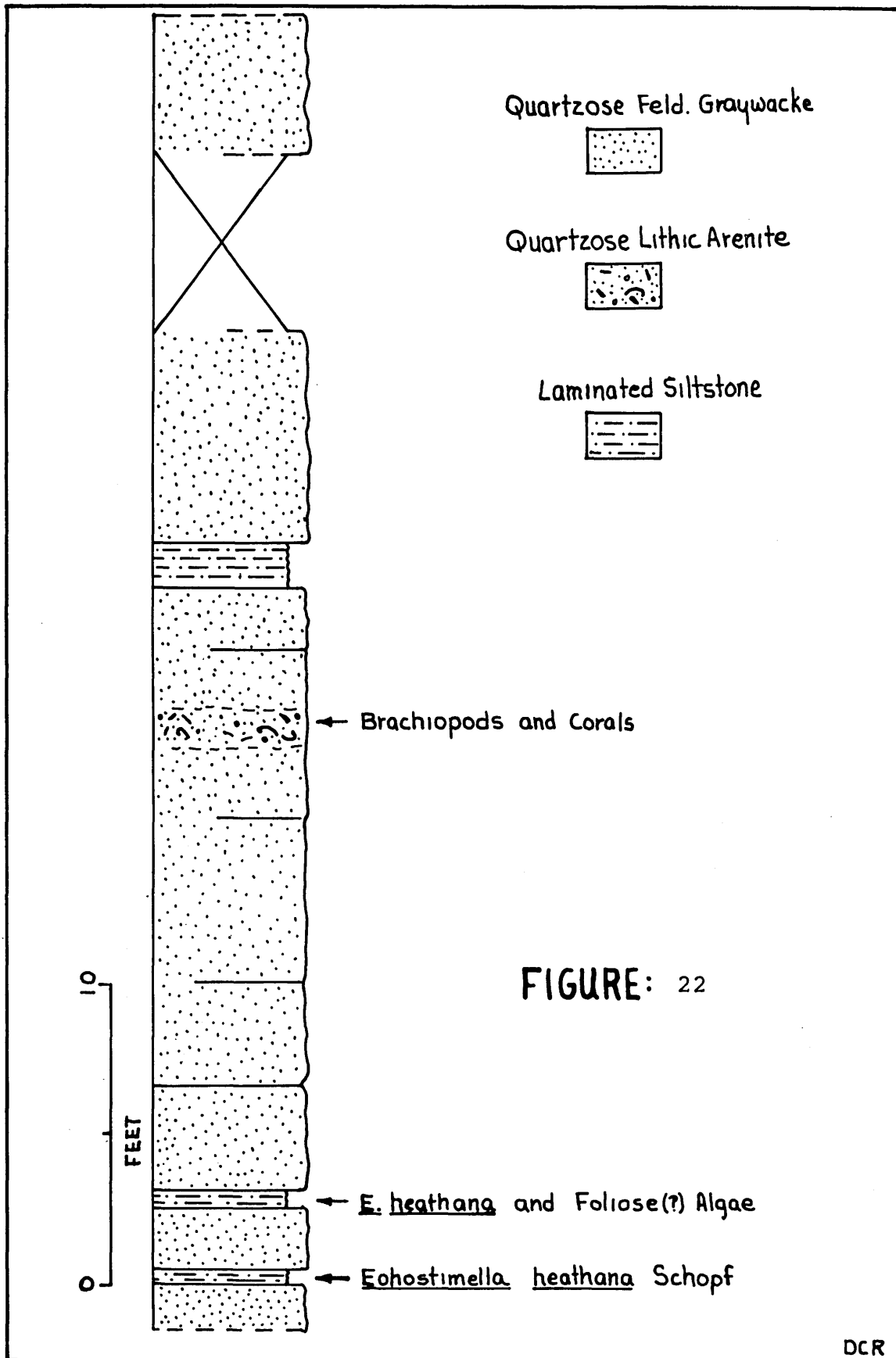


Stockholm, provides the best exposure (approximately 40 feet or 12 meters of section) of the member (Figure 22). The exposed beds are in a low anticlinal flexure. Most of the section consists of light-gray and green-gray, medium-grained, medium- and thick-bedded, quartzose feldspathic graywacke and less quartzose lithic arenite. Two thin beds and one medium bed (poorly exposed) of laminated green, siltstone and silty shale are interlayered with the sandstones. The sandstones are texturally uniform: no lamination or other internal structuring has been observed.

North of locality 37, along the railroad tracks and in parallel lumber roads, are several exposures in which dark-gray and olive-green slate is interlayered with medium and fine quartzose sandstone. Less medium-grained lithic graywacke is present at some exposures.

Outcrops in the vicinity of fossil localities 38-41 represent the uppermost portion of Frenchville Formation and transitional beds into the overlying Jemtland. The stratigraphically lowest beds exposed are interlayered quartzose feldspathic and lithic graywackes of medium and coarse grain size. Immediately overlying these beds is the almost continuous section of localities 38-41, which consists of gray, brown-weathering, calcareous, laminated, silty shale interlayered with lesser light-gray, calcareous, pebbly, medium sandstone. The platy character of some of the shale, the abundant carbonate content, and the brown to orange weathering colors are

Figure 22: Generalized stratigraphic section at fossil locality 37.



suggestive of transition into the lithofacies of the Jemtland Formation. Placement of the Frenchville-Jemtland contact in this area is somewhat arbitrary; however, the strata exposed at the fossil localities are placed in the Frenchville, since they do not display the thin interbedding of distinctive rock types that characterizes the Jemtland Formation.

Fogelin Hill Area. On the southeastern slope of Fogelin Hill and on a small hill to the southeast, the quartzose sandstone member is relatively well exposed (Figure 23). At DR 1220, near the Frenchville-Jemtland contact, a sequence of thin- to thick-bedded, gray, calcareous, lithic sandstone with thin interbeds of fine sandstone and shale is present. The lithic sandstones are commonly graded, with basal coarse intervals containing chert, pelite, and volcanic rock fragments. One seven-foot (2.1-m) sandstone bed with multiple grading, and an 18-inch (46-cm) bed of fine-pebble conglomerate are present.

Along West Road and in adjacent fields to the south of DR 1220, medium-grained, medium- to thick-bedded quartz arenite, and quartzose feldspathic arenite and graywacke with lesser pebble conglomerate is well exposed. The quartzose sandstones are quite similar to those at



Figure 23: Geologic map of the Fogelin Hill area.

Geologic symbols are given in Plate II. Dotted lines outline cleared areas; dot-dash lines are lumbering or farm roads.

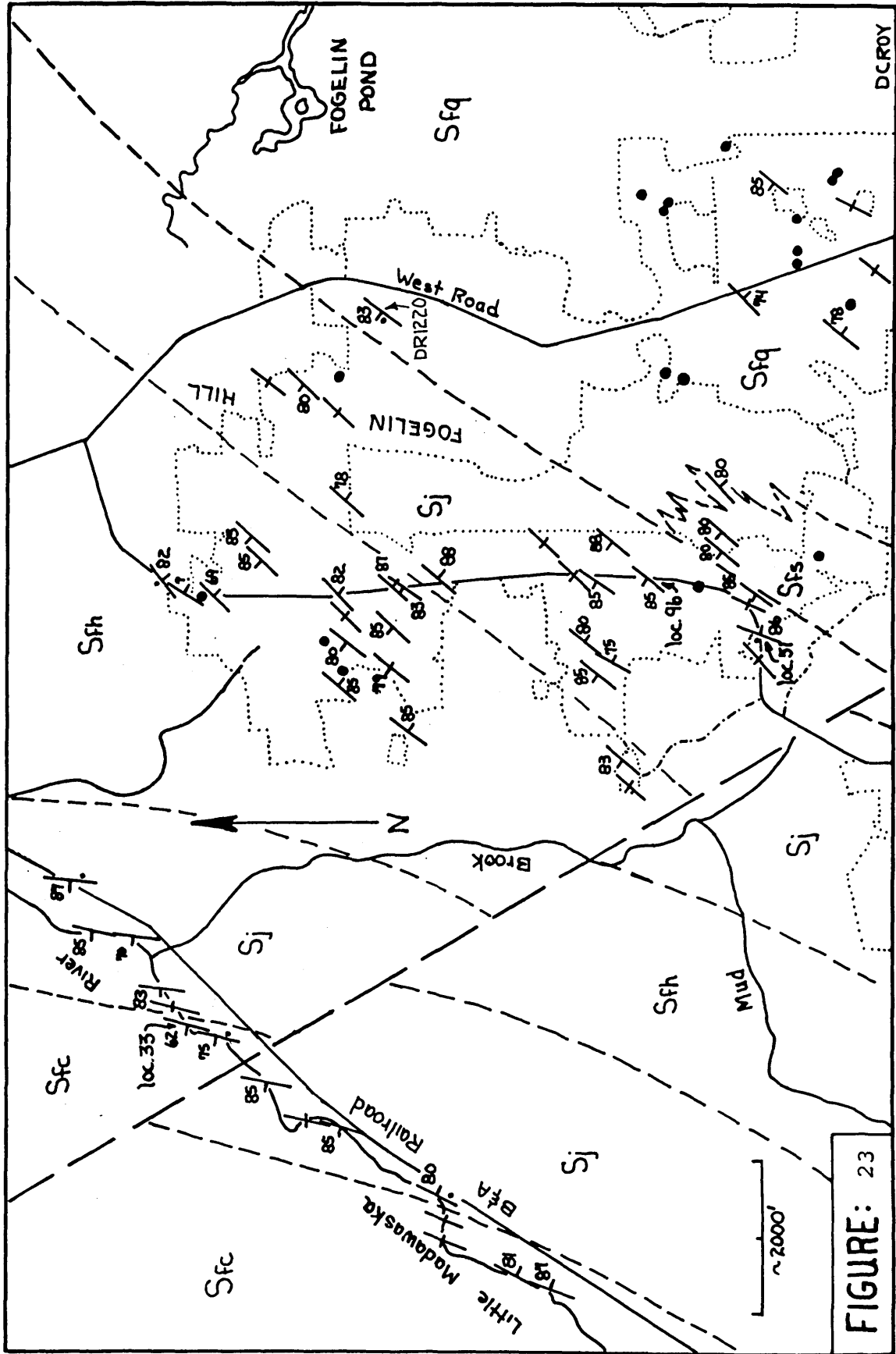


FIGURE: 23

fossil locality 37 north of Stockholm. The pebble conglomerate contains abundant granophyre fragments as well as the chert-pelite-volcanic assemblage.

Sandstone Composition. Modal analyses of sandstones from the member are given in Table 11. The abundance of quartz and the low concentrations of fine-grained rock fragments and composite grains are typical features. Interlayered low-quartz sandstone (lithic graywacke) is represented by analyses 60 and 63. In hand specimen or outcrop, the quartz-rich sandstones that have low argillaceous matrix content (arenites) are typically light gray in color, whereas those richer in matrix have a distinct green tinge and are darker gray.

The quartz grains of these sandstones are almost all well rounded, and secondary overgrowths are common. Randomly oriented lamellar quartz is abundant in some samples. The feldspar grains are commonly angular to subrounded.

A modal analysis of a fine pebble conglomerate interbedded with the quartz-rich sandstones southeast of Fogelin Hill is given in Table 7 (analysis 29). Comparison of this mode with those from the conglomerate member shows that a higher proportion of quartz, feldspar, and composite grains is present in the Fogelin Hill sample.

The triangular diagrams of Figure 20 indicate the presence of at least two compositional populations in the

Component	Analysis Number				
	53	54	55	56	57
Quartz	49.6	91.0	54.0	67.8	61.0
Plagioclase Feldspar	14.6	4.2	12.2	12.7	11.8
Potassium Feldspar	0.2	--	--	--	--
Detrital Mica	Tr	--	--	0.6	0.2
Pyroxene	--	--	Tr	--	0.2
Sphene (?)	--	--	--	--	--
Argillaceous Matrix	15.6	4.0	25.2	9.3	22.0
Secondary Carbonate	7.2	--	--	0.2	--
Opaque	0.2	0.6	0.2	0.4	0.8
Micrographic Qtz-Feld	0.8	--	1.0	1.7	0.4
Fine-grained Mafic Rocks	2.2	--	5.4	4.4	2.4
Fine-grained Felsic Rocks	6.4	0.2	0.2	1.1	0.8
Chert and "Cherty" Rocks	1.8	Tr	0.2	0.9	0.2
Sericitic Fragments	--	--	--	--	--
Pelite Fragments	1.2	--	--	--	--
Sandstone	--	--	--	--	--
Detrital Carbonate	--	--	--	--	--
Fossil Fragments	--	--	--	--	--
Misc.	--	--	--	--	--
Unidentified	0.2	--	1.6	0.9	0.2
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	1.4	--	5.0	2.1	1.4
Composite Feld-Qtz	0.8	0.2	3.6	1.9	0.6
Composite Feldspar	1.0	--	1.7	0.9	0.2
Composite Quartz	3.0	0.4	7.2	1.9	2.4
<b>Calculated Parameters</b>					
A	64.6	95.4	74.0	76.5	79.6
B	19.3	4.4	16.7	14.3	15.4
C	16.1	0.2	9.3	9.1	5.0
D	62.8	95.4	67.1	74.2	77.8
E	16.9	4.2	9.5	11.2	14.4
F	20.3	0.4	23.4	14.7	7.8
G	75.5	99.6	74.1	83.5	90.9
H	6.3	0.2	17.1	8.4	4.0
I	18.2	0.2	8.8	8.1	5.2

TABLE 11

Modal Analyses of Sandstones from the Quartzose Sandstone Member of the Frenchville Formation

Component	Analysis Number				
	58	59	60	61	62
Quartz	60.6	82.0	14.6	61.6	69.3
Plagioclase Feldspar	17.2	7.8	23.2	12.4	10.2
Potassium Feldspar	Tr	--	--	--	0.2
Detrital Mica	Tr	0.2	0.8	0.6	Tr
Pyroxene	0.2	--	--	0.6	0.4
Sphene (?)	1.6	--	--	--	--
Argillaceous Matrix	14.2	6.8	25.6	12.6	12.2
Secondary Carbonate	0.2	0.8	0.2	1.4	0.6
Opaque	0.2	0.2	0.6	0.2	0.8
Micrographic Qtz-Feld	--	0.2	15.8	0.8	0.6
Fine-grained Mafic Rocks	2.2	1.0	16.2	1.4	0.2
Fine-grained Felsic Rocks	2.2	--	0.8	5.4	0.2
Chert and "Cherty" Rocks	Tr	0.4	1.0	0.8	0.2
Sericitic Fragments	--	--	--	--	--
Pelite Fragments	--	--	0.4	1.0	3.5
Sandstone	--	0.6	Tr	--	1.6
Detrital Carbonate	0.4	--	--	--	Tr
Fossil Fragments	--	--	--	--	--
Misc.	--	--	--	--	--
Unidentified	1.0	--	0.8	1.2	--
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	3.2	0.4	0.2	1.0	3.4
Composite Feld-Qtz	2.6	0.8	0.8	0.8	3.5
Composite Feldspar	0.4	0.2	1.2	0.6	1.0
Composite Quartz	5.6	4.4	0.6	1.4	12.6
<b>Calculated Parameters</b>					
A	73.4	89.1	20.3	73.9	80.6
B	20.8	8.5	32.2	14.9	12.1
C	5.8	2.4	47.5	11.3	7.3
D	69.5	88.7	20.0	72.7	76.6
E	17.2	7.4	29.4	13.2	6.9
F	13.3	3.9	50.6	14.1	16.5
G	83.9	95.8	28.3	83.7	82.3
H	9.1	1.9	35.4	4.4	10.6
I	7.0	2.3	36.2	11.9	7.1

TABLE 11 (Cont)

Component	Analysis Number		
	63	$\bar{X}$	$\sigma$
Quartz	7.5	56.4	25.3
Plagioclase Feldspar	23.5	13.6	5.9
Potassium Feldspar	--	--	0.1
Detrital Mica	--	0.2	0.3
Pyroxene	--	0.1	0.2
Sphene (?)	--	0.1	0.5
Argillaceous Matrix	24.9	15.7	7.7
Secondary Carbonate	6.7	1.6	2.7
Opaque	0.6	0.4	0.3
Micrographic Qtz-Feld	4.0	2.3	4.6
Fine-grained Mafic Rocks	12.9	4.4	5.3
Fine-grained Felsic Rocks	13.1	2.8	4.1
Chert and "Cherty" Rocks	4.6	0.9	1.3
Sericitic Fragments	--	--	--
Pelite Fragments	0.4	0.6	1.1
Sandstone	--	0.2	0.5
Detrital Carbonate	Tr	--	0.1
Fossil Fragments	--	--	--
Misc.	--	--	--
Unidentified	1.8	0.7	0.7
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	
Composite Qtz-Feld	3.8	2.0	1.6
Composite Feld-Qtz	3.0	1.7	1.3
Composite Feldspar	3.6	1.0	1.0
Composite Quartz	--	3.6	3.7
<b>Calculated Parameters</b>			
A	11.4	69.4	
B	35.5	16.8	
C	53.1	13.8	
D	5.6	67.0	
E	25.5	13.4	
F	68.9	19.6	
G	7.5	77.4	
H	29.3	10.0	
I	63.1	12.7	

TABLE 11 (Cont)

sandstones of the member. One population contains more than 70 percent quartz as a principal detrital constituent, whereas the second population has less than 50 percent quartz.

The field of the second population (represented by two analyses) lies within the field established for the sandstone-slate member. It is possible that more analyses of quartz-poor sandstones from the member would broaden the quartz-poor field, making it more or less coincident with that of the sandstone-slate member.

#### Lower Contact

The Frenchville Formation overlies the Winterville, Madawaska Lake, and Aroostook River formations in addition to the Pyle Mountain Argillite (Castle Hill area) as established by Boucot, et al. (1964a). Though it has been extensively mapped in the area of this study, the basal contact is rarely exposed. It has been observed, however, at three localities, where angular (two cases) and conformable (one case) relations can be demonstrated. In a few areas the contact can be closely located, but the nature of the interface is not well known.

The Frenchville overlies the Aroostook River Formation conformably; an unconformity is inferred to exist between the Frenchville and the other three older units for the following reasons:

- (1) The basal contact of the conglomerate member of the Frenchville with the underlying Winterville and

Madawaska Lake formations was observed at two exposures. Angular relations exist at both localities.

(2) There is a general absence of demonstrable pre-Late Llandoveryan Frenchville strata. The seventeen fossil localities in the formation, from every subunit except the graywacke member, indicate ages of Late Llandoveryan or younger. The graywacke member may be somewhat older than Late Llandovery, but no direct paleontologic evidence is available.

(3) The pre-Frenchville units are in large part Ashgillian or older. It is possible that lower Llandoveryan strata are present in the Madawaska Lake Formation, but again no direct paleontologic evidence exists and the possibility is based on stratigraphic arguments in the Van Buren area.

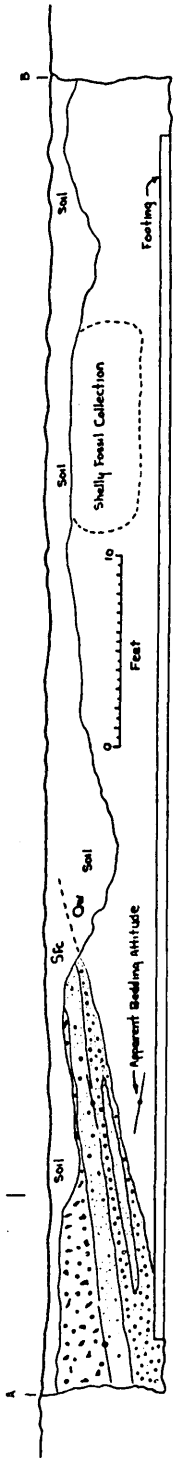
(4) There is an abrupt change in type of sedimentation across the contact, particularly where the conglomerate member of the Frenchville is present.

Angular Unconformities. In the village of Ashland at fossil locality 1, the contact between the Frenchville Formation and the underlying Winterville Formation was exposed in the basement excavation for a house. The location, excavation geology, and local geologic setting for the exposure (now covered) are given in Figure 24.

The Winterville Formation, below the contact, consists of olive-green pebbly argillite, gray to black altered



Figure 24: A geologic map and cross-sections of the angular unconformity between the Winterville and Frenchville formations at fossil locality 1, in Ashland. The contact is no longer exposed.



East Wall of the Excavation

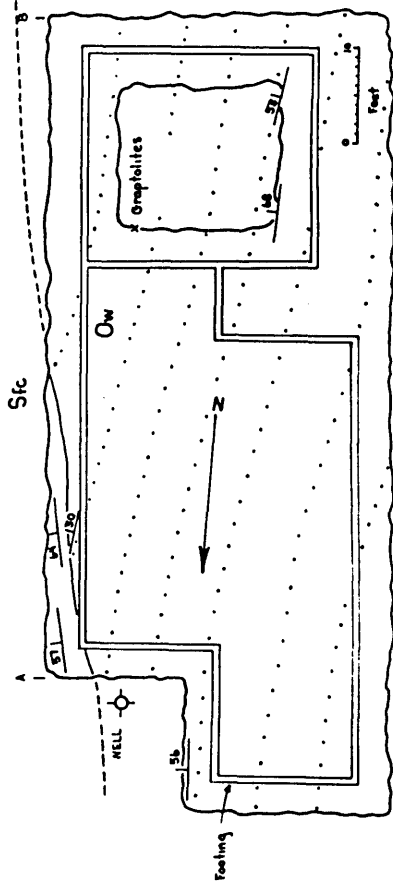
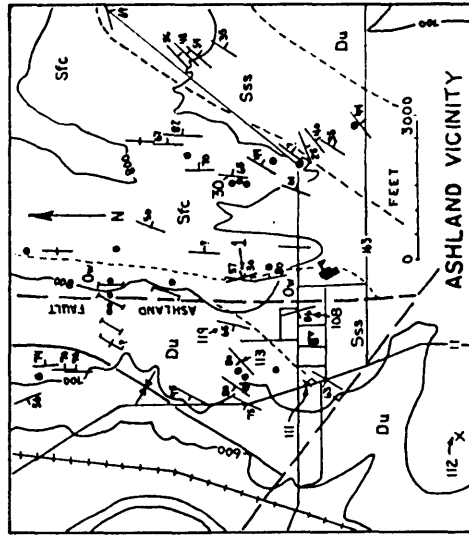
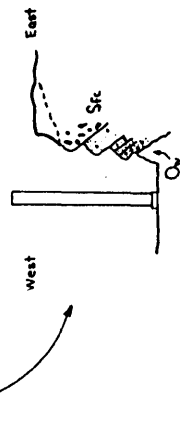


FIGURE : 24

slate, and minor thin-bedded black chert. In the east wall of the excavation, three beds of the Frenchville were observed above the contact:

Bed 1 (lowest): Gray, poorly sorted, brown-weathering, pebbly, coarse lithic graywacke. Modal analysis of this sandstone is given as analysis 15 of Table 8. Pebbles of chert, olive-green pelite, quartz, mafic and felsic volcanic rocks, and detrital carbonate are common. Pelite fragments are unusually abundant, both as angular pebbles and sand-sized fragments. Bed 1 varies from almost zero thickness to 2 feet (60 cm) thick and contains a quasilenticular bed of medium-grained lithic graywacke.

Bed 2: Medium- to coarse-grained lithic graywacke. Pebbles, though present, are less abundant than in Bed 1. Bed 2 varies from 8 to 10 inches (20 to 25 cm) in thickness.

Bed 3 (highest): Rusty-brown-weathering pebble conglomerate. Angular pebbles of olive-green and black pelite dominate, with chert, volcanic, carbonate, and quartz fragments forming lesser proportions.

To the east of the excavation are glacially polished pavement exposures of thick-bedded sharpstone pebble conglomerate and less interbedded lithic graywacke. These conglomerate exposures (still visible) are typical of the conglomerate member, except for the conspicuous

abundance of pelite (olive green, gray, and black) and limestone fragments.

The interface between the Frenchville and Winterville formations is sharp and, so far as could be observed, planar. A thin (less than 1 inch or 2.5 cm) interval of broken pelite debris is discontinuously present between Bed 1 and the underlying argillite and slate. These pelite fragments are very similar to the underlying argillaceous strata in both "fresh" and weathered appearance. Rounded and subrounded pebbles of chert and volcanic rocks are mixed with the pelitic fragments but are rare.

As shown in Figure 24, the attitude of the Winterville strata is both subparallel and discordant to the beds of the Frenchville. The maximum angularity observed at the contact is 24 degrees in strike and 37 degrees in dip. No indication of relative motion of the overlying and underlying rocks was observed.

The contact exposed at locality 1 is interpreted to be an angular unconformity. "Unfolding" the Frenchville strata produces a pre-Frenchville attitude of N31W 37N for the Winterville beds with maximum discordance. The unexposed extensions of this contact to the north and south are inferred to represent this same unconformity. The basal contact of the Frenchville east and northeast

of Ashland (but south of the Alder Brook Fault) is similarly interpreted.

On the west flank of the Stockholm Syncline south of Madawaska Lake the contact between the Frenchville and slates of the Madawaska Lake Formation has been observed. An excavation made by the writer at DR 1309 on the south side of the major lumber road from Blackstone Siding (Figure 25) revealed a discordant contact between the slate and pebbly graywacke. Approximately 5 feet (1.5 m) of the contact was made visible (Figure 26).

The exposed lower surface of the pebbly sandstone is not plane; it consists of asymmetric "ridges" and "troughs" which are casts of irregularities in the surface onto which the sand was deposited. The center "ridge" had a bulbous termination which fell off during excavation. This bulbous termination, coupled with the morphology of the ridges themselves, suggests that the features are large, asymmetrical flute casts. The left-hand (lowest) "ridge" shown in Figure 26 is the least asymmetrical, and diminishes in height and broadens slightly before it disappears.

The flute molds were scoured into the slate substratum; the cohesiveness of the slate was sufficient to allow the undercutting represented by the pronounced curl of the steep face of the flute casts (Figure 26). More pronounced curling was observed on the bulbous termination

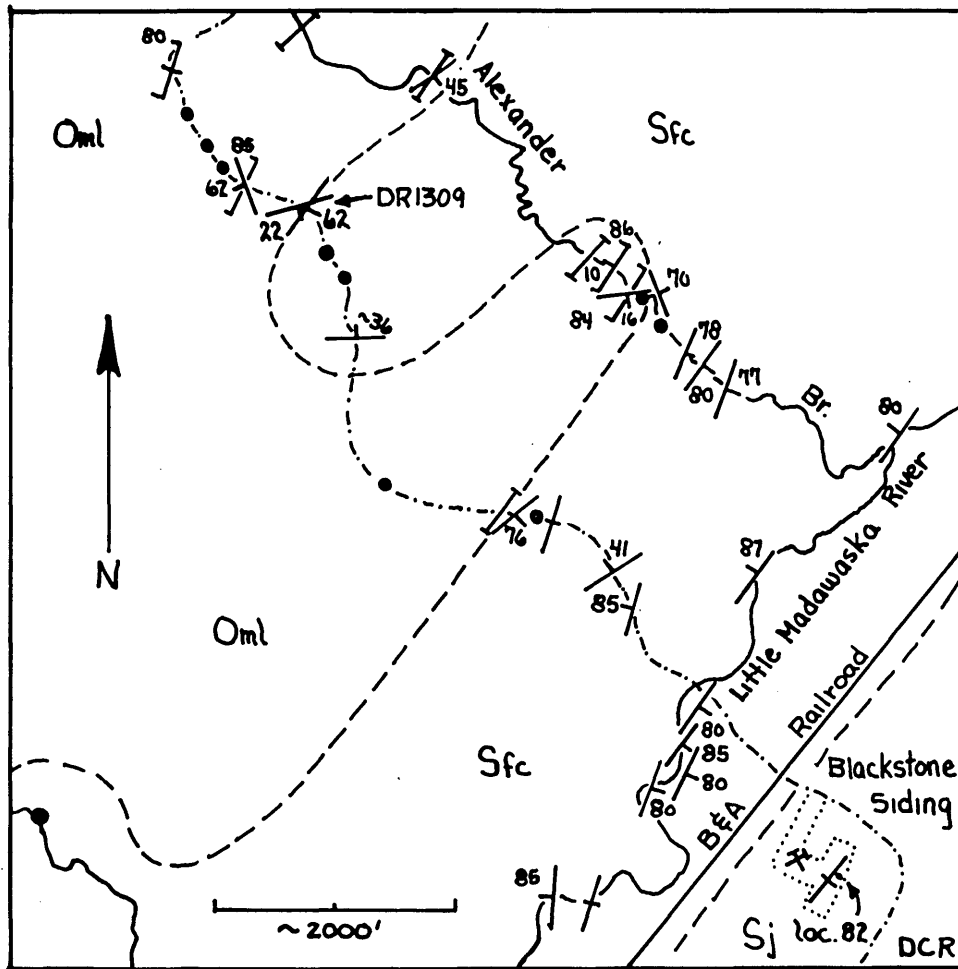


Figure 25: Geologic map of the Blackstone Siding area. Geologic symbols are given in Plate II. Dotted lines outline a quarry; dot-dash lines are lumbering roads. An angular unconformity between the Frenchville and Madawaska Lake formations is exposed at DR1309.

Figure 26: Angular unconformity between the Frenchville and Madawaska Lake formations near Blackstone Siding (DR 1309). The plane surfaces in the underlying slate that dip toward the water represent the bedding of the Madawaska Lake; the near water-line on the bedding surfaces provides a convenient strike reference. The hammer rests on the overlying Frenchville sandstone bed, the under surface of which forms three "ridges" discussed in the text. Note the general parallelism of the "shallow" slope of the central ridge and the bedding in the slate. Hammer is 12.8 inches (31.8 cm) long.

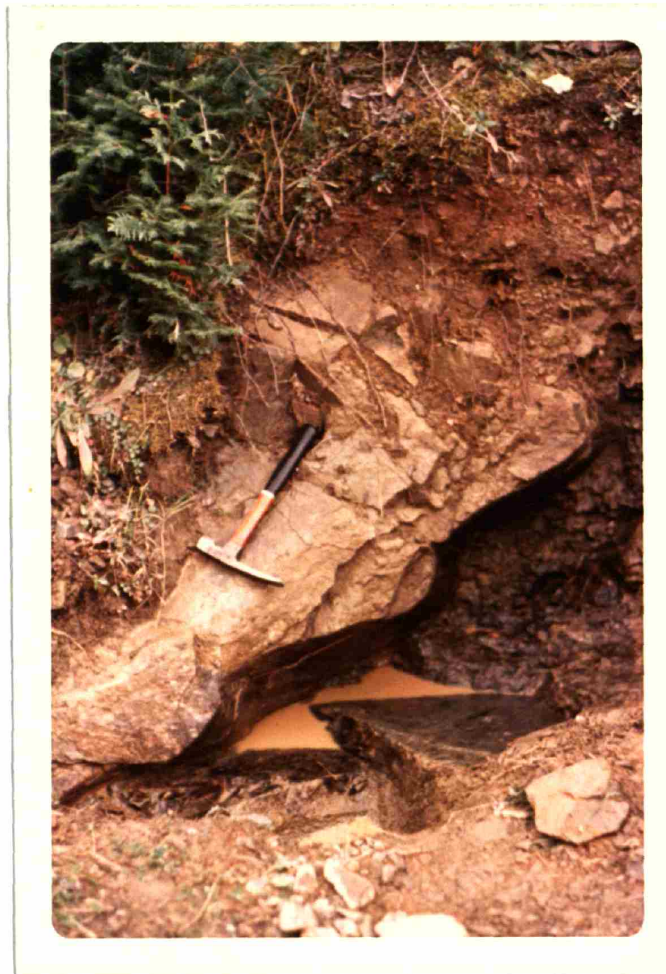


Figure: 26



which would represent undercutting at the "beak" end of the flute cast.

A lineation which crosses the trend of the flute casts at a small angle is also present on the sole of the sandstone bed (Figure 27). This lineation is produced by 1-2 mm "steps" on the surface which are interpreted to be impressions left by the upturned and differentially eroded bedding of the slate. The bedding attitude of the Frenchville sandstone (basal surface) and Madawaska Lake slate, plunge of the lineation, and plunge of the flute casts are depicted on a stereographic net (lower hemisphere) in Figure 28A. The plunge of the lineation is shown to be close to the plunge of bedding intersection; the difference is within the uncertainties of the measurements on the irregular sole of the sandstone bed. The plunges of the flute casts are also subparallel to the bedding intersection.

Simple unfolding of the Frenchville beds produces the pre-Frenchville attitude of the Ordovician slates (referred to the present north-south line) and indicates the bedding, lineation, and flute-mold relations on the erosional surface (Figure 28B). The general parallelism of the gentle slope of the flute cast to the bedding planes in the slate (see Figure 26), suggests that the scouring of the slate surface may have been at least partially controlled by its internal layering.



Figure 27: Close-view of the under surface of the basal Frenchville sandstone showing the lineations referred to in the text. Slate bedding surface in the lower right corner of the picture intersects the sole of the sandstone bed along a line parallel to the lineation.

Figure 28: A. Lower-hemisphere stereographic presentation of the present Frenchville and Madawaska Lake bedding attitudes, lineation plunge, and flute cast plunge at the unconformity shown in Figures 26 and 27. Parallelism or subparallelism of the trends of the bedding intersection, lineation, and flute casts is suggested.

B. A stereographic presentation of the pre-Frenchville relationships of the Madawaska Lake bedding, lineation, and flute molds (casts) referenced to present north.

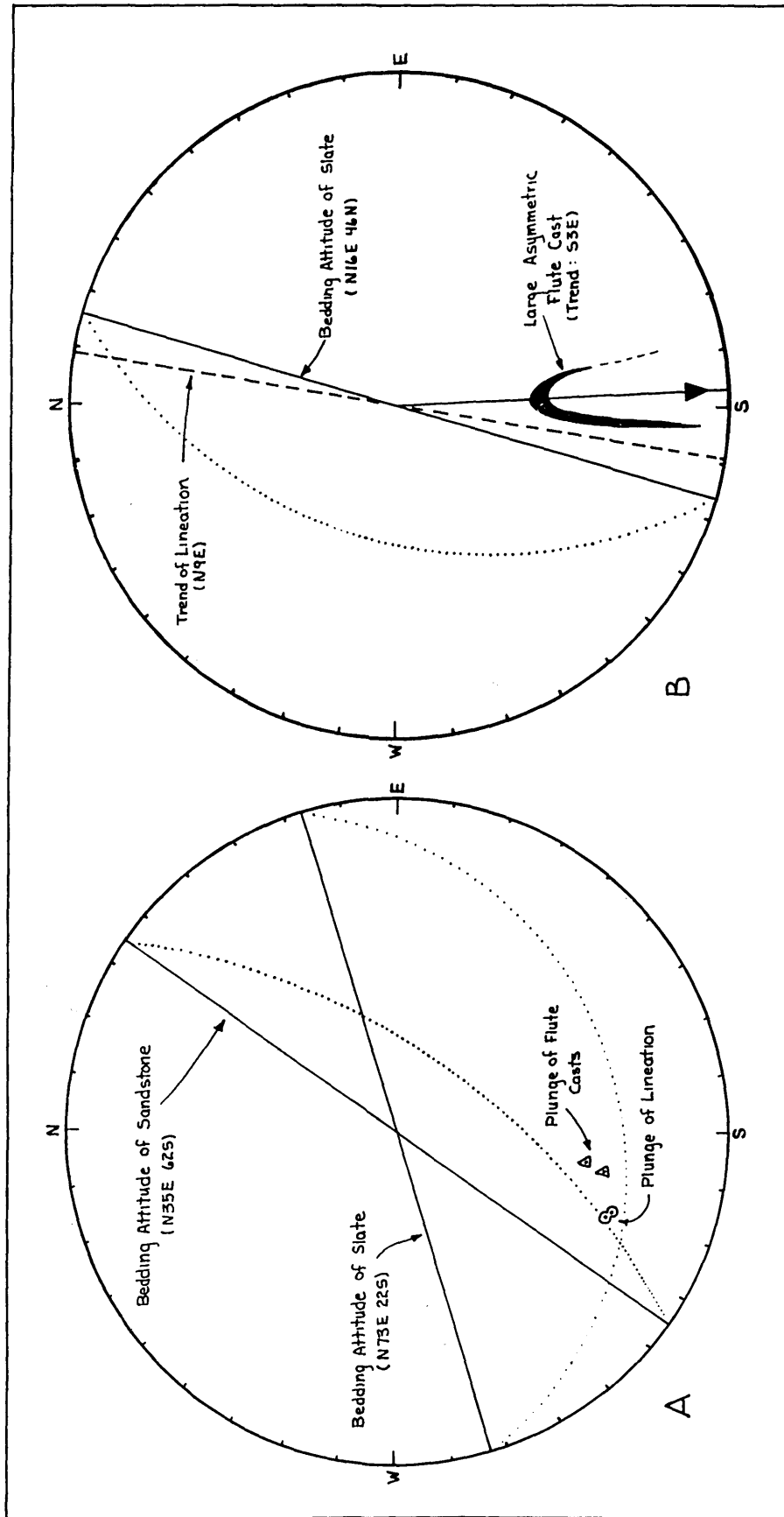


FIGURE: 28

Within the area shown in Figure 25, the basal contact is closely approached at two other places. Along Alexander Brook just east of DR 1309, green and red slate underlie the sandstones of the Frenchville, and the structural data suggest an angular relationship. Along the lumber road just west of the Little Madawaska River, olive-green slates are separated by approximately 120 feet (37.6 m) of cover from thick-bedded pebble conglomerates of the Frenchville.

Disconformities or Angular Unconformities. The basal contact of the Frenchville in areas where the sandstone-slate and quartzose sandstone members are present has not been observed but is closely located in three areas:

(1) For the Castle Hill Area (Figure 16), Boucot, et al. (1964a) suggested an unconformable, possibly disconformable, relation between the Frenchville and Pyle Mountain. Although the writer has modified the distribution of the Frenchville in the plunge of the Castle Hill Anticline and obtained more structural control, the exact nature of the contact continues to be uncertain.

(2) West of Story Hill (Figure 19), strata on both sides of the Madawaska Lake-Frenchville (sandstone-slate member) contact are parallel in strike; the dips are steep and vary about vertical. A disconformity is a strong possibility in this area.

(3) North of Stockholm (Figure 21), parallelism in strike and steep dips also characterize the Madawaska Lake and Frenchville (quartzose sandstone member) beds on opposite sides of the contact, and a disconformity is again quite possible.

Conformity. The Frenchville rests conformably on older strata only where it is underlain by the Aroostook River Formation. In the anticline north of Ashland (Figure 9) the contact is exposed at fossil locality 25 and DR 798 (see discussion of the Aroostook River Formation). There, the graywacke member is in gradational contact with the Aroostook River and is in turn overlain by the conglomerate member.

#### Thickness

Structural complexity and lack of precise contact location in many areas prohibits precise determinations of formational thicknesses. The following discussion is based on estimates from numerous cross-sectional profiles, a few of which are presented in Plate III. These profiles do not represent completely independent estimates of thicknesses since thickness assumptions are required in areas of poor structural control. The thickness values presented for the Frenchville (and other units) are those that best fit all the available structural and stratigraphic evidence in each area.

In the Ashland area (south of the Alder Brook Fault) only the conglomerate member is present. In the vicinity of locality 31 the member has a minimum thickness of zero (?) feet but thickens northward to possibly as much as 1500-2000 feet (457-609 m). Approximately 2650 feet (807 m) of the member is present, in Ashland, between the unconformable basal contact at locality 1 and the overlying unnamed sandstone and slate unit.

The thickness of the Frenchville section overlying the Aroostook River Formation at DR 795 (Figure 9) may be subdivided as follows:

Graywacke Member	500 feet	(153 m)
Conglomerate Member	700 feet	(214 m)
Feldspathic Sandstone Member	2250 feet	(686 m)
Total	3450 feet	(1053 m)

In the northern part of the Ashland quadrangle (section C-C' of Plate II) a total formational thickness of about 3750 feet (1144 m) is present which consists of:

Graywacke Member	500 feet	(153 m)
Conglomerate Member	2250 feet	(686 m)
Feldspathic Sandstone Member	1000 feet	(305 m)

These figures suggest a thickening of the conglomerate member and a thinning of the overlying feldspathic sandstone member as the units are traced northward from the vicinity of locality 35 (Figure 9). The graywacke member is present only along the anticline west of

of Frenchville; it does not occur between the conglomerate member and the Madawaska Lake Formation on the flanks of the small anticline northeast of Frenchville (Figure 4). The graywacke member is therefore inferred to wedge out eastward from its occurrence along, and west of, the Aroostook River (Section C-C', Plate III).

On the west flank of the Stockholm Mountain Syncline, the conglomerate and quartzose sandstone members are both between 3000 and 3500 feet (914-1070 m) thick. The conglomerate member apparently thins to approximately 1500 feet (457 m) southwest of where the basal contact crosses the Little Madawaska River (Figure 4), but structural definition in this area is poor.

East of the Stockholm Mountain Syncline the thickness of the Frenchville is difficult to estimate, since the base of the formation is generally not exposed. In the Story Hill area (Figure 19) a minimum of about 2500 feet (761 m) of the sandstone-slate member is present between the Madawaska Lake and Jemtland formations; however, the presence of internal folding, possible faulting, and uncertainties in the location of the upper contact suggest that this figure could be as much as 1000-2000 feet (305-610 m) too low. In the Castle Hill Area as much as 7000 feet (2119 m) of Frenchville is suggested, but the thickness of the formation in the plunge area of the Castle Hill Anticline is probably exaggerated because of structural thickening during folding and the



presence of unrecognized faults.

In summary, the Frenchville over most of the area has an aggregate thickness of between 3000 and 4000 feet (914 to 1220 m). In the Ashland area and along portions of the western limb of the Stockholm Syncline, much thinner sections are present; in these areas the conglomerate member is the only subunit present. The conglomerate and feldspathic sandstone members are quite variable in thickness within the northern part of the Ashland quadrangle.

#### Age

Seventeen fossil localities have been found in four of the five Frenchville members. The paleontologic data from these localities are given in Table 12. Collectively these data indicate a possible age span of Late Llandoveryian ( $C_1$ ) to Early Ludlovian for the Frenchville. Regional stratigraphic relationships (see Figure 5) with the overlying Jemtland Formation and the unnamed sandstone and slate unit (Ashland area) suggest that the youngest age is Wenlockian (probably Early Wenlockian). Since the graywacke member is stratigraphically between units of Late Llandoveryian and Ashgillian-or-Early Llandoveryian ages, it is possible that it represents a local middle or lower Llandoveryian phase of the Frenchville.

Conglomerate Member. Fossil locality 34 is from approximately 500 feet (153 m) above the base of the

Table 12: Fossil localities from the Frenchville Formation. All graptolites identified by W. B. N. Berry; all brachiopods, corals, gastropods, and trilobites identified by A. J. Boucot; conodonts from locality 33 identified by C. Rexroad; conodonts from locality 43 identified by G. Klapper; Artriotreta identified by R. B. Neuman; Plants identified by J. M. Schopf. Data for localities 35 and 36 from Boucot, et al. (1964a). The following ages are assigned to the collections: localities 28, 35, and 36, C<sub>4</sub> - C<sub>5</sub> of the Llandoveryan; localities 32, 40, and 42, Late Llandoveryan; localities 30 and 38, C<sub>3</sub> of the Llandoveryan-Wenlockian; locality 29, pre-Wenlockian, probably C<sub>4</sub> - C<sub>5</sub> of the Llandoveryan; locality 41, Late Llandoveryan (zones 22-25); locality 44, C<sub>3</sub> - C<sub>5</sub> of the Llandoveryan; localities 34 and 43, cellóni Zone (conodont) or approximately C<sub>2</sub> - C<sub>4</sub> of the Llandoveryan; locality 33, C<sub>5</sub> of the Llandoveryan-Earliest Wenlockian; locality 37, C<sub>4</sub> of the Llandoveryan-Early Wenlockian; locality 39, Late Llandoveryan-Ludlovian; locality 31, Wenlockian-Ludlovian. Fossil localities are grouped by members: conglomerate member (Sfc), feldspathic sandstone member (Sff), quartzose sandstone member (Sfq), and sandstone-slate member (Sfs).



conglomerate member where that member overlies the Madawaska Lake Formation north of the village of Frenchville (Plate I). Conodonts from this exposure indicate an age range of  $C_2 - C_4$  of the Llandoveryan, and the beds represent the lowest stratigraphic horizon thus far dated within the Frenchville north of the Alder Brook Fault. Higher above the basal contact (with the Winterville) and just south of the Alder Brook Fault are two pebbly mudstone localities in the member which yielded  $C_4 - C_5$  faunas (localities 38 and 29). Locality 30 near Ashland and about 1500 feet (457 m) above the unconformity at locality 1 (Figure 24) has produced fauna indicative of a  $C_3$  - Earliest Wenlockian age.

At locality 31, east of Ashland and a few tens of feet above the basal contact, a Wenlockian-Ludlovian assemblage was obtained, thus establishing the presence of post-Llandoveryan strata in the conglomerate member. The conglomerate at locality 31 is near an inferred wedge-out of the member and is interpreted to represent post-Llandoveryan southward onlap of the facies onto the Winterville source terrane. The possibility of a Ludlovian age for locality 31 is considered remote, since no indication of post-Wenlockian Frenchville is present elsewhere where stratigraphic control is better.

Along the western flank of the Stockholm Mountain Syncline the conglomerate member is of Late Llandoveryan to earliest Wenlockian age as indicated by localities 32 and

33. Locality 33 ( $C_5$  to earliest Wenlockian) is approximately 85 feet (26 m) below the upper contact of the member with the Jemtland (see Figure 23). It is therefore probable that the upper phase of the Frenchville along the western flank is Wenlockian; this is consistent with the data from the Ashland area. The age of the base of the member along its contact with the Madawaska Lake Formation is not well established, and pre-Late Llandoveryian ages are possible.

Feldspathic Sandstone Member. Locality 35 ( $C_4 - C_5$ ) is the only dated exposure in this member. The presence of  $C_4 - C_5$  strata well above the conglomerate member (about 1250 feet, 380 m) suggests that in the type area (Figure 9) the conglomerate member is no younger than Late Llandoveryian ( $C_4 - C_5$ ). The implications of variations in the age of the upper parts of the conglomerate member between Frenchville and the Ashland area to the south will be discussed in a subsequent section.

Sandstone-Slate and Quartzose Sandstone Members. A total of nine fossil localities (36-44) have been found in these two members. They are consistent with an age span of Late Llandoveryian-Early Wenlockian established for the conglomerate and feldspathic sandstone members. Locality 29 (Late Llandoveryian-Ludlovian), in the strata transitional from the Frenchville to the Jemtland Formation (Figure 21), is overlain by Late Llandoveryian-Wenlockian localities (88 and 90) in the Jemtland; these

younger localities preclude the possibility of a Ludlovian age for locality 39 (see Figure 21) for relationships). Near Martin's Siding (northeast Stockholm Quadrangle), slates of the New Sweden Formation containing zone 19 ( $A_4 - B_1$ ) graptolites (locality 47) are interfingered with the quartzose sandstone member (Plate I) near its base, which suggests that the lower Frenchville there is late Early or Middle Llandoveryan in age.

Brachiopod Communities. Ziegler (1965), in a study of Llandoveryan brachiopod faunas of Wales and the Welsh Borderland, found that the fossil assemblages form several characteristic groups or communities. He was able to relate these communities to each other and to show a regular distribution of the communities with respect to the Llandoveryan shoreline. The following five communities, listed in order of increasing distance from shore, were recognized:

- (1) Lingula community (coastal)
- (2) Eocoelia community
- (3) Pentamerus community
- (4) Stricklandia community
- (5) Clorinda community

Ziegler listed the "characteristic" and "associated" species for each community and pointed out that adjacent communities have many common species but separated groups are mutually exclusive. The communities are not strongly

lithofacies-dependent, "but there is a general tendency for communities 1 and 2 to occur in sandstones, communities 3 and 4 in sequences of varying proportions of sandstone and shale beds, and community 5 in shale" (Ziegler, 1965).

Depth of water was shown to be a critical factor in the establishment of a given community; for example, a bed underlying a 20-foot thick pillow basalt contains the Eocoelia community, while the bed overlying the flow has the Lingula community. Shallowing of 20 feet was apparently sufficient to displace the Eocoelia and establish the Lingula community. In a similar fashion, a shallowing of 135 feet was found adequate to displace the Stricklandia community and establish that of Eocoelia.

As shown in Table 13, many of the Frenchville fossil localities containing brachiopods have a mixture of elements from two or more of Ziegler's brachiopod communities. Since most of the fossil collections contain badly broken shell debris and mixtures of brachiopod communities (Boucot, oral communication, 1969), the faunas together with the enclosing detritus must have been transported offshore before deposition. The depth of deposition would be that of the deepest (most offshore) community present, or possibly deeper. Although the mixing of two adjacent communities could conceivably occur as the result of deposition in the transitional zone between the

Formation/Locality	Fossil Community					Remarks
	L	E	P	S	C	
Frenchville						
28	—			X		
29				X		
30	Sfc			X?		
32			X	X		
33				X		
35	Sff	X	X	X		
36		X	X	X		
37	Sfq	X	X?	X		
38			X	X		
42	—			X	X	
44	Sfs	X				
New Sweden						
45		X	X	X		Shells in good condition
46		X?	X	X		Shells in good condition
Spragueville						
106			X?	X	X	Shells in good condition

TABLE 13

Llandoveryan brachiopod communities as defined by Ziegler (1965) that are represented in fossil localities of the Frenchville, New Sweden, and Spragueville formations.

L=Lingula Community; E=Eocoelia Community; P=Pentamerus Community; S=Stricklandia Community; C=Clorinda Community.



communities, the presence of three communities indicates the mechanical mixing of shell material from different depths during sediment transportation down a slope.

Early Silurian Plants. At fossil locality 37 there is an unusual occurrence of Early Silurian plant remains. Small plant axes and foliose (?) algal fragments from the two lower laminated siltstone layers (Figure 22) have been described by Schopf, et al. (1966). The sediment-filled tubular plant axes (1-2 mm in diameter) are assigned to a new genus and species (Eohostimella heathana Schopf) which is interpreted to be a possible "transmigrant form" from which vascular plants may have evolved. Since cross-sectional views of the plant axes were commonly observed on surfaces parallel or subparallel to the bedding lamination, it was suggested that they are the remains of erect plants which may have been preserved in a growth position.

Schopf suggests that the plant axes may represent a land (emergent) form, but the absence of preserved vascular tissue characteristic of primitive Devonian land plants precludes definite assignment to a subaerial growth environment. Additional doubt concerning an emergent environment is caused by the association of the plant-bearing beds with more massive sandstone containing marine shelly fossils. The shelly assemblage contains the Stricklandia community (Table 13), a relatively

offshore group, mixed with the shoreward Eocoelia and Pentamerous (?) communities. Since no record of transgression or regression is present (Figure 22), it is reasonable to infer that the beds containing the plants were formed at least as far offshore as the Stricklandia environment.

If the plants are indeed in growth positions and represent a marine flora, then their presence places some constraints on the water depth.

A minimum light intensity of about one percent of noon sunlight is required for modern marine green plants to grow, and this level of illumination is ordinarily used to define the base of the photic layer (Nielsen, 1963;; Clarke and Denton, 1962). In marine waters free of particulate and dissolved organic matter the base of the photic layer would be about 459 feet (140 m); however, in the most transparent modern ocean water (Sargasso Sea) the lower boundary is nearer 393 feet (120 m) (Nielsen, 1963). These considerations suggest that the depth of water during the deposition of the clastic material at locality 37 was on the order of hundreds of feet (tens of meters), which is in general agreement with the limited depth information available on the brachiopod communities given by Ziegler (1965).

#### NEW SWEDEN FORMATION

##### Name and Distribution

Boucot, et al. (1964a) defined the Perham Formation

as consisting of a lower, largely slate member and an upper, mostly calcareous siltstone and micaceous shale member. Since these members may be mapped over an extensive area outside the Presque Isle quadrangle and represent distinctive lithofacies, it is here proposed that they be elevated to formational rank and together form the Perham Group. The lower member is here named the New Sweden Formation after the community of New Sweden, in the north-central part of the Caribou quadrangle. Rocks assigned to this formation form a belt extending from the town of Mapleton northward through New Sweden to the St. John River Valley near Van Buren. The unit also is present extensively on the west flank of the Stockholm Mountain Syncline along the St. John River Valley in both Maine and New Brunswick (Hamilton-Smith, 1969).

The formation is well exposed in the vicinity of New Sweden and particularly on Capitol and Gelot hills, where red and green slates containing intervals of manganese ironstone are found (Miller, 1947). The principal lithologic features of both the New Sweden and Jemtland formations may be seen in the vicinity of Perham (Figure 29). Just northeast of Perham, near fossil locality 49, there is a partial section through the Perham Group which was cited by Boucot, et al. (1964a, Appendix IV) as the type section for the Perham Formation of their usage.

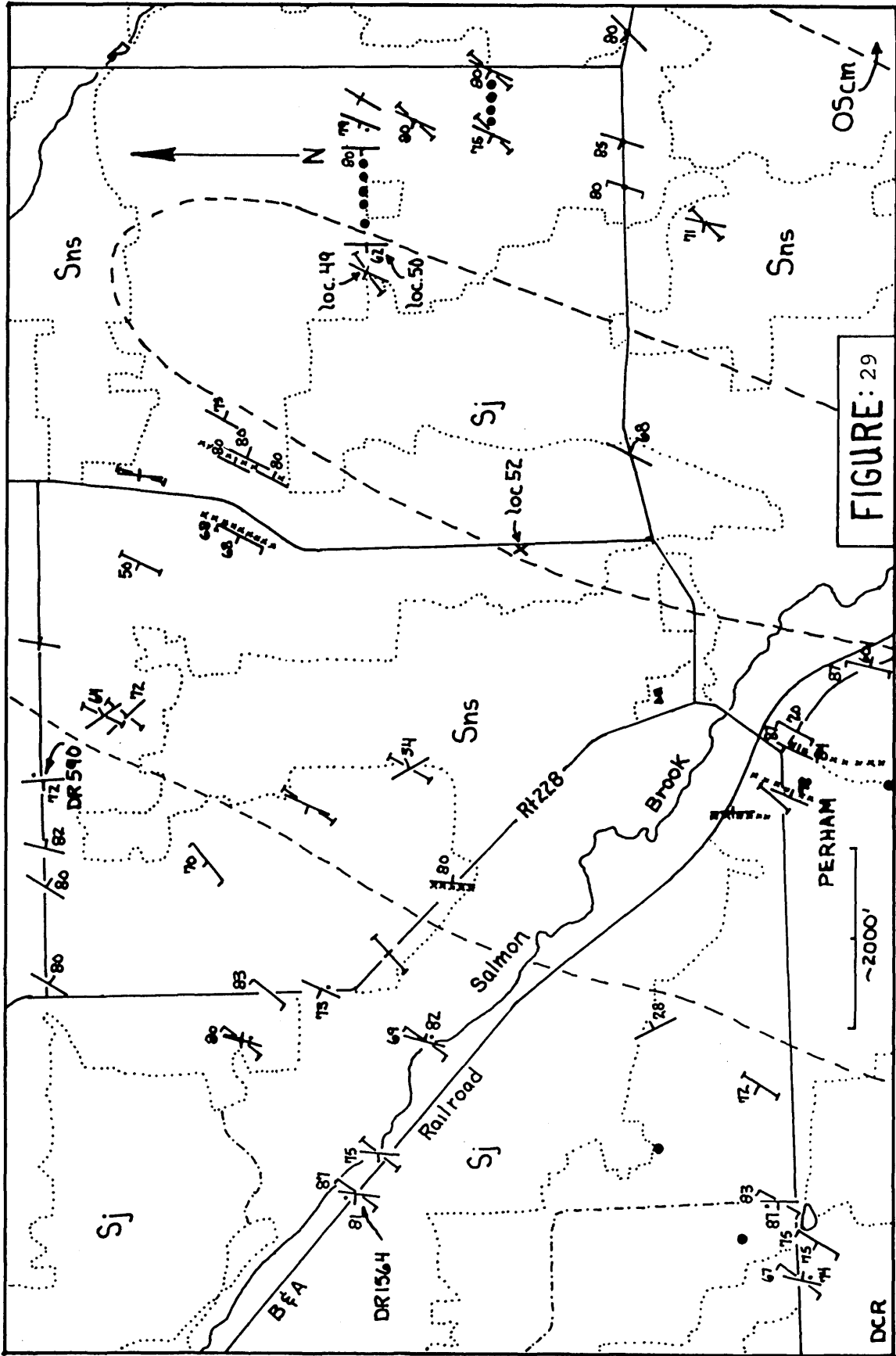
## Lithology

The New Sweden Formation is almost entirely a slate sequence. Locally interlayered with the slate are limestone, fine and medium sandstone, banded manganiferous ironstone, and pebble conglomerate. The slate is altered to hornfels near teschenite and granite intrusives in the Presque Isle quadrangle (Boucot, et al., 1964a).

Slate. Approximately 90 percent of the exposed rocks of the New Sweden is slate. The slate is typically calcareous and phyllitic in appearance. Flow cleavage, approximately parallel to the axial planes of folds, characterizes the phyllitic slates; a silver-gray silky sheen is common on cleavage surfaces. Calcareous siltstone laminæ are usually abundant and may be folded on a small scale.

Red, green, and green-gray slate, generally non-calcareous, is abundant locally in the New Sweden section, particularly in the vicinity of the manganiferous, ironstones and shales. These slates are well developed near Mapleton, along Turner Road (northwest of Mapleton), and on Capitol and Gelot hills near New Sweden. Along Turner Road, red slate (e.g. at fossil locality 45) immediately overlies the Pyle Mountain Argillite and thus forms the base of the New Sweden Formation along much of the eastern flank of the Castle Hill Anticline. At the Dudley manganese deposit just west of Mapleton

Figure 29: Geologic map of the Perham area, Caribou quadrangle. Type section for the Perham Formation (Group of this report) cited by Boucot, et al. (1964a) is the series of exposures extending east from fossil locality 49. "X" marks show the traces of exposed manganiferous ironstone horizons. Geologic symbols are shown in Plate II. Dotted lines outline cleared areas and dot-dash lines are farm or lumber roads.



(Miller, 1947), similar slates associated with ironstone are present in contact with the Jemtland Formation and are therefore at the top of the formation. Elsewhere, red and green slate are present in the formation at various stratigraphic levels, but because of poor exposure these occurrences cannot be correlated over significant distances.

Limestone. Gray aphanitic and argillaceous limestone in thin beds, lenses, or nodules is present at most exposures and comprises 5 to 8 percent of the Formation. These limestone layers rarely exceed 2 inches (5 cm) in thickness and <sup>are</sup> identical in appearance to those of the Carys Mills Formation. Cleavage commonly segments these limestone beds, forming a series of "lenses" elongated parallel to the cleavage direction. In some exposures, these "cleavage lenses" may be misinterpreted as originally lenticular limestone beds; usually, however, internal lamination within the limestone or enclosing slate indicates true bedding.

Sandstone and Conglomerate. Sandstone and conglomerate form less than 5 percent of the New Sweden. Thin beds of fine sandstone (less than 3 inches or 7.5 cm thick), commonly calcareous and laminated or cross-laminated, are interlayered with the slate at several localities. Coarser sandstone and pebble conglomerate are less common and are present only in the western parts of the formation.

Medium-grained graywacke and arenite are interbedded with the phyllitic slates along the east limb of the syncline shown in Figure 19 (west of Washburn) and may be observed at DR 906 (Figure 16) and fossil locality 46, (Figure 19). The sandstones are commonly graded and locally are calcareous, as at locality 46.

The only conglomerate bed observed in the New Sweden is located east of Castle Hill and in fields north of Maine Route 227; the bed is near the New Sweden-Jemtland contact on the east limb of a small Jemtland infold within the New Sweden terrane. The conglomerate is composed of angular to rounded chert and felsitic volcanic pebbles with lesser mafic volcanic fragments, is interbedded with feldspathic graywacke and green-gray slate, and is lithologically similar to conglomerates in the Frenchville to the west.

Modal analyses of two medium-grained sandstones from the New Sweden are given in Table 14. Analysis 64 is from sandstone associated with the conglomerate east of Castle Hill and analysis 65 is from DR 906 (Figure 16). The relatively high contents of quartz, feldspar, micrographic quartz-feldspar and other composite grains indicate close compositional affinities of these sandstones with those of the feldspathic sandstone member of the Frenchville.

Ironstone. White (1943), Miller (1947), and Pavlides (1962) have described in detail the numerous laminated,



Component	Analysis Number	
	64	65
Quartz	31.6	32.8
Plagioclase Feldspar	31.2	24.6
Potassium Feldspar	--	0.6
Detrital Mica	0.4	--
Pyroxene	--	--
Sphene (?)	--	--
Argillaceous Matrix	18.4	9.6
Secondary Carbonate	0.6	0.6
Opaque	0.2	4.4
Micrographic Qtz-Feld	13.8	19.0
Fine-grained Mafic Rocks	0.2	1.0
Fine-grained Felsic Rocks	1.6	2.6
Chert and "Cherty" Rocks	1.6	4.2
Sericitic Fragments	--	--
Pelite Fragments	--	0.2
Sandstone	0.2	--
Detrital Carbonate	--	--
Fossil Fragments	--	--
Misc.	--	--
Unidentified	0.2	0.4
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	4.2	8.0
Composite Feld-Qtz	1.4	7.6
Composite Feldspar	1.8	2.4
Composite Quartz	3.0	3.2
<b>Calculated Parameters</b>		
A	39.4	38.6
B	38.9	29.6
C	21.7	31.8
D	34.2	29.2
E	34.9	17.9
F	30.9	52.9
G	52.5	35.5
H	40.6	53.0
I	6.9	11.5

TABLE 14

Modal Analyses of Sandstones from the  
New Sweden Formation

manganiferous ironstones that occur at various stratigraphic levels within the New Sweden Formation and correlative units as far south as Houlton, Maine. The ironstones in the area of this study form the northern manganese district of Aroostook County. The manganese- and iron-bearing rocks vary in thickness from thin beds or laminae visible in a single outcrop to complex zones or lenses, several hundred feet thick, that can be traced for several thousand feet.

As described by Pavlides (1962), the manganese deposits consist of two principal rock types:

(1) Red hematitic shale, slate, and banded ironstone ("oxide facies").

(2) Green siliceous carbonate rocks ("carbonate facies"). These rock types may exist singly or be interlayered with each other. Barren slates, typical of the New Sweden elsewhere, commonly enclose or are interbedded with the iron- and manganese-rich rock types. A typical association of "barren" phyllitic slate, red slate, banded ironstone, and siliceous carbonate rocks is present in the village of Perham (Miller, 1947, plate 11; Figure 29).

The oxide facies consists of hematite-rich pelitic rocks. These rocks may be subdivided into red slate or shale and banded (or laminated) ironstone. In the slate and shale, disseminated hematite produces the red color.

The banded ironstones typically show thinly alternating "....very dark red to black layers rich in hematite or braunite, lighter colored red layers with less iron and manganese oxides, and pink and gray layers virtually free of opaque iron and manganese minerals. The lighter colored bands normally contain carbonate and are more readily leached than the ferruginous layers during weathering....The laminations are either even bedded or wavy bedded. Some layers pinch and swell" (Pavlidis, 1962).

Specularitic hematite forms some laminae. Black pods that are braunite-rich, lighter-colored pods of complex mineralogy, and rhodonite-bearing veinlets are common in the banded ironstones (Pavlidis, 1962).

The carbonate facies of the ironstones is characterized by thin light-green-gray to green, chlorite-and carbonate-rich beds. These beds may be interlayered with gray to green calcareous slate or beds of the oxide facies. Pyrite, apatite and quartz are important accessory minerals; pyrite, as single crystals, clustered crystals, or layers, is typically present (Pavlidis, 1962).

Magnetite-bearing rocks of the oxide and carbonate facies are reported by Pavlidis in the Maple and Hovey mountains area and interpreted by him to be the result of metamorphism of the facies, particularly near the axial planes of folds. No magnetite-rich rocks have been

reported from the deposits in the northern manganese district.

Miller (1947) reports the presence of thin tuff beds interbedded with the ironstones at the Dudley deposit near Mapleton.

#### Lower Contact

The New Sweden Formation overlies the Carys Mills and Madawaska Lake formations and the Pyle Mountain Argillite. The basal contact of the New Sweden has not been actually observed, but it is closely approached locally. Gradational contacts are inferred to be present between the New Sweden and the Carys Mills and Spragueville formations, and an unconformable (disconformable ?) contact with the Pyle Mountain Argillite is probable. On the northwest flank of the Stockholm Mountain Syncline, near Martins Siding, the New Sweden probably overlies the Madawaska Lake Formation unconformably; but poor outcrop control leaves the matter unsettled.

Along most of the eastern boundary of the synclinorium between Mapleton and Van Buren, the New Sweden Formation overlies the Carys Mills Formation. The contact between these two units from Mapleton to Washburn is inferred to be a fault; however, from Washburn to Van Buren the contact is considered to be conformable and gradational. This contact was reported to be present in the section cited by Boucot, et al. (1964a, Appendix IV). The contact

was placed in a three-foot (1 m) gap between blue-gray, brown-weathering limestone and "glossy, paper shale" they assigned to the "ribbon rock" member of the Meduxnekeag Formation (now the Carys Mills Formation of the Meduxnekeag Group) and "dark-gray, brown-weathering shale" which they defined as the lowest beds of the Perham Formation. After examining the section and mapping along the contact both north and south of the section, the writer has concluded that strata assigned by Boucot and others to the "ribbon rock" member (Carys Mills) should be placed in the New Sweden Formation, since they consist of 80-90 percent phyllitic slate. The distinctions drawn here between the Carys Mills and New Sweden are:

1. The Carys Mills contains less than 50-60 percent slate, with the remainder consisting of aphanitic limestone, siltstone, and graywacke.

2. Manganese- and iron-rich rocks are confined to the New Sweden Formation.

The first criterion for distinguishing these two formations, which contain similar appearing slate and limestone, is based essentially on the relative abundances of these two rock types. The second criterion is compatible with the first, in that no ironstones or associated red-beds have been found in sequences containing abundant limestone.

These criteria are, in general, consistent with most of the previous mapping along the contact from Mapleton to Van Buren by White and Cloud (White, 1943), Miller (1947), Naylor (1961, unpublished data) and Smith (1962, unpublished data). The similarity in the slate and limestone rock types and the structural conformity of the two formations in the contact zone suggests that along the contact there is a gradation between the limestone-rich Carys Mills and limestone-poor New Sweden.

In the Mapleton area, the New Sweden overlies the Spragueville Formation (Boucot, et al., 1964a), but the contact is not exposed. The contact is inferred to be gradational on the basis of stratigraphic and paleontologic evidence, discussed in subsequent sections, that indicates that the units are largely coeval.

Along Turner Road on the east flank of the Castle Hill Anticline, red and green slates of the New Sweden overlie the Pyle Mountain Argillite. The contact has been closely established, though not seen, between fossil localities 17 and 45 (Plate I). The wide age difference represented by these localities (Ashgillian and Late Llandoveryan, respectively) suggests that a disconformity is likely.

West of Martins Siding in the northwest part of the Stockholm quadrangle (Plate I), phyllitic slates assigned to the New Sweden Formation interfinger with sandstones

of the Frenchville Formation. In that area the New Sweden (fossil locality 47) apparently overlies the Madawaska Lake Formation, but outcrop scarcity makes inferences regarding the stratigraphic relations of these units very uncertain. Around Siegas, New Brunswick (to the northeast of Martins Siding), Hamilton-Smith (1969) found that both the Carys Mills and Siegas Formations (the latter established by Hamilton-Smith) are present between the Madawaska Lake and New Sweden. The apparent absence of the Carys Mills and Siegas formations west of Martins Siding suggests that an unconformity may be present there at the base of the New Sweden.

#### Thickness

The thickness of the New Sweden in the Presque Isle quadrangle was estimated by Boucot, et al. (1964a) to be approximately 2000 feet (600 m) along the western limb of the Chapman Syncline. The writer's work in that area confirms this estimate. Along its principal outcrop belt from west of Mapleton to Van Buren, however, the New Sweden is closer to 4000 feet (1200 m) thick (section B-B' of Plate III).

Hamilton-Smith (1969) estimated only 600 feet (180 m) of the New Sweden to be present in the Siegas, New Brunswick, area.

On a regional scale the New Sweden Formation is, therefore, quite variable in thickness; a range of 600-

4000 feet (180 to 1200 m) is probably a reasonable estimate of the variation. The formation is apparently thickest in its principal outcrop belt along the eastern margin of the Stockholm Mountain Synclinorium, but either thins or interfingers with other units (Frenchville and Spragueville) laterally to the west and east.

#### Age

Boucot, et al. (1964a) cite two fossil localities that they assigned to the New Sweden Formation (localities 51 and 59 of this report). On lithologic grounds the writer and Pavlides (1968) have placed these two exposures in the Jemtland Formation; both localities represent the basal phase of that formation.

During the course of this study, two fossil localities (45 and 46) were found in the New Sweden, and E. Mencher collected definitive graptolites from slates assigned here to the formation at locality 47 near Martins Siding. Locality 47 was originally discovered by Douglas Smith during reconnaissance mapping in 1961 (Smith, unpublished information).

The paleontologic data, shown in Table 15, indicate that the New Sweden Formation spans the time interval of the Llandoveryan (zone 19 or 20) to the Wenlockian. Since both locality 45 (Turner Road) and locality 107 (west of Martins Siding) are near the bottom of the formation, it is apparent that the basal beds vary in age from as old as



Table 15: Fossil localities from the New Sweden Formation (Sns) and the Spragueville Formation (Ss). Locality 106 is locality E-10 of Boucot, et al. (1964a) but the fossil list is modified (Boucot, personal communication, 1970). Locality 107 is locality 2 of Pavlides (1968). Brachiopods identified by A. J. Boucot, graptolites identified by W. B. N. Berry, Portlockia identified by R. B. Neuman, and ostracods identified by J. Berdan. The following ages are assigned to the collections: Locality 45, C<sub>3</sub> - C<sub>5</sub> of the Llandoveryan; locality 46, Wenlockian; locality 47, approximately graptolite zone 19 of the Llandoveryan; locality 106, C<sub>3</sub> - C<sub>5</sub> of the Llandoveryan; locality 107, graptolite zone 19 or 20 of the Llandoveryan. Locality 107 is located near Limestone Maine (Pavlides, 1968) and is not plotted in Plate I (see Pavlides, 1968).

FAUNA

LOCALITY

	Sns		47	Ss	
	45	46		106	107
<b>GRAPTOLITES:</b>					
<i>Climacograptus scalaris</i> var. <i>miserabilis</i> Elles and Wood					X
<i>Climacograptus</i> of the <i>C. scalaris</i> type			X		
<i>Monograptus communis</i> (Lapworth)					X
<i>Monograptus triangulatus</i>			X		
<i>Rastrites approximatus approximatus</i> (Perner)					X
<b>BRACHIOPODS:</b>					
<i>Amphistrophia</i> sp.		X			
<i>Atrypa "reticularis"</i>		X		X	
<i>Coolinia</i> sp.		X			
<i>Curtia</i> sp.		X			
<i>Dalejina</i> sp.		X		X	
<i>Dicaelosis</i> sp.		X			
<i>Eocoelia</i> cf. <i>intermedia</i> or <i>curtisi</i>	X				
<i>Eospirifer</i> sp.		X			
<i>Glossia</i> sp.				X	
qupidulid		X			
<i>Howellella</i> sp.		X		X	
<i>Leangella</i> sp.		X			
<i>Leptaena "rhomboidalis"</i>		X		X	
<i>Linoporella</i> sp.		X?			
<i>Meristina</i> sp.		X			
<i>Mesopholidostrophia</i> sp.		X		X	
<i>Nucleospira</i> sp.				X	
orthotetaceid				X	
<i>Pentamerus</i> sp.	X				
<i>Plectodonta</i> sp.	X	X		X	
<i>Protomegastrophia</i> sp.	X?	X			
<i>Ptychopleurella</i> sp.	X				
<i>Resserella</i> sp.		X		X	
rhynchonellid		X		X	
<i>Salopina</i> sp.		X			
stricklandid	X				
<i>Strophonella</i> sp.		X			
undetermined		X			
<b>OSTRACODS:</b>					
<i>Apotobolbing</i> sp.				X	
<i>Bolbineosia</i> sp.				X	
<i>Zugobolba inflata</i> Ulrich and Bassler				X	
<b>GASTROPODS:</b>					
undetermined		X			
<b>TRILOBITES:</b>					
undetermined					
<i>Portlockia</i> sp.		X		X	

TABLE 15

A<sub>4</sub> - B<sub>3</sub> to as young as C<sub>3</sub> - C<sub>5</sub> of the Llandoveryian. The seemingly gradational contact between the Carys Mills (youngest age: zone 18-19 of the Llandoveryian) and the New Sweden formations/<sup>along</sup> much of the eastern boundary of the synclinorium, and the absence of lower and middle Llandoveryian rocks in the Castle Hill Anticline suggest that this variation occurs over a short distance, as shown in section C-C' of Plate III.

The top of the formation is Wenlockian in age, since Late Wenlockian faunas have been obtained from near the base of the overlying Jemtland Formation (localities 51 and 59) and a gradational contact between the two units can be seen at three localities (see discussion of the lower contact of the Jemtland). In addition, locality 46, near the top of the New Sweden (see Figure 19), contains a rich fauna which Boucot (personal communication, 1965) states is of Wenlockian age since the ranges of the Plectodonta and Leangella genera overlap only in that stage.

Figure 5 shows the inferred stratigraphic position of the New Sweden and indicates the age ranges of the fossil assemblages. Table 13 gives the brachiopod communities of Ziegler (1965) represented in localities 45 and 46; both localities show a mixture of communities and a low degree of fossil fragmentation. The most off-shore group, the Clorinda community, is present at

locality 46, where the fossils occur at the base of a graded sandstone bed.

## SPRAGUEVILLE FORMATION

### Name and Distribution

Pavlidis (1965) defined the Spragueville Formation to be synonymous with the upper ("nubbly") member of the "Aroostook Limestone" as used by White (1943) and the "Unnamed Silurian Limestone" of Boucot, et al. (1964a) (refer to Figure 2). The writer and Pavlidis (1968) have modified the distribution of this formation in the Presque Isle quadrangle from that presented by earlier workers, and Mencher, Roy, and Pavlidis (unpublished data) have mapped a synclinal infold of Spragueville in the Carys Mills terrane in the vicinity of Fort Fairfield (Figure 1).

Pavlidis (1965) designated the vicinity of the village of Spragueville (south of Presque Isle) as the type area. Excellent exposures of the unit are also found along Maine Route 163 near Mapleton at and near fossil locality 106.

### Lithology

Thinly interbedded and interlaminated medium-gray silty pelite and light-gray silty limestone or calcareous siltstone comprise most of the Spragueville Formation. At most exposures this interbedded sequence is subdivided into layers that are 0.5 to 6 inches (1.3-15 cm) thick;

this layering gives the unit a flaggy appearance. The layers are bounded by partings along pelite beds which may represent planes that were kinematically active during folding. Medium-gray, aphanitic limestone similar to that in the underlying Carys Mills, (Figure 30A) and light-gray, orange-weathering, silty and sandy limestone are important minor rock types in the formation.

Cleavage is generally absent or very poorly developed in the Presque Isle-Mapleton area, where the formation is involved in the broad Chapman Syncline. In the more complex synclinal infold of the formation near Fort Fairfield, cleavage is better developed, especially near the base of the unit.

The characteristic features of the thin-bedded and laminated rock type are shown in Figure 30. The light-gray laminae are composed of carbonate and variable amounts of quartz, feldspar, mica, detrital carbonate, and bioclastic debris. The darker gray pelitic intervals consist of a carbonate and argillaceous matrix enclosing silt-size quartz, feldspar, and mica grains. The silt-size mica flakes are oriented parallel to the bedding. In Figure 30B, internal layering is visible within the pelite beds. This layering is caused by apparently cyclic variation in the relative amounts of carbonate and argillaceous material; within each layer, the carbonate-argillaceous ratio decreases upward. Similar internal

Figure 30: Illustration of the thinly interlayered character of the Spragueville Formation.

A. Outcrop photo showing a thin aphanitic limestone bed (gray) in the thinly interlayered sequence. Wet surface shows silty carbonate (orange) and dark pelite layers as well as one truncated animal (worm?) boring which appears as a "knot."

B. Sawed and lacquered surface cut perpendicular to a flaggy layer. Small scale deformation of the light-gray beds (silty carbonate) and internal layering of the pelitic beds are evident. White vein is composed of calcite.

Knife is 3.5 inches (9 cm) long.

A



Figure 30

B



variations can be seen in some of the light gray laminae, where "clay" concentrations appear to form the top of each cycle.

Small-scale deformation of the laminae is almost always present. Folding of the light-gray beds, commonly approaching a ptygmatic morphology, and small offsets are typical. In thin section, isolated "balls" of carbonate-quartz material and similar "balls" terminating laminae have been observed that may have been produced during deformation. The small-scale structures are principally responsible for the irregularities that are typical of the surfaces of the flaggy layers.

The interlaminated sequence commonly shows evidence of burrowing animals. Roughly cylindrical, sediment-filled "tubes" up to 1-2 cm in diameter cut across, and disrupt, the layering (Figure 31); networks of small tubes that are more or less confined to a single bedding plane have also been observed. The sediment filling in some of the larger tubes is partitioned into segments by thin clay-rich (?) seams (Figure 31). These animal (worm?) borings are commonly seen on weathered surfaces perpendicular to the bedding, where they appear as "knots"; one such truncated boring is present in the outcrop photograph of Figure 30A. These truncated animal borings, as well as the mechanically produced "balls"





Figure 31: Animal borings from the Spragueville Formation. Large cylindrical, curving, and apparently radiating borings cutting across the stratification. Note the "segmentation" in the boring along the lower right-hand margin of the specimen.

discussed previously, form the "rounded nodules" referred to by Boucot, et al. (1964a) and are probably the structures that caused White (1943) to describe the unit as consisting of "nubbly" limestone.

Thin- and medium-bedded, light gray, orange-weathering limestone is seen at numerous exposures, particularly in the Mapleton area. A modal analysis of a sample of this limestone showed the following composition:

Carbonate (ankeritic?)	49.8%
Quartz	44.2%
Mica	2.8%
Feldspar	.2%
Unidentifiable	3.0%

The high clastic content of these limestone beds is seen in the field as a distinctive orange, noncalcareous, porous, weathering "rind." The orange color is probably due to the presence of ankerite; though not specifically determined in the Spragueville limestones, this mineral is present in the orange-weathering limestones of the underlying Carys Mills Formation (Pavrides, 1968).

#### Lower Contact

In the Presque Isle-Mapleton area the lower contact of the Spragueville is not observed and is nowhere closely established. In the vicinity of Giggey Hill, just northwest of Fort Fairfield, and on Stewart Hill, south of Limestone, successions of exposures indicate that complete

transition is present between the Carys Mills and Spragueville formations (Roy and Mencher, unpublished data). The regional presence of zone 19 graptolites in the Carys Mills and graptolites of zones 19-20 in the Spragueville further suggest that no hiatus exists between the units.

#### Thickness

Boucot, et al. (1964a) estimated the Spragueville to be no greater than 4000 feet (1220 m) in the Presque Isle area, and Pavlides (1968), after modifying the distribution of the formation in the Presque Isle vicinity, suggested a value of 3,000 feet (915 m), with apparent thinning to the south. The writer's modification of the distribution of the formation in the Mapleton area suggests a thickness of approximately 3700 feet (1130 m), but the location of the Spragueville-Carys Mills contact is uncertain and there is the possibility of higher order folding in the plunge of the Mapleton Anticline (Plate I). Mencher and Roy (unpublished data) have found 2500-3000 feet (760-915 m) of the Spragueville to be preserved in the Fort Fairfield area, but the top of the formation is apparently absent in the syncline.

#### Age

The critical fossils for dating the Spragueville come from two localities (106 and 107, Table 15). The ostracod faunas of locality 106 in Mapleton indicate a Late Llandoveryan ( $C_3 - C_5$ ) age; the associated brachiopod

assemblage is consistent with this age but is more broadly ranging, C<sub>3</sub> of the Llandoveryan-Ludlovian (Boucot, et al., 1964a). Pavlides (1968) reports that the graptolites of locality 107 are Early or Middle Llandoveryan (zone 19 or 20) in age. The Spragueville is therefore inferred to span at least the A<sub>4</sub> - B<sub>1</sub> to C<sub>3</sub> - C<sub>5</sub> time interval of the Llandoveryan and to be a temporal equivalent of much of the Frenchville and New Sweden formations.

The presence of post-Llandoveryan strata in the Spragueville cannot be demonstrated directly. Near the community of Spragueville the Jemtland Formation immediately overlies the Spragueville Formation. The contact is neither observed <sup>nor</sup> / closely established, but the absence of the New Sweden Formation and the general conformity of Jemtland strata on older rocks elsewhere suggest that the Jemtland-Spragueville contact is also gradational. The presence of Wenlockian rocks in the Spragueville as indicated in Figure 5 is therefore quite probable.

#### MIDDLE LLANDOVERIAN-EARLY WENLOCKIAN STRATIGRAPHIC RELATIONSHIPS

##### Frenchville, New Sweden, and Spragueville Formations

The Frenchville and Spragueville formations were interpreted by Boucot, et al. (1964a) to be time equivalents, with the strata here defined as the New Sweden Formation

overlying both. Regional stratigraphic arguments summarized by Pavlides (1968) as well as physical and paleontologic information obtained during the course of this study have now established the New Sweden as an intermediate unit between the Frenchville and Spragueville formations. The evidence bearing on the relations of these units to each other may be summarized as follows:

(1) There is near coincidence in age ranges of the formations as established by fossil localities. This age range is from Middle Llandoveryan (approximately zone 19) to Early Wenlockian (possibly into Late Wenlockian). The presence of strata of B<sub>1</sub> - C<sub>1</sub> age in the Frenchville and post-C<sub>5</sub> strata in the Spragueville cannot be supported by direct paleontologic information, but stratigraphic relations with older and younger units discussed in previous sections indicate that these time spans are probably represented (assuming internal stratigraphic continuity of the units). The lowest beds of the Frenchville and New Sweden formations in the Castle Hill Anticline are apparently upper Llandoveryan, as shown in Figure 5.

(2) Manganiferous ironstone and red slate are present in the Frenchville, and sandstone and conglomerate compositionally and texturally similar to those in the Frenchville occur locally in the New Sweden.

(3) Gradation from both the Frenchville and New Sweden formations into the overlying Jemtland Formation

can be demonstrated in the field in several places.

Although the Spragueville underlies the Jemtland Formation south of Presque Isle, the contact has not been observed.

(4) Both the New Sweden and Spragueville formations overlie the Carys Mills with apparent conformity.

#### Members of the Frenchville Formation

Inferences concerning the stratigraphic relationships among the members of the Frenchville Formation are based on map patterns and comparisons of sections where structural control is good. The conglomerate, sandstone-slate, and quartzose sandstone members are regionally extensive and commonly form the entire formation where present. The graywacke and feldspathic sandstone members are of more local extent around the village of Frenchville, where they are, respectively, below and above the conglomerate member.

Marked vertical and lateral changes in the Frenchville and its stratigraphic setting in the northeastern corner of the Ashland quadrangle are apparent when the stratigraphic successions in Frenchville and Ashland are compared as shown in Figure 32. Over a short distance across the Alder Brook Fault, the following major changes are evident:

(1) The Aroostook River Formation, graywacke member, and feldspathic sandstone member are absent in the Ashland section. Though the graywacke member is clearly absent in

Ashland  
(south)

Lower Devonian  
(mostly slate)

Upper Silurian-Lower Devonian (?)  
Sandstone and Slate

Frenchville Fm.  
Conglomerate Member  
(2650')

Winterville Fm.

Frenchville  
(north)

Jemtland Fm

Feldspathic Sandstone Member  
(2250')  
Conglomerate Member  
(700')  
Graywacke Member  
(500')

Aroostook River Fm.  
(2000')

-----?-----?-----?  
Madawaska Lake Fm.

Figure: 32

Comparison of the stratigraphic successions in Ashland and Frenchville.

Ashland itself, this thin unit may be present locally south of the Alder Brook Fault.

(2) An unconformity between the Frenchville and Winterville formations has been documented in the Ashland area; however, north of the fault the Frenchville conformably overlies the Aroostook River Formation, which in turn is inferred to overlie the Madawaska Lake. The base of the conglomerate member in the northern sequence is not observed but is closely located just northwest of locality 35 (Figure 9); though inferred to be essentially a conformable transition, it is possible that a disconformity is present between the conglomerate and graywacke members.

(3) The conglomerate member in Frenchville is  $C_4 - C_5$  (Late Llandoveryan) or older, whereas the member south of the fault is  $C_4 - C_5$  and younger. Much of the conglomerate section in Ashland may be younger than the dated rocks of the feldspathic sandstone member to the north. In addition to being younger, the conglomerate member is considerably thicker south of the fault.

The pronounced north-south stratigraphic changes in the Frenchville Formation may be explained as the result of southward onlap of the succession together with variations in provenance. This explanation will be discussed at length in a later section.



In addition to being absent south of the Alder Brook Fault, the Aroostook River Formation and the graywacke member of the Frenchville are not present beneath the conglomerate member in the small anticline cored by the Madawaska Lake just northeast of Frenchville. These units are also absent in the Castle Hill and Story Hill areas (Figures 16 and 19), where the sandstone-slate member alone comprises the Frenchville.

The sandstone-slate member is interpreted to be a lateral equivalent of the conglomerate and feldspathic sandstone members because:

- (1) paleontologic data indicates temporal equivalency;
- (2) in the Castle Hill and Story Hill areas, the sandstone-slate member forms the complete Frenchville section;
- (3) the conglomerate and feldspathic sandstone members on the east flank of the anticline west of Frenchville are in large part replaced on the west flank (just south of Beaver Brook) by the sandstone-slate member (Plate I);
- (4) the compositions of sandstones from the sandstone-slate member cover the ranges of those from both the conglomerate and feldspathic sandstone members.

In much of the area, the sandstone-slate member forms a facies transitional between the slate-poor members and the more eastern New Sweden Formation. The quartzose

sandstone member replaces the sandstone-slate member in the Stockholm area as the transitional facies. Interfingering of the quartzose sandstone member and the New Sweden Formation is inferred to occur just west of Martins Siding (Plate I).

## ROCKS OF LATE WENLOCKIAN-LUDLOVIAN AGE

### JEMTLAND FORMATION

#### Name and Distribution

The upper member of the Perham Formation as used by Boucot, et al. (1964a) in the Presque Isle quadrangle is here designated the Jemtland Formation of the Perham Group. The formation is named for the small community of Jemtland, near Stockholm. The writer has mapped the formation extensively outside the Presque Isle quadrangle in the synclinorium (Figure 4) and also along the northwestern margin of the western anticlinorium from Cross Lake to the St. John River valley (Roy and Mencher, unpublished data). The formation is one of the most fossiliferous units in New England.

Within the area of this study, the Jemtland is present along both flanks of the Stockholm Mountain Syncline, in synclinal infolds in Frenchville and New Sweden terranes, and along the flanks of the Chapman Syncline and Mapleton Anticline (Plate I). The formation is best exposed in the Stockholm Mountain Syncline, where several large roadcut and quarry exposures show the sandstone-rich facies. The more eastern slate-rich facies is found in the synclinal infolds in the Washburn-Perham area.

The Stockholm-Jemtland area is here established as the type area for the Jemtland. Fossil locality 61 along

Maine Route 161 in the village of Jemtland (Plate I) contains a sequence considered typical of the formation. Excellent and extensive exposures also occur at fossil localities 62 and 82.

### Lithology

The Jemtland Formation consists of several distinctive rock types that are thinly interbedded. Most of the unit consists of intercalated fine sandstone, siltstone, slate, and silty shale in beds on the order of centimeters or tens of centimeters thick, as shown in Figure 33. Within this sequence, medium and coarse sandstone are common; locally, conglomerate, aphanitic limestone, limestone breccia, and water-laid devitrified tuff are present. All rock types except the slate, conglomerate, and tuff are very calcareous and commonly deeply weathered.

Slate (shale). Medium to dark gray, very fine-grained slate or shale composes 4 to 60 percent of the formation. As discussed in more detail in a subsequent section, this rock type increases in abundance from west to east. In beds greater than 1-2 cm thick, this rock type generally shows cleavage which parallels or nearly parallels the axial planes of the folds. Beds thinner than about 2 cm are uncleaved or are cleaved parallel to bedding. The slate is noncalcareous or only very slightly calcareous. Injections of this fine-grained pelite into overlying coarser

Figure 33. Thinly interbedded rock types of the Jemtland Formation. The three types of pelitic beds are shown: laminated silty shale (labeled "2"), silty shale (labeled "3"), and slate (labeled "4"). A fine-grained, quartz-rich, calcareous graywacke bed (labeled "1") is also present. The slate is composed of very fine pelite, which, in beds thicker than about 2 cm, shows a well defined axial-plane cleavage. Indistinct lamination in the laminated silty shale is due to discontinuous quartz-carbonate concentrations; this rock type appears more carbonaceous than the other two pelitic rock types and commonly contains well preserved graptolites. Note orange weathering "rind" that results from the leaching of carbonate and the oxidation of iron in ankeritic carbonate phases.



Figure 33

beds to form small-scale flame structures are common in the Jemtland (Figures 34A, 35A, and 37A).

Silty shale. Medium-gray silty shale forms as much as 20 percent of the Jemtland and decreases in abundance eastward. This rock type is medium gray in color, homogeneous in appearance, calcareous, micaceous, and weathers to a brown or orange-brown color (Figure 33). Though rarely cleaved across the bedding, the silty shale commonly shows an irregular bedding fissility which is especially apparent in weathered exposures.

Laminated Silty Shale. Medium gray, calcareous, micaceous, indistinctly laminated silty shale forms as much as 25 percent of Jemtland and, like the nonlaminated silty shale, diminishes in abundance from west to east in the formation. The presence of discontinuous, largely quartz-carbonate, laminae that are 0.1 to 1 mm thick is a distinguishing feature of this rock type (Figure 33). Some of these laminae may be traced on a surface cut normal to the bedding for as much as a few centimeters, but most are only a few millimeters long. The boundaries of the laminae are diffuse.

After weathering, a bedding fissility becomes well developed, producing planar sheets or plates. The micaceous nature of the laminated shale is usually well displayed on the surfaces of the plates. Most of the well preserved graptolites found in the Jemtland occur in this

lithology and are easily recovered because of its platy character. Oriented graptolites and specimens up to 1 foot (30 cm) in length have been seen locally.

A modal analysis (500 counts; section stained for both K-feldspar and plagioclase) of the laminated silty shale produced the following results.

Argillaceous minerals	50.8%
Quartz	22.4%
Carbonate	9.2%
Plagioclase Feldspar	8.2%
Detrital Mica	5.6%
Opaque material	3.4%
Pyroxene (?)	0.2%
Unidentified	0.2%
TOTAL	100.0%

Fine Sandstone and Siltstone. Interbedded with the above pelitic rocks are beds of light-gray, very calcareous, fine sandstone and siltstone (Figure 33). These beds are generally laminated and/or cross-laminated and vary in thickness from less than 1 cm to 4 m; beds thicker than 30 cm are uncommon and most are less than 5 cm thick. A distinct orange, leached "rind" is usually developed in these rock types. The rind is caused by oxidation of iron in ankeritic carbonate phases of the cement to limonite/hematite and removal of calcite. The rind has a porous texture, and, in cases of intense weathering, is friable.



Internal lamination and cross-lamination are caused by variations in abundance of argillaceous material. The thin dark laminae in the upper fine sandstone bed of the specimen shown in Figure 35A have higher pelite and lower carbonate contents than the intervening light gray laminae. A complete gradation is seen from argillaceous laminae that are faint and indistinct, as in the bed in Figure 35A, to thin pelite or "muddy" laminations, as seen beneath the ripples in Figure 34A.

Most, if not all, of the cross-lamination observed in the fine sandstone and siltstone beds was formed during the development of ripples. The ripple development varies from trains of simple ripples (Figure 34A) to beds up to a few tens of centimeters thick consisting of complex ripple-drift lamination (primarily types 2 and 3 of Walker, 1963), as seen in Figures 34B and 36. Rippled intervals commonly overlie parallel-laminated intervals of the same lithology, with a surface of erosion separating them (Figure 34B).

Convolute lamination, with or without associated cross-lamination, is occasionally observed; in most cases, there appears to have been convolution of originally parallel laminae. Multistructured beds showing combinations of sandstone or siltstone laminae, pelite laminae, simple ripple trains, ripple-drift lamination, convolute lamination, and unstructured intervals are frequently seen (Figure 34

Figure 34: Ripple lamination in fine-grained graywacke beds from the Jemtland Formation at fossil locality 48.

A. Sawed section of a portion of a train of simple ripples that show well developed foreset laminae and an absence of stoss lamination. Note the apparent draping of the pelite layer over the ripples and the remnant of parallel-laminated fine sandstone at the base of the complete ripple shown. Beneath the ripple train is a series of alternating fine sandstone (siltstone) and pelite laminae classified as a "B interval with pelite lamination" following the usage of Walker (1967). Small-scale load-casting and pelite injection features are visible at the base of the fine sandstone layers; pelite flame structures also "inject" overlying silty shale about 2 cm above the base of the ripple train.

B. Sawed section of a complexly structured graywacke bed. Parallel-laminated fine graywacke (base of bed) was apparently reworked, in part, into a simple ripple train which was subsequently buried by ripple-drift lamination showing an upward-increasing pelite content. Note complex soft-rock deformation in pelite bed to left of scale marker.



A.



B.

Figure: 34

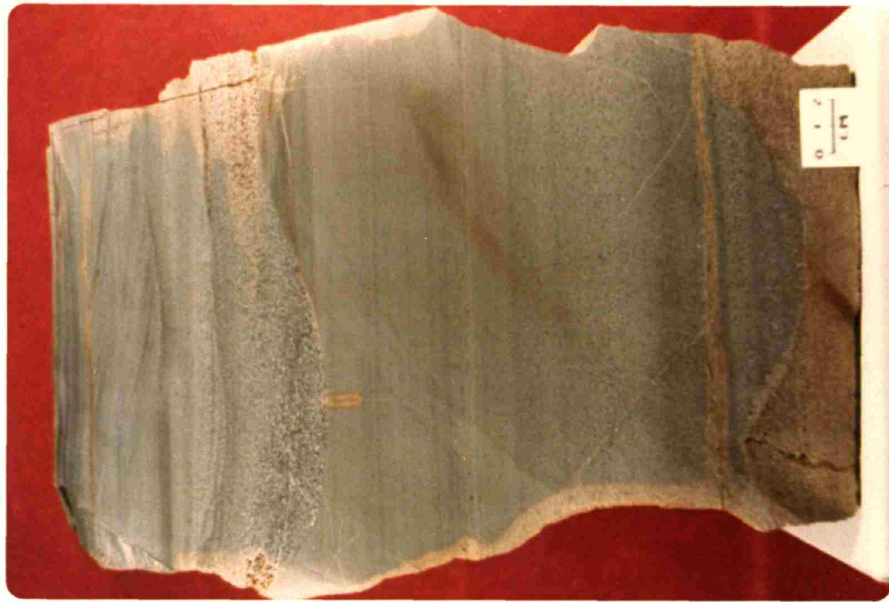
Figure 35: Single and amalgamated graywacke beds from the Jemtland Formation.

A. Sawed specimen showing three graywacke beds inter-layered with one bed of each pelitic rock type. The lower and upper graywacke beds are parallel laminated and the middle graywacke bed shows complex ripple-drift lamination. Concentrations of argillaceous material form the dark laminae in the upper bed; close examination shows the fine scale and cyclic character of the lamination. There are pelite-injection features at the base of each graywacke bed.

B. Amalgamated graywacke beds (numbers 344 and 345) from the section at locality 61 (Figure 39); The lower bed (344) is laminated and graded (medium to fine sandstone) throughout; the upper bed contains a lower unstructured interval (A), a thin laminated interval (B), and a cross-laminated upper interval (C). A surface of erosion separates the two beds.



A



B

Figure: 35



Figure 36: Two fine-grained graywacke beds from the Jemtland Formation. Bed 290 is an A-B type sequence in which a lower unstructured fine sandstone interval (A) is overlain by a parallel laminated interval (B), with pelitic laminae. Bed 293 is a complexly ripple-drift laminated fine-grained graywacke. Clip of the pen is 1.5 inches or 4 cm long.

Figure 37: Medium- and coarse-grained lithic graywacke beds in the Jemtland Formation.

A. Bed 427 in the section at locality 61 (Figure 39).

This bed consists of a medium-grained lithic graywacke A interval (ungraded), a "muddy" laminated B interval, and a pelite-rich, ripple-drift laminated C interval.

Note the presence of flame structures of pelite at the base of the bed. The bed is overlain and underlain by slate. Hammer is 12.5 inches or 31 cm long.

B. A 78 cm (2.6 feet), graded lithic graywacke bed containing a large block and numerous smaller fragments of silty shale in its lower half. Bedding lamination in the silty-shale block is parallel to the pen. The block measures 120 X 30 cm on the pavement surface of the exposure. The up-facing direction is to the right. Hammer is 12.8 inches or 32 cm long.



A



B

Figure: 37



and 36). The unstructured, parallel laminated (with or without pelite laminae), and cross-laminated (or convolute-laminated) portions of multistructured beds are ordinarily arranged in the vertical order given by Bouma (1962) (see illustration in Figure 8). Deviations from Bouma's order are rare and generally involve surfaces of erosion separating the intervals juxtaposed in "truncated" or apparently inverted successions. Application of Bouma's sequence model to the Jemtland rock types is discussed at length in a subsequent section.

Two compositional analyses of typical fine sandstones from the Jemtland are given in Table 16 (numbers 66 and 67). These sandstones are calcareous, quartz-rich graywackes of quite uniform composition.

Medium and Coarse Sandstone. Medium and coarse sandstones are interlayered with the pelitic and fine sandstone (siltstone) beds. The coarser sandstones are present as individual beds and as basal phases of beds having fine sandstone or siltstone upper parts; they typically form the A and lower B intervals in multistructured beds.

Grading is commonly developed in the coarser sandstones, with both gradual and sharp transitions into overlying laminated intervals. Evidence of erosion of the substrata is generally observed at the basal contact, and pelite fragments are usually present, as least locally, along the beds. One 78 cm graded bed was observed to

Component	Analysis Number			
	66	67	68	69
Quartz	44.7	40.0	8.0	6.0
Plagioclase Feldspar	1.4	5.6	14.8	12.0
Potassium Feldspar	--	--	--	--
Detrital Mica	6.1	1.2	--	0.2
Pyroxene	--	0.2	--	--
Sphene (?)	--	--	--	--
Argillaceous Matrix	19.1	19.5	23.6	17.0
Secondary Carbonate	28.1	29.5	4.4	18.6
Opaque	0.6	0.6	2.0	0.8
Micrographic Qtz-Feld	--	--	--	--
Fine-grained Mafic Rocks	--	0.4	40.4	44.0
Fine-grained Felsic Rocks	--	--	2.0	0.4
Chert and "Cherty" Rocks	--	1.4	3.8	0.2
Sericitic Fragments	--	--	--	--
Pelite Fragments	--	--	--	--
Sandstone	--	--	--	--
Detrital Carbonate	--	0.4	1.0	0.4
Fossil Fragments	--	--	--	--
Misc.	--	--	--	--
Unidentified	--	0.2	--	0.4
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	--	--	0.2	0.2
Composite Feld-Qtz	--	--	0.2	0.4
Composite Feldspar	--	--	0.6	0.2
Composite Quartz	--	1.0	0.8	0.6
<b>Calculated Parameters</b>				
A	97.0	83.7	11.4	9.5
B	3.0	11.7	21.1	19.0
C	--	4.6	67.4	71.4
D	97.0	83.7	11.1	9.2
E	3.0	11.7	20.0	18.1
F	--	4.6	68.9	72.7
G	100.0	94.8	13.9	11.2
H	--	--	1.8	1.6
I	--	5.2	84.3	87.2

TABLE 16

Modal Analyses of Sandstones and a Conglomerate  
from the Jemtland Formation

Analyses 66 and 67 are of fine-grained sandstones; analyses 68-71 are of medium-grained sandstones; analysis 72 is of a conglomerate.

Component	Analysis Number		
	70	71	72
Quartz	9.6	5.4	7.6
Plagioclase Feldspar	20.2	10.8	--
Potassium Feldspar	--	--	--
Detrital Mica	--	Tr	0.2
Pyroxene	0.2	Tr	--
Sphene (?)	--	--	--
Argillaceous Matrix	15.0	23.5	5.4
Opaque	1.2	1.4	0.4
Micrographic Qtz-Feld	0.4	--	1.2
Fine-grained Mafic Rocks	13.2	31.6	7.2
Fine-grained Felsic Rocks	1.4	0.6	13.3
Chert and "Cherty" Rocks	1.6	0.8	45.0
Sericitic Fragments	--	--	--
Pelite Fragments	--	0.2	0.8
Sandstone	--	--	--
Detrital Carbonate	6.6	1.4	1.2
Fossil Fragments	--	--	0.2
Misc.	--	--	9.3
Unidentified	1.2	1.6	1.4
<b>TOTAL</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>
Composite Qtz-Feld	--	0.4	--
Composite Feld-Qtz	--	--	0.2
Composite Feldspar	0.6	0.8	--
Composite Quartz	0.6	0.2	2.4
<b>Calculated Parameters</b>			
A	18.1	10.6	--
B	38.1	21.3	--
C	43.8	68.1	--
D	18.1	9.8	--
E	37.0	19.7	--
F	44.9	70.5	--
G	28.7	12.3	9.9
H	3.0	2.9	1.8
I	68.3	84.8	88.3

TABLE 16 (Cont)

contain a large block (exposed dimensions: 120 X 30 cm) and abundant smaller fragments of pelitic rock, (Figure 37B); the long axis of the block is oriented parallel to the bedding and the block is composed of silty shales found in the Jemtland.

Analyses 68-71 of Table 16 show the compositional features of the medium and coarse Jemtland sandstones. These sandstones are calcareous lithic graywackes with low quartz content and abundant fine-grained volcanic rock fragments. With few exceptions (e. g. analysis 68) the carbonate content is very high; feldspar and volcanic rock fragments are commonly replaced by secondary carbonate, suggesting that their abundance was originally greater than is indicated by the analyses. Detrital carbonate is ordinarily present, and these grains commonly have "rims" of secondary carbonate. Much, if not all, of the present carbonate may have originally been detrital, and redistributed subsequent to deposition.

Conglomerate. At DR 393 near the crest of Story Hill (Figure 19), a bed of chert pebble conglomerate is present in the Jemtland section. Only a few feet (1-2 m) of this bed are exposed, but it may be traced for approximately 3,000 feet (900 m) in the fields north and south of its occurrence at DR 393.

The composition of this bed is indicated by analyses 72 of Table 16. The abundance of chert and felsic rock

fragments is a marked feature of the rock. Though detrital carbonate is present, the secondary carbonate content is low. "Cherty" cement (included in "miscellaneous") forms a portion of the matrix.

Aphanitic Limestone. Medium- to dark-gray, aphanitic, and argillaceous limestone in thin beds and lenses is only rarely seen in the Jemtland.

Limestone Breccia. Limestone breccia is present near the base of the Jemtland Formation along much of the western flank of the faulted syncline west of Mapleton (fossil locality 102), as reported by Williams and Gregory (1900), Miller (1947), and Boucot, et al. (1964a). Williams and Gregory (1900) and Twenhofel (1941) correlated this breccia with similar limestones in Ashland; present paleontologic data now show that this correlation is invalid. Limestone breccia exposures in and near Chapman (south of Mapleton) have been correlated with the breccia west of Mapleton by Boucot, et al. (1964a).

The breccia at fossil locality 102 consists of angular to subrounded fragments of dark gray, finely crystalline, crinoidal limestone and an interfragment matrix of argillaceous limestone. Limestone fragments occur in both mosaic-like arrangement and in random orientation. Fragments up to 8 inches (20 cm) have been observed but the average size is nearer 3 inches (8 cm).

Tuff. Beds of tuff are not common in the Jemtland, but are locally of importance as marker beds. Thin (less than inch or 2.5 cm) layers of light gray tuff appear in the section at fossil locality 86 along the Trans-Canada Highway near St. Leonard, New Brunswick; such thin beds have not been observed elsewhere. An important sequence of devitrified tuff is present, however, in the Jemtland along the west flank of the Stockholm<sup>Mountain</sup> Syncline just northwest of Stockholm (Figure 21). This tuff section, about 63 feet (19 m) thick, is approximately in the middle of the formation and may be traced in a series of exposures for at least 4.5 miles (7 km). A similar, though apparently thinner, interval of tuff occurs at about the same stratigraphic position on the southeastern flank of the Stockholm Mountain Syncline just west of Spalding (Plate I), and may be followed for about 1 mile (2 km).

The best stratigraphic section through the tuff beds is at DR 1269 (Figure 21) near Stockholm. A measured section at this locality is presented in Figure 38. Four types of tuff have been recognized in this section:

Type I: Type I is a devitrified tuff that forms most of the section. This type is light gray-green, chalk-white weathering, and siliceous. In thin section it is seen to be composed of well compacted devitrified shards and pumice fragments in a matrix of microcrystalline quartz-chlorite-plagioclase (?). The original outlines

Figure 38: Stratigraphic section through the tuff sequence at DR 1269 near Stockholm (Figure 21). Rock types are discussed in the text. The right column is an upward continuation of the section shown in the left column.

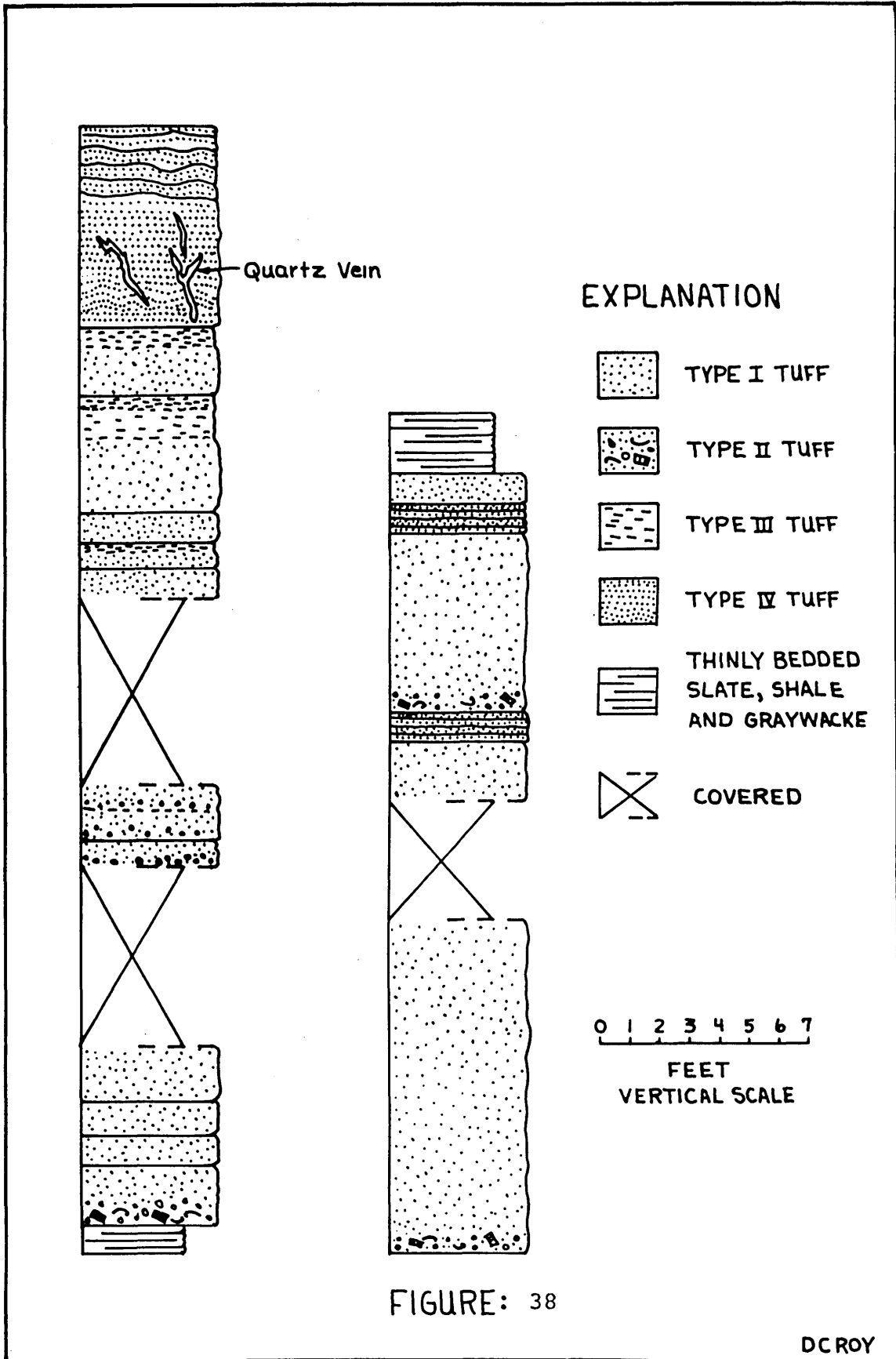


FIGURE: 38

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of the shards and pumice fragments are clearly visible in plain light at low illumination; these ash fragments have been recrystallized to plagioclase and minor quartz which in larger fragments may show a subvolcanitic texture. The microcrystalline matrix is less abundant than the devitrified shards and pumice fragments. Chlorite is abundant as irregular patches, mafic-mineral alterations, and intersertal mosaics. Sand- and silt-size grains of angular quartz and feldspar are widely scattered throughout; lithic fragments of mafic volcanic rocks are sparse.

Type II: Type II is a devitrified lithic tuff consisting of angular sand- to pebble-size fragments of (in order of decreasing abundance) mafic volcanic rocks, plagioclase, quartz, myrmekitic quartz-feldspar (trace), and detrital carbonate (trace) in a matrix which is composed of devitrified shards and pumice fragments and microcrystalline quartz-chlorite-plagioclase (?). The matrix is essentially the same as the type I tuff described above. In hand specimen, the lithic tuff is medium gray in color and weathers to a chalk-white color. Shell debris (largely brachiopod, coral, and crinoid fragments) are generally seen in this lithology; fossil locality 89 is located in a lithic tuff interval at the base of the tuff sequence. Lithic tuff commonly grades upward into tuff of type I.

Type III: This type is a chlorite-rich devitrified tuff that differs from the type I tuff primarily in its high chlorite content. A distinct "bedding cleavage," giving the tuff a crude "shaly" appearance, is present in this lithology. Large chlorite "patches" up to about 1 cm across may be seen on cleavage surfaces. In thin sections cut perpendicular to the bedding, discontinuous zones of chlorite enrichment cross the thin section and abundant intersertal chlorite is present between the zones. Gradation from type I to type II tuff is observed in three beds of the DR 1269 section (Figure 38).

Type IV: Type IV is a fine-grained devitrified tuff that is light gray-green in color and has a cherty appearance. It occurs in thin beds (less than about 6 inches or 15 cm thick) and commonly shows a faint lamination which is best observed on a weathered surface. In thin section, the rock is seen to be composed of devitrified shards and pumice fragments in a dominant matrix of microcrystalline quartz-chlorite-plagioclase (?). The greater abundance of microcrystalline matrix is the principal difference between this tuff and that of type I. Quartz veins locally cut through this fine tuff and small-scale warping of the bedding is common.

Unequivocal definition of individual pyroclastic deposits is not possible in the section studied. Numerous apparent bedding planes, which may represent primary

separations of individual deposits, are present in the sequence, as indicated in Figure 38. Texture is uniform across many of these contacts, however, and it is possible that some of them are of secondary origin.

Since the Jemtland tuff sequences are underlain and overlain by graptolitic shale, it is reasonable to infer a subaqueous environment for their formation. The observed gradation from type II to type I and from type I to type III in the DR 1269 section is suggestive of the grading described by Fiske (1963) in subaqueous pyroclastic deposits of inferred turbidity-current, ash-fall, and pyroclastic-flow origin from the Ohanapecosh Formation (Eocene and Oligocene?) of Washington. In the Ohanapecosh deposits, Fiske noted both particle-size grading and particle-density grading, commonly in the same deposit. The more vesicular a particle of a given size, the higher in the deposit it tends to occur; non-vesiculated fragments are generally distributed in a bed according to size, if graded at all. The apparent grading, in the Jemtland tuffs, from lithic to nonlithic tuff (type II to type I) results from the upward decrease in abundance and size of nonvesiculated lithic fragments; upward increase in vesiculated fragments, if ever present, is now obscured by postdepositional crushing and devitrification.

The vertical change from type I tuff to chlorite-rich tuff (type II) may be due to an upward increase in original

finely powdered ash and admixed nonvolcanic argillaceous material. The thinly bedded fine-grained devitrified tuff is here interpreted to represent a series of aquagene ash-fall deposits.

The presence of fragmented shelly fossil debris mixed with the lithic fragments indicates that the coarser tuffaceous material was transported prior to deposition. Settling ash and lithic ejecta would be expected to smother benthonic faunas (Shrock, 1948) with little or no mixing and fragmentation.

#### Stratigraphic Variations

General Statement. The Jemtland Formation displays marked areal variations in the relative abundances of some of the rock types discussed above. In addition, there is an apparent tendency for repetitive ordering of features in the graywacke beds which follows the model formulated by Bouma (1962). A detailed study of the Jemtland was undertaken to determine whether the lateral lithologic variations are systematic and to see if the vertical cyclicity in the sequence involves the pelitic rock types as well as the graywacke beds. Systematic lithologic variations, if present, would allow important paleogeographic conclusions to be drawn, and a regular superposition of the rock types, or the lack of it, should shed light on the sedimentology of the sequence.

Seven relatively large exposures of the formation were analyzed using a field procedure only slightly modified from that developed by Walker (1967; personal communication, 1969). Walker's method was altered to allow the numbering and classification of the pelitic beds. Bed thicknesses were measured to the nearest centimeter, and siltstone laminae less than 4 mm thick were noted but included with the enclosing pelitic rock type. All internal sedimentary structures were determined in the field; in most cases the weathered surfaces of the graywacke beds sufficiently displayed the internal structures to allow the differentiation of intervals A, B, and C.

All of the sections studied are from the lower half of the formation; since no large-scale vertical variations have been observed in the formation, these sections (with one exception) are assumed to be representative of the formation in the area where they occur. The thinly bedded nature of the sequence permits the examination of a relatively large number of sedimentation events in a typical roadcut or quarry exposure.

The results of the study allow the Jemtland to be divided into "graywacke" (western) and "slate" (eastern) facies. These facies will be first described separately to introduce the major sedimentologic features of the sequence. Next, the systematic lateral lithologic variations in the formation will be presented to show the

gradual nature of the transition from the graywacke to the slate facies. Finally, the vertical ordering of the rock types will be examined to test the applicability of the complete Bouma "turbidite" model to the sequence, and, in particular, to study the relations of the pelitic rock types to each other and the graywacke beds. A summary of data pertinent to these discussions is given in Table 17.

Graywacke Facies (west). The graywacke facies consists of greater than 50 percent graywacke and less than 40 percent slate. This facies occurs in the Stockholm Mountain Syncline, southeastern Portage quadrangle (Story Hill area), northern Ashland quadrangle, and in the vicinities of Mapleton and Spragueville (Presque Isle Quadrangle). There are excellent exposures of the facies at fossil localities 48, 61, 62, 82, and DR 394 (Figure 19).

The lithologic and sedimentologic features of the graywacke facies are well illustrated by the section at locality 61 along Maine Route 161 in Jemtland. A graphic presentation of this section (section 2 of Table 17) is shown in Figure 39.

The graywacke beds consist of one or more of Bouma's lower three sedimentologic intervals (A, B, or C). Transitions from interval A (below) to interval B (above) are gradational or sharp-conformable; a sharp-erosional contact is very rare. Interval C overlies interval B with gradational and, more commonly, sharp-erosional

	Section						
	1	2	3	4	5	6	7
<b>SECTION DATA</b>							
Total Measured Section (cm):	3157	2780	1847	622	1060	2348	411
Graywacke Thickness (percent):	52.3	57.6	55.1	29.4	38.9	54.2	27.7
Pelite Thickness (percent):	47.7	42.4	44.9	70.6	61.1	45.8	72.3
Graywacke/Pelite ratio:	1.09	1.34	1.23	0.42	0.64	1.18	0.38
<b>GRAYWACKE BEDS</b>							
Total Number of Beds:	201	175	198	39	60	88	23
Percent of Beds Beginning with							
Interval A:	49.2	41.7	22.3	15.4	13.3	71.6	4.0
Interval B:	25.4	41.7	59.5	82.0	70.0	9.1	44.0
Interval C:	25.4	16.6	18.3	2.6	16.7	19.3	52.0
<b>PELITIC BEDS</b>							
Aggregate thickness (cm) of							
Laminated Silty Shale:	458	488	221	40	1	--	99
Silty Shale:	736	242		32	--	165	181
Slate:	295	448	609	367	647	908	17
Aphanitic Limestone:	16	--	--	--	--	2	--
Total Thickness (cm) of Pelitic Beds:	1489	1178	831	439	648	1073	297
Laminated Silty Shale (Percent):	30.8	41.5		9.2	0.2	--	33.4
Silty Shale (Percent):	49.8	20.5		7.3	--	15.5	60.8
Slate (percent):	19.8	38.0	73.4	83.4	99.8	84.4	5.7

TABLE 17

Stratigraphic data from relatively large exposures of the Jemtland Formation. Laminated and nonlaminated silty shale were not distinguished at section 3. Locations of the sections are shown in Figure 54.

Figure 39: Stratigraphic section of a portion of the Jemtland Formation at fossil locality 61. The section was described following a procedure modified from that developed by Walker (1967). Current sense for paleo-current measurement is indicated by a single arrowhead; double arrowhead indicates that no current-sense information was available.



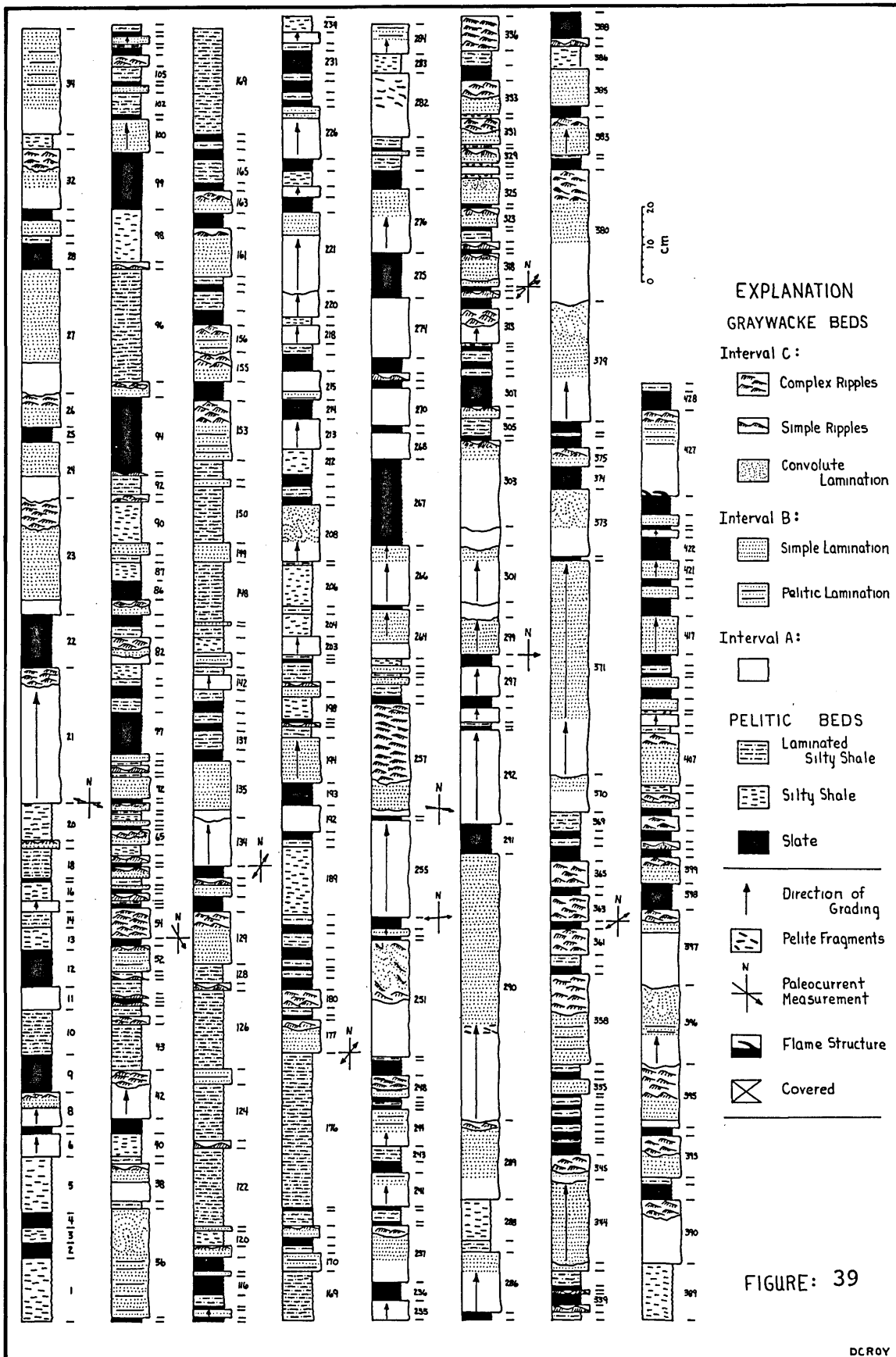


FIGURE: 39

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contacts. Convolute C intervals (particularly those without ripple lamination) have gradational lower contacts and may rest directly on A intervals; many of the convolute C intervals appear to be deformed B intervals. A rippled C interval may rest on an A interval, but a surface of erosion typically separates them. Erosional surfaces are involved in upward changes of C to A, C to B, B to A (Figure 37B), and A to A. These transitions occur in "amalgamated beds" as defined by Walker (1967) ("composite beds" of Wood and Smith, 1959), such as those formed by beds 299-303 and 395-397. The A intervals commonly consist largely of medium to coarse lithic graywacke which may or may not be graded.

The graywacke beds rest with sharp contacts on underlying pelitic beds. Small-scale load casts and flame structures are ordinarily visible along the basal contacts of most of these beds. Evidence of erosion of the underlying pelitic bed is seen along some of the contacts (maximum of about 3 cm of contact relief observed), but most show no obvious erosional effects. Longitudinal ridges and tool marks are present on the soles of a few beds; flute marks are not common.

Upper contacts of intervals A and B with overlying pelitic beds are almost universally sharp. On the other hand, C intervals commonly grade upward into the pelitic material (especially slate) because of vertical increase

in argillaceous material in the ripple-drift lamination (Figures 34B and 37A).

The three types of pelitic beds are thinly interbedded with each other and the graywacke beds. It is not uncommon for several pelitic beds to be present between graywacke beds. Sharp-conformable contacts are present between pelite beds.

Slate Facies. The slate facies of the Jemtland is composed of 50 percent or more slate and generally less than 40 percent graywacke. Slate may locally be the only pelitic rock type present. This facies is found in the synclinal infolds of the Jemtland in the Washburn-Perham area (Figure 4), but has not been observed in the Presque Isle quadrangle, although section 6 (Table 17) has some of its characteristic features as discussed below.

The stratigraphic sections measured at DR 1564 and DR 590 (Figure 29) are presented in Figure 40, and data for them are included in Table 17 as sections 4 and 5, respectively. For the most part, the same rock types are present in these sections as in the section at locality 61 previously discussed, but their relative abundances are markedly different. Comparison of Figures 39 and 40 and examination of the data of Table 17 indicate the following features as distinctive of the slate facies:

- (1) Graywacke/pelite ratio is less than 1.0.
- (2) Graywacke beds beginning with interval B are

Figure 40: Stratigraphic sections of portions of the Jemtland Formation at DR 1564 (A) and DR 590 (B) of Figure 37. The sections were described following a procedure modified from Walker (1967). Refer to explanation in Figure 39.

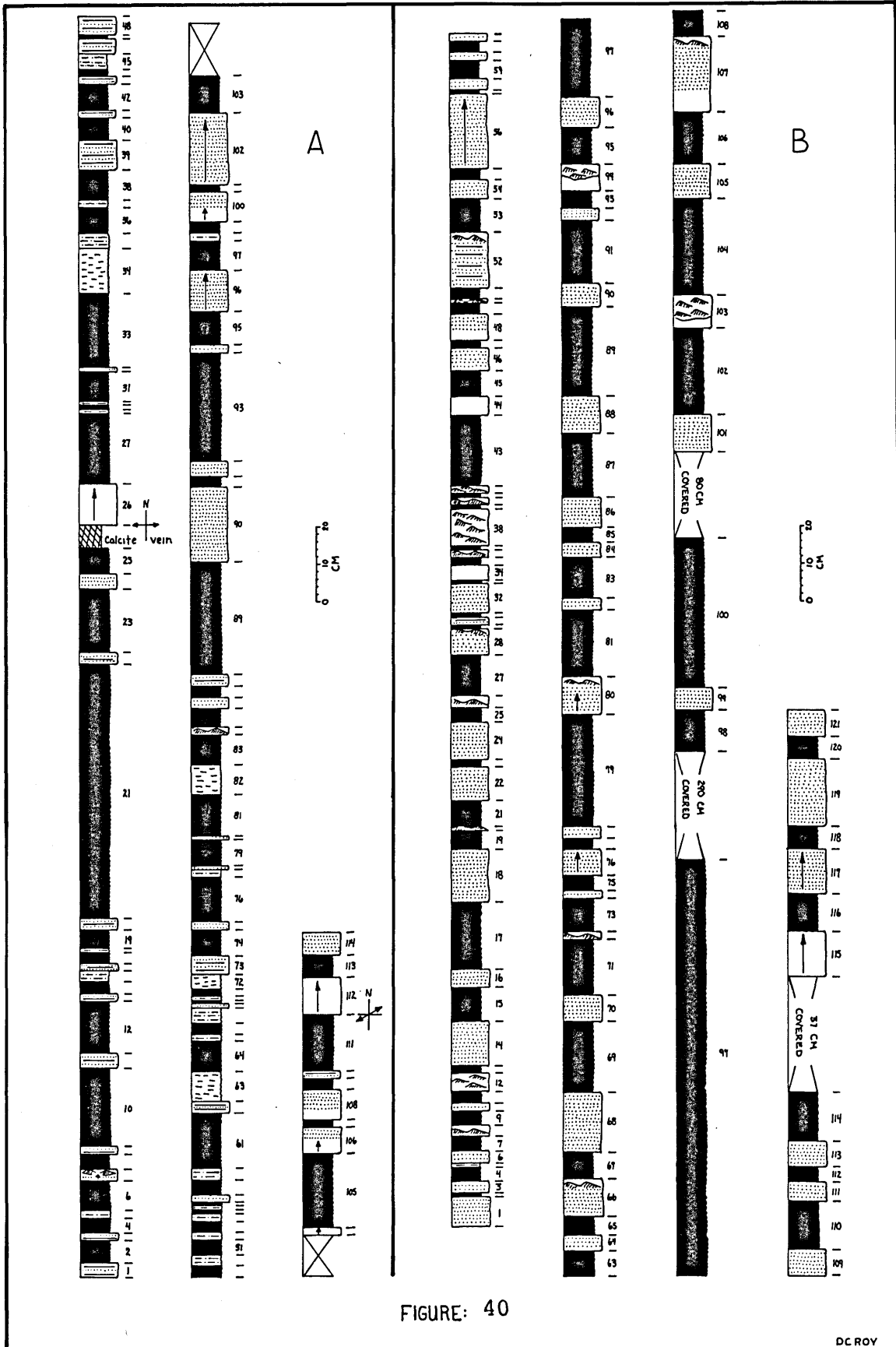


FIGURE: 40

far more abundant than those beginning with intervals A and C.

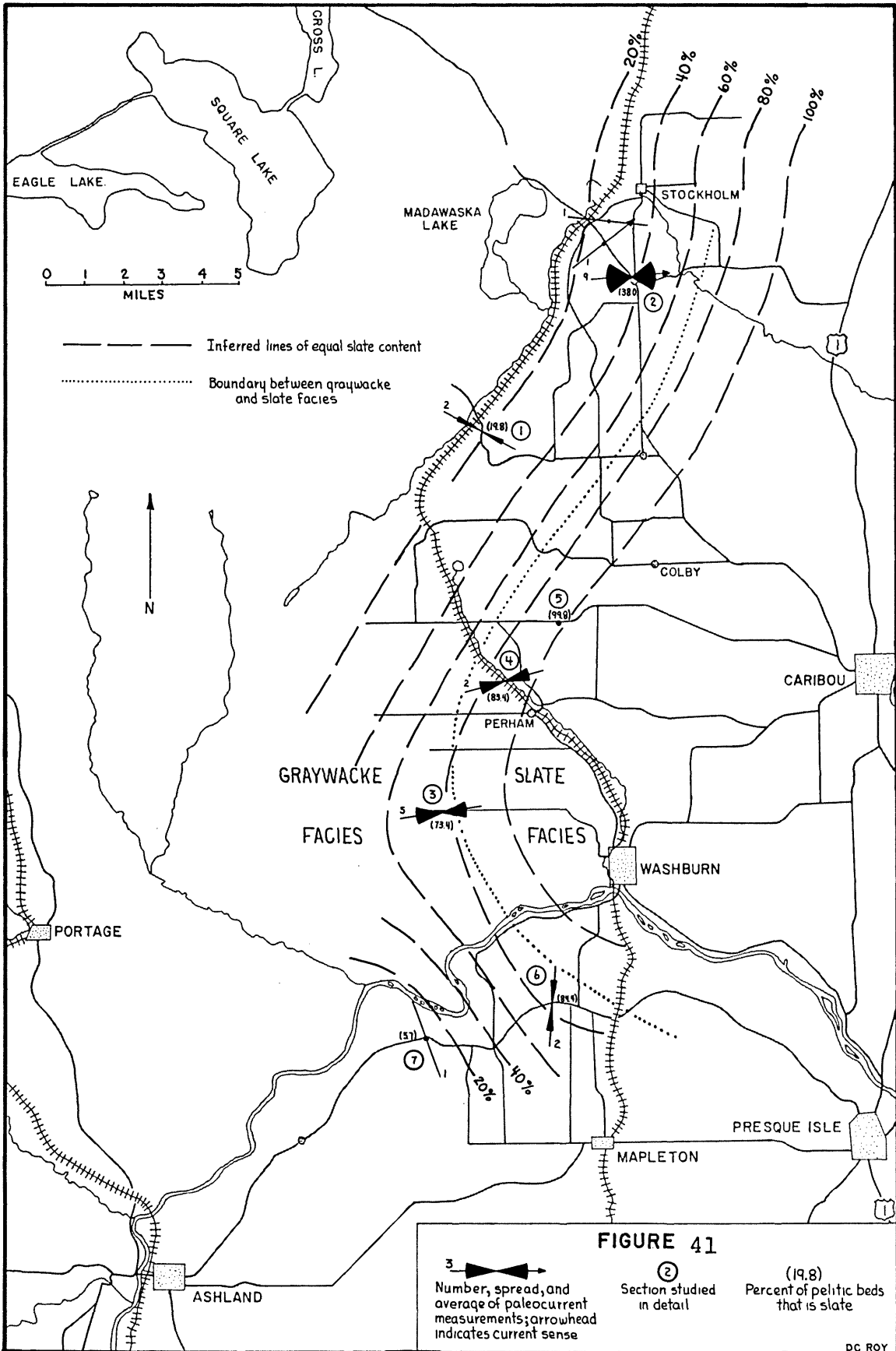
(3) Abundance of the laminated silty shale and silty shale rock types is much lower than in the graywacke facies.

(4) Analgamated graywacke beds are virtually absent.

Areal Lithologic Variations and Paleocurrents. The most obvious lithologic variation is the slate-rich character of the eastern part of the formation in the Washburn-Perham area (slate facies) as compared with the slate-poor, graywacke-rich sequence to the west (graywacke facies). The slate proportion of the pelitic beds in the sections studied (Table 17) are contoured in Figure 41. The data indicate that the slate portion of the pelitic beds increases rapidly and systematically from west to east. The rate of increase perpendicular to the contours between sections 1 and 5 is about 17 percent per mile; correction for the folding yields a rate of about 9 percent per mile.

If the proportion of slate in the Jemtland as a whole is considered, a contour pattern very similar to that shown in Figure 41 results; the line separating the graywacke facies from the slate facies in Figure 41 approximates the location of the 50 percent slate contour. The rate of increase of slate in the Jemtland sequence between sections 1 and 5 is approximately 11 percent per mile and correction

Figure 41: Paleocurrent data, lithofacies, and slate abundance in the Jemtland Formation. Contours represent the proportion of slate in the pelitic beds. The seven sections studied in detail (Table 17) form the basis for information presented here.





for folding reduces this rate to nearer 6 percent per mile.

Changes in the graywacke beds are also evident north of the latitude of Washburn. As shown in Table 17, there is a systematic reduction in the proportion of graywacke beds beginning with interval A between section 1 and section 5. The proportion of beds beginning with interval B, on the other hand, shows a general increase from northwest to southeast. Beds beginning with interval C show no systematic variation.

Southwest of Washburn the variation in types of graywacke beds is not clear. Section 6, for example, consists of fine graywacke (in beds up to 13 feet, or 4 m, thick) interlayered with slate (Table 17). The sequence thus appears to be near the graywacke-slate facies boundary. A high proportion of the graywacke beds (72 percent), however, are composed in part or totally of nonlaminated and homogeneous-appearing fine sandstone which has been assigned to the A interval. The abundance of A intervals and the great thickness of a few of the beds suggest affinities with the more western phase of the graywacke member. It is possible that "latent" lamination in the fine graywacke beds has prevented the proper recognition of many of the "homogeneous" intervals as B intervals, and hence has resulted in an over estimation of the proportion of A intervals in the section. Section 7 has a very low slate content (5.7 percent) but also has a low graywacke

proportion (8 percent); most of the section is made up of laminated and nonlaminated silty shale. Since only 411 cm of the formation is available at section 7, the measured abundances of lithologic types may not be representative.

The paleocurrent directions, indicated by sole features of the graywacke beds, are shown in Figure 41. Although it is not possible to make large numbers of measurements, the paleocurrent data obtained in this study show a regular pattern which suggests that the currents transporting the graywacke detritus came from the west and south (southwest). In general, the currents moved in the direction of decreasing graywacke and increasing slate abundance. Also, the proportion of graywacke beds with basal A intervals decreases downcurrent whereas beds beginning with B intervals increase.

Cyclic Sedimentation. In almost every exposure of the Jemtland Formation, the most conspicuous vertical variation is the consistent arrangement, in ascending order, of intervals A, B, and C. Systematic relations of the pelitic rock types to this A-B-C sequence, if present, is not obvious in the field. In this section, lithologic correlations of the pelitic rock types of the Jemtland to the pelite-rich intervals of Bouma (D and E) and "pelagic" interval (F) of subsequent workers will be made; this ordering will then be tested using a Markov chain

analysis to determine the consistency of the model sequence with sections of the Jemtland.

In the Peira-Cava Flysch of the Maritime Alps, Bouma (1962, p. 51-52) defined a "turbidite" layer as "....a part of the sediment section in which the grain size either remains constant or decreases from bottom to top. Its upper limit is therefore the junction with coarser material, even if this is very indistinct....An abrupt upwards decrease in grain size...., is not interpreted as the limit of a layer, but as a 'break'." Bouma's criteria reflect a long-standing observation that graded units (of wide-scale range) occur repetitively, even cyclically, in many flysch-type sequences (for a review, see Kuenen, 1953, and Dzulynski and Walton, 1965). Bouma found that his criteria led to an ordering of intervals displaying predominantly one type of internal sedimentary structure. Bouma's sequence model has received wide usage, and variations of it have been proposed for specific sequences (e. g. Bassett and Walton, 1960; Hubert, 1966 and 1967; Ballance, 1964; Van Der Lingen, 1969). In the Peira-Cava area, Bouma found that the entire flysch sequence could be described using his model (allowing for "base cut-out" and "truncated" sequences); only thin "clayey marl or marl" beds were omitted from the sequence and interpreted as "pelagic sediment."

The graywacke beds and pelitic rock types of the Jemtland Formation may be arranged in order of vertical decrease in average grain size and compared with Bouma's intervals as follows:

	<u>Jemtland Formation</u>	<u>Bouma Intervals</u>
Top	Slate	"F"
	Silty Shale	E
	Laminated Silty Shale	D
	Interval C	C
	Interval B	B
Bottom	Interval A	A

This arrangement suggests that the laminated silty shale may be equivalent to Bouma's D interval, which he describes as a layer characterized by an "indistinct lamination" which is not visible if the layer is "weathered or tectonized." He further describes the rock as a "fine sandy to silty pelite" that may show an upward decrease in sand content and that usually overlies the C interval with a sharp contact. The laminated silty shale of the Jemtland appears to be quite similar to that described for the D interval by Bouma (refer to Figure 33), but is not consistent with the assignment of thinly interlaminated fine siltstone and pelite to this interval (Figure 8; see Walker, 1967 and Hubert, 1967).

The correlation of the nonlaminated silty shale beds with the E interval is also consistent with Bouma's

description of that interval. Contrary to Bouma's observation that interval D grades into interval E, however, macroscopically sharp contacts are generally seen between the laminated and nonlaminated silty shales of the Jemtland.

The slate of the Jemtland Formation is not usually calcareous and does not compare favorably to Bouma's "marl." Designation of the slate as an "interturbidite" or "pelagic interval" is attractive because of its very fine-grained character. The fairly common observation of the same type of pelite as muddy laminations in B intervals, and involved in ripple-drift lamination in C intervals suggests, on the other hand, that some fine argillaceous material was present during the formation of the graywacke beds.

The Jemtland exposures were studied to determine whether repetitive sequencing of the basic rock types occurs. A first-order Markov chain analysis as described by Griffiths (1966) and Krumbein (1967) was applied to several Jemtland sections. The data from the sections shown in Figures 39 and 40 are presented and discussed here to illustrate the results.

If the sequence model based on decreasing grain size and lithologic similarity presented above represents a "complete" or "composite" cycle which occurs repetitively (in whole or in parts) in the sections, one would expect

upward lithologic transitions from A to B, B to C, C to D, D to E, and E to F to be more frequent than their reciprocals. This is equivalent to asserting that in the development of the sequence, an element of "memory" is present in which the occurrence of a given lithology is statistically dependent on the immediately preceding (underlying) rock type. A first-order Markov chain may be used to describe a sequence of rock types in terms of the frequencies and probabilities of given transitions and aids in assessing the presence of cyclical successions (Griffiths, 1966; Krumbein, 1967).

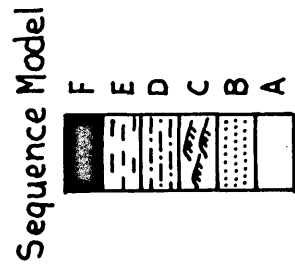
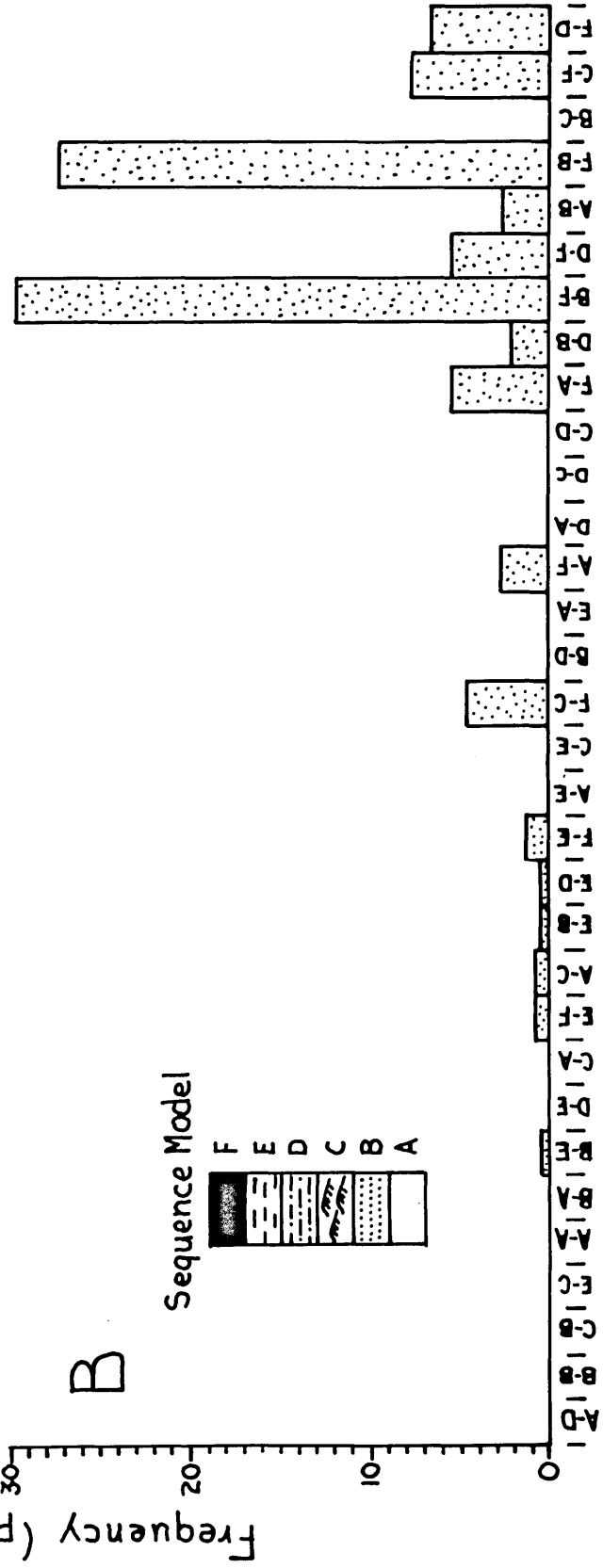
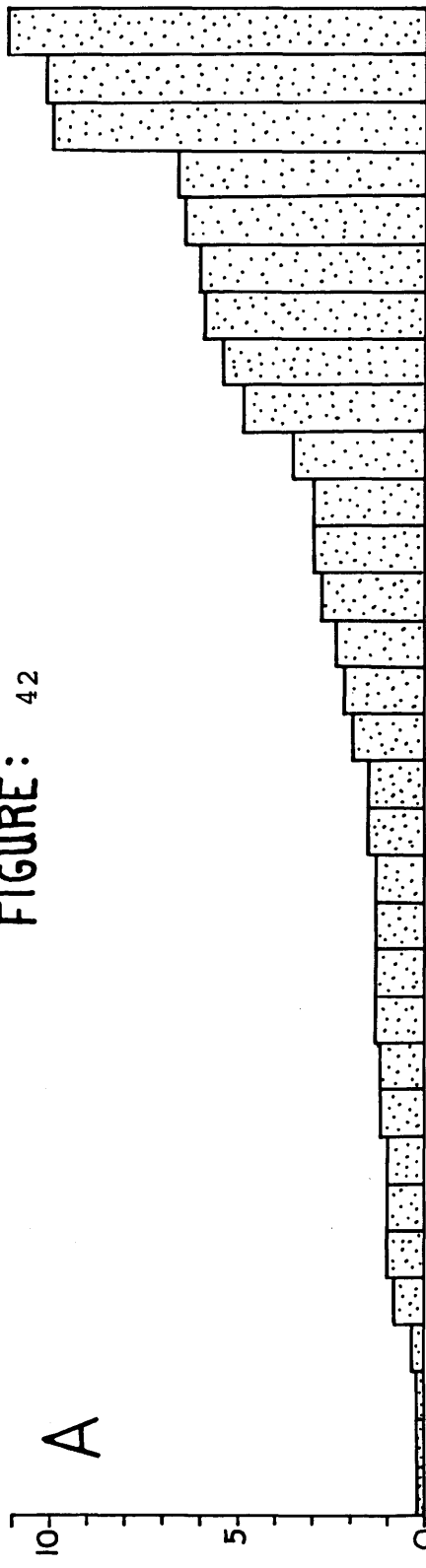
The frequency distribution for the vertical lithologic changes in the graywacke facies section shown in Figure 39 is given in Figure 42A. The letter designations for the lithologic intervals are the same as those presented above. All types of transition occur except C to C, D to D, E to E, and F to F; A to A and B to B transitions are not frequent. Transitions from A to B, B to C, and C to D emerge as more common than their reciprocals, a feature of the section which tends to favor the model. The preference for C to D transitions, as opposed to those involving D to C, is not great at locality 61 and at locality 82 (section 1 of Table 17) these transitions are about equally likely. Transitions involving intervals E and D are not strongly ordered, but E to D appears to be slightly favored, which is not consistent with the

Figure 42: Frequencies of upward lithologic transitions in sections from the Jemtland Formation. The abscissa is a nominal scale (Krumbein, 1962), and the second letter of each pair (e.g. C-B, B-D, etc.) indicates the lithologic interval above the contact. Symbols used in the sequence model are the same as those in Figure 39.

A. Frequency distribution for the section at locality 61 (Figure 39) of the graywacke facies. Upward transitions are arranged in order of increasing frequency from left to right.

B. Sum of the frequency distributions for the sections shown in Figure 40.

FIGURE: 42





proposed sequence. Changes involving F are among the most frequent, but no consistent frequency pattern emerges to support a sequencing involving this interval.

Transition probability matrices (Griffiths, 1966) of the graywacke facies at localities 61 and 82 are given in Table 18. These matrices show the probabilities of a given vertical transition and allow the most probable transitions to be easily seen. In Table 18A, for example, interval A is seen to be followed by interval B 50 percent of the time, by interval F 21 percent of the time, and so forth. The transition probabilities tend to support the A to B to C sequencing of the graywacke intervals, particularly if transitions to the pelitic rock types (D, E, and F) from B are ignored in Table 18B. In the graywacke facies, where the three pelitic rock types are well represented, no consistent sequencing of them is suggested. Comparison of the probability data of Table 18 and the abundance of the pelitic rock types in Table 17 suggests that the C intervals tend to be overlain by the more abundant of the two nonlaminated pelitic types (E or F).

A similar analysis of sequences in the slate facies of the Jemtland are shown in Figure 4B and Table 19. The results may be summarized as follows:

- (1) transitions involving interval F (slate) are the most frequent, as might be expected from the abundance of slate in the sections (Figure 40).

Upper Lithology

	A	B	C	D	E	F
Lower Lithology	A .062	.497	.100	.016	.116	.209
	B .050	<u>.010</u>	.497	.104	.050	.289
	C .073	.012	<u>.000</u>	.212	.090	.613
	D .159	.297	.159	.000	.055	<u>.330</u>
	E .353	.200	.062	.200	.000	.185
	F <u>.186</u>	.256	.074	<u>.434</u>	.050	.000

A

Upper Lithology

	A	B	C	D	E	F	G
Lower Lithology	A .110	.382	.133	.040	.162	.173	.000
	B .079	<u>.000</u>	.296	.105	.369	.151	.000
	C .013	.013	.000	.195	<u>.454</u>	.325	.000
	D .263	.145	.195	.000	.195	.189	.013
	E <u>.233</u>	.256	.187	.256	.000	.034	.034
	F .315	<u>.067</u>	.114	<u>.363</u>	.128	.000	.013
	G .200	.000	.000	<u>.200</u>	<u>.300</u>	<u>.300</u>	.000

B

TABLE 18

Transition probability matrices for the sections at locality 61 (A) and locality 82 (B). These are sections 2 and 1, respectively, of Table 17. Underlined probabilities indicate the most likely "upper lithology" to follow a given "lower lithology" in the sequences. Probabilities in each row total 1.0. Lithology G is aphanitic limestone.

		Upper Lithology					
		A	B	C	D	E	F
Lower Lithology	A	.000	<u>.431</u>	.138	.000	.000	<u>.431</u>
	B	.000	.000	.076	.012	.012	<u>.899</u>
	C	.000	.000	.000	.000	.000	<u>1.0</u>
	D	.000	.274	.000	.000	.000	<u>.726</u>
	E	.000	.250	.000	.250	.000	<u>.500</u>
	F	.119	<u>.603</u>	.101	.150	.027	.000

TABLE 19

Transition probability matrix for the sum of the sections at DR 1564 and DR 590 (sections 4 and 5 of Table 17). Underlined probabilities indicate the most likely "upper lithology" to follow a given "lower lithology." Probabilities in each row total 1.0.

(2) Intervals A, B, and C tend to be overlain and underlain by slate, but A to B and B to C transitions are important.

(3) The D and E intervals are not abundant and are largely interlayered with slate.

From the preceding discussion it is concluded that the A-B-C portion of Bouma's model is well represented in the Jemtland Formation, as seen in the field. This sequence involves only the graywacke beds. The pelitic beds do not appear to be part of either a separate repetitive succession or one linked closely to the A-B-C sequence. However, the apparent tendency for C intervals of the graywacke beds to be overlain by either the silty shale or slate rock types, depending on which is the more abundant in the section, may have genetic implications, as discussed in a later section. The laminated silty shale, though lithologically similar to that described by Bouma for his D interval, does not appear to fit into a recurring succession as predicted by Bouma's model.

#### Lower Contact

The Jemtland Formation overlies (from west to east) the Frenchville, New Sweden, and Spragueville formations. Transitional contacts with the Frenchville and New Sweden can be observed; the contact with the Spragueville is not observed, but may also be conformable.

The contact of the Jemtland with the underlying Frenchville is best seen in the vicinities of fossil localities 38-41 (Figure 21) and 33 (Figure 23). In both of these areas the transition involves the upward introduction of the pelitic and graywacke beds of the Jemtland. Near the contact, the lithic graywackes of the Frenchville become fine grained and generally more calcareous.

The transition from the Jemtland to the New Sweden is exposed: (1) in the section on the Blackstone farm (Boucot, et al., 1964a, Appendix IV; Figure 29), (2) along Maine Route 227 at section 6 (Figure 41), and (3) along the east-west road north of fossil locality 102 on the Dudley Farm (Plate I). In all three cases, essentially noncalcareous slates of the New Sweden are replaced, over a few tens of feet stratigraphically, by the typical Jemtland rock types. At section 6 (Figure 41) and on the Dudley farm, manganiferous ironstone together with red and green slate are present below the contact; locally, near the contact at the Dudley farm are occurrences of limestone breccia (see Miller, 1947, plates 13 and 15, for a detail map and section for the Dudley farm).

#### Thickness

The Jemtland Formation is remarkably uniform in thickness over a wide area. In the Stockholm Mountain Syncline, where both the top and bottom of the unit are

generally well located, the formation averages about 2500 feet (760 m) and locally may be as much as 2800 feet (850 m) thick. Boucot, et al. (1964a) estimated the unit to be approximately 2000 feet (610 m) thick in the Presque Isle quadrangle. This figure is in substantial agreement with the writer's estimate of between 2000 and 2200 feet (610 m) in the Mapleton-Presque Isle area (section C-C' of Plate III). It is therefore possible that the Jemtland thins to the east (southeast), but this thinning probably does not exceed 500 feet (150 m).

#### Age

A total of 55 fossil localities have been found in the Jemtland Formation, which make it one of the best dated stratigraphic units in New England. The paleontologic data given in Tables 20 and 21 and shown graphically in Figure 5 indicate that the Jemtland is of Wenlockian and Early Ludlovian age. The data include localities cited by previous workers and those obtained during this study.

The contact of the Jemtland with the overlying Fogelin Hill Formation is clearly established as Early Ludlovian in age (probably graptolite zone 34), since the lower portion of the Fogelin Hill has yielded graptolites of probable Early Ludlovian age (locality 105). A large number of the localities (47) produced faunal assemblages indicative of the Ludlovian and in most cases the Early Ludlovian. The stratigraphic distribution of

Table 20: Fossil localities 48-87 from the Jemtland Formation. Graptolites identified by W. B. N. Berry; brachiopods identified by A. J. Boucot; trilobites identified by A. R. Palmer in consultation with H. E. Whittington and Kenneth Campbell (Pavrides, 1968); ostracods identified by J. M. Berdan. Locality 48 is locality IX of Berry (1960); Locality 49 is approximately equal to locality "PV" of Boucot, et al. (1964a); locality 56 is locality "LB" of Berry (1964); locality 59 is Locality E-13 of Boucot, et al. (1964a) and locality 12 of Pavrides (1968); locality 65 is locality D-3 of Boucot, et al. (1964a) and locality "DB" of Berry (1964). Localities 64, 66-68, 79-81, and 83-87 are located outside the area of Plate I. The following ages are assigned to the localities: localities 50, 58, and 90, Late Llandoveryan-Wenlockian; locality 88, C<sub>3</sub> of the Llandoveryan-Wenlockian; localities 51 and 59, Late Wenlocian; locality 75, Ludlovian; localities 48, 54, 56, 57, 62, 65 and 67, Early Ludlovian (zone 33); localities 49, 52, 53, 55, 60, 61, 64, 68, 69, 70, 72, 73, 74, 76, 78, 79, 81, and 82-87, Early Ludlovian (zones 33-34); localities 63, 66, 71, 77 and 80, probably Early Ludlovian (zones 33-34).





Table 21: Fossil localities from the Jemtland (Sj) and Fogelin Hill (Sfh) formations, Graptolites identified by W. B. N. Berry; brachiopods and gastropod identified by A. J. Boucot. Locality 97 is locality B-2 of Boucot, et al. (1964a) and locality "DF" of Berry (1964); localities 98, 99, 109 and 102 are localities E-5, E-9, E-7 and A-2, respectively, of Boucot, et al. (1964a); locality 100 is locality A-8 of Boucot, et al. (1964a) and locality "CS" of Berry (1964). The following ages are assigned to the fossil localities: locality 91, Late Llandoveryan-Ludlovian; locality 101, Late Wenlockian-Ludlovian; locality 102, Ludlovian; localities 89, 92-96, and 105, probably Early Ludlovian (zones 33-34); localities 103 and 104, Ludlovian-Siegen.



the Early Ludlovian localities indicates that the upper 85-90 percent of the Jemtland is of that age.

The age of the lower contact of the Jemtland is not precisely established, but is known to be within the Wenlockian. Two localities (51 and 59) have produced Late Wenlockian fauna, and fossils from five localities indicate age spans of Late Llandoveryan-Wenlockian. As shown in Figure 5, the contact is inferred to lie in the Early Wenlockian, but it could be as young as Late Wenlockian.

#### FOGELIN HILL FORMATION

##### Name and Distribution

A sequence of slate, fine sandstone, and siltstone overlying the Jemtland Formation in Stockholm Mountain Syncline is here named the Fogelin Hill Formation. The unit is named for Fogelin Hill, a prominent topographic feature in west-central New Sweden Township. No complete section of the formation is available, but excellent exposures of it are found on both flanks of the syncline between Hanford and Stockholm. In particular, the formation is well exposed: (1) in the village of Stockholm (especially at fossil locality 104), (2) on the west slopes of Fogelin Hill, (3) in the fields just northeast of Hanford, and (4) along Tangle Ridge Road at fossil locality 103 just southwest of Hanford.

## Lithology

The Fogelin Hill consists of light-green and red slate interlayered with calcareous fine sandstone and siltstone. The rock types are quite variable in abundance, and a particular outcrop may be formed of only one lithology.

Slate. It is estimated that slaty rocks form between 40 and 60 percent of the formation. Most of these rocks are light-olive-green or red-brown, silty, micaceous slate which contains thin seams of light-green or red, fine-grained pelite. The slates are variably calcareous. The cleavage is commonly parallel or subparallel to the bedding and may locally give the rocks a platy appearance.

The red and green slates of the Fogelin Hill are a distinctive feature of the formation and contrast sharply with the gray pelitic beds of the underlying Jemtland. The color pattern in many exposures does not appear to be stratiform, and patches of one color may exist in the other. Thin beds of slate (between fine sandstone beds) have been observed, however, in which the colors are stratiform, with the red phases consistently overlying the green. The boundary between the red (or red-brown) and green slates is usually irregular and diffuse.

Fine sandstone and siltstone. Light-greenish-gray, very calcareous, and micaceous fine-grained sandstone or siltstone beds are interbedded with the slates. These rocks are generally parallel laminated, and an orange-buff,

porous-weathering rind is usually present.

The lamination is caused by cyclic variations in argillaceous material and detrital mica (muscovite?) on the scale of 2 mm or less. Splitting of the sandstone or siltstone along the planes of mica concentration is typical, especially in weathered roadcuts. Non-laminated beds are also common, but cross-laminated and convolute-laminated beds are rare.

The sandstone and siltstone occur in beds from 1/8 inch (3 mm) to several feet (1 to 2 m) thick, but most are 1 to 6 inches (2 to 15 cm) thick. These rock types are similar to those of like grain size in the Jemtland but differ primarily in the conspicuous absence of ripple lamination and the presence of a distinct greenish tinge in their color.

#### Lower Contact

The Fogelin Hill Formation rests conformably on the Jemtland Formation in the Stockholm Mountain Syncline. A similar relationship probably exists between the units just north of Ashland near the Bellville Road, but stratigraphic and structural control there is poor.

The contact is closely located just northeast of Hanford, just north of Jemtland, and in the village of Stockholm. In Stockholm, an almost continuous sequence of exposures extends from fossil locality 95 in the Jemtland Formation down the hill (along the road north

from the village) to basal red slates of the Fogelin Hill Formation. Green slates occur in the Jemtland section below the red slates and are taken to indicate the changing character of the sequence; the contact is placed just below the red slate.

#### Thickness

The top of the Fogelin Hill has not been observed in the Stockholm Mountain Syncline; therefore, the total thickness of the formation is not known. Approximately 2500 feet (760 m) of the unit is present along the axis of the syncline from Stockholm to just west of Spalding. It is possible that thicker sections of the formation are preserved in the broader northeast and southwest extensions of the fold.

#### Age

Three fossil localities have been found in the Fogelin Hill which suggest a possible age range of Ludlovian to Siegenian (?) (Table 19). Locality 105 is stratigraphically near the base of the unit, and Berry (personal communication, 1970) considers the graptolite assemblage to be of probable Ludlovian and possibly Early Ludlovian age. The poorly preserved graptolites of localities 103 and 104 are placed in the Ludlovian-Siegenian span by Berry. The monograptid of locality 103, however, has thecae similar in shape to those of the M. hercynicus group; if the monograptid belongs to that group, an Early Devonian age is indicated.

Locality 103 is near the axis of the Stockholm Mountain Syncline and therefore represents the highest dated strata in the formation.

#### SILURIAN SANDSTONE AND SLATE IN THE ASHLAND AREA

In and east of Ashland, the writer has mapped an undifferentiated Silurian sequence consisting largely of sandstone and slate, but also locally containing some conglomeratic mudstone. The sequence is not sufficiently well understood to justify establishing it as a formal stratigraphic unit at this time; it will be described here only briefly.

Typical rock types of the unit may be seen immediately east of the village of Ashland, where it overlies the conglomerate member of the Frenchville Formation (Plate I; Figure 4). There the sequence appears to consist mostly of light-gray, quartzose, and calcareous fine sandstone with less abundant interbeds of green-gray to olive-green slate. The sandstone is thin- to medium-bedded and locally fracture-cleaved. On the east flank of the broad synclinal plunge, at fossil locality 109, strata resembling those of the Jemtland Formation are present. Graptolites from this locality (Table 22) are placed by W. B. N. Berry (personal communication, 1970) in the Early Ludlovian.

In Ashland itself, Ludlovian brachiopods (A. J. Boucot, personal communication, 1965) were obtained from

light-green, calcareous, thinly bedded, micaceous siltstone at locality 108 (Plate II). Also, along Main Street (Maine Route 11) in the town, just north of its intersection with Maine Route 163 (Plate II), is a badly weathered exposure of shale, fine sandstone, and pebbly mudstone. Both of these exposures are placed in the sandstone-slate sequence and are inferred to be separated from the more eastern occurrences of the unit by the north-south Ashland Fault and intervening terrane of Winterville and Frenchville rocks (inset map, Figure 24).

Conglomeratic mudstone is exposed at fossil locality 110 and in nearby exposures along Maine Route 163 (Plate I). Cobbles up to 8 inches (20 cm) in greatest dimension are present in the cleaved mudstone matrix which forms about 60 percent of the rock. A large proportion of the pebbles and cobbles (80-90 percent) are of rock types that may be assigned to the Jemtland Formation, and several of the larger fragments even show thinly interlayered pelitic and graywacke beds. The mudstone matrix is micaceous, silty, calcareous, and gray in color.

Light-gray, fine-grained, silty limestone and beds of green-gray, pebbly, medium-grained sandstone have been observed interbedded locally with the conglomeratic mudstone.

Brachiopods from the mudstone matrix of the conglomerate at locality 110 (Table 22) have been assigned a Late Llandoveryan age by A. J. Boucot (personal communication,



FAUNA	LOCALITY		
	108	109	110

GRAPTOLITES:

Monograptus colonus var compactus Wood cf.  
Monograptus sp. (of the M. dubius types) x

BRACHIOPODS:

Coelospira saffordi cf.  
Isorthis arcuaria (Henryhouse type) aff. x  
Pentamerus sp. x  
Resserella sp. x  
Stricklandia sp. x

304 CORALS:

indeterminate x

TABLE 22

Fossil localities in an unnamed Silurian sandstone-slate sequence near Ashland. W. B. N. Berry identified the graptolites, and A. J. Boucot identified the brachiopods. Ages are assigned to the assemblages as follows: locality 108, Ludlovian; locality 109, Early Ludlovian; locality 110, Late Llandoveryan. The possibility of the brachiopods of locality 110 being a reworked fauna is discussed in the text.

1969). The presence of Late Llandoveryian brachiopods in a conglomerate containing fragments closely resembling the rock types of the Wenlockian-Ludlovian Jemtland Formation presents a contradiction that cannot be solved using presently available data. Three possible explanations can be offered:

1. The brachiopods are reworked and the conglomerate is younger (Latest Silurian-Early Devonian) than the Jemtland Formation.

2. The conglomerate is of Late Llandoveryian age and the rock fragments are not from the Jemtland, but come from an older, lithologically similar, sequence.

3. Nothing is as it appears: the brachiopods are reworked and the rock fragments do not come from the Jemtland.

Boucot, et al. (1964a) cite the apparent absence of Upper Ludlovian and lower Gedinnian rocks between strata here assigned to the Jemtland and volcanic rocks of the upper Gedinnian (Hedgehog Formation) in the Presque Isle quadrangle as indicative of a period of nondeposition and/or erosion. This nonsequence was correlated with the Salinic disturbance proposed earlier by Boucot (1962). The occurrence of conglomeratic mudstones with fragments of Jemtland (?) rock types immediately to the west of the area of nonsequence is the principal reason the writer favors alternative (1) above. Regardless of which

alternative is correct, the relationship of conglomerates to the rest of the sequence in which they are tentatively included is not clear; future work may show that the conglomerates are part of a separate (possibly younger) period of sedimentation than that represented by the sandstone and slate succession nearer Ashland.

## DEVONIAN ROCKS OF THE ASHLAND AREA

Devonian rocks are present in the study area only in the vicinity of Ashland. Rocks of Devonian age do, however, form extensive neighboring terranes; the reader is referred to Boucot, et al. (1964a) for a discussion of the Devonian of the Presque Isle quadrangle; Boone (1959), Pavlides, et al. (1964), and Horodyski (1968) describe the major features of the Devonian rocks west of the Presque Isle quadrangle. Since the study of Devonian rocks is beyond the scope of this investigation, only a brief discussion of strata of that age mapped by the writer in the Ashland area is given here.

East of the Ashland Fault, lower Devonian rocks are present in a syncline (refer to inset map of Figure 24). These rocks consist largely of gray, brown-weathering, micaceous, silty slate. Interbedded with this slate are:

- (1) Micaceous, laminated, platy siltstone. This siltstone is commonly weathered to an orange color and may contain carbonized plant debris.
- (2) Fine-grained, laminated, micaceous sandstone in beds from 1 inch to 1 foot (2-30 cm) thick. The sandstone contains abundant macerated carbonaceous (plant?) material and is usually weathered to an orange or orange-brown color. In some exposures this sandstone may form up to 50 percent of the section.

(3) Light-gray, finely crystalline, argillaceous limestone. Beds of this limestone at fossil locality 113 (Appendix) contain abundant brachiopods, which A. J. Boucot (personal communication, 1966) assigns to the Middle or Late Helderbergian (Late Gedinnian-Early Siegenian).

(4) Light-gray, coarsely crystalline crinoidal limestone. This limestone is commonly fractured. A collection made by the writer from this rock type at fossil locality 111 (locality 1098 A1 of Williams and Gregory, 1900, p. 52) has produced conodonts (Appendix) which G. Klapper (communication to A. J. Boucot, 1966) assigns to the Gedinnian. Similar limestone at locality 112 has yielded brachiopods, pelecypods, corals, a trilobite, and a gastropod (Appendix), which A. J. Boucot (personal communication, 1966) places in the middle to upper Helderbergian.

(5) Limestone conglomerate. This conglomerate consists of tabular to rounded pebbles and cobbles of light-gray, finely crystalline limestone in a matrix of gray, calcareous, commonly cleaved pelite. This lithology is well exposed south of Ashland in the south road ditch of Fenderson Road at the Winslow Cemetery (Plate I).

No volcanic rocks have been observed in the Devonian section in and near Ashland; this is surprising in view of the extensive volcanic section present at Hedgehog and

Squa Pan mountains a few miles to the southeast (Boucot, et al., 1964a). Volcanic rocks of the Winterville Formation in and north of Ashland were tentatively correlated with the Devonian volcanics of the Presque Isle quadrangle in early mapping (R. S. Naylor, personal communication, 1970), and this correlation is indicated on the recently published geologic map of Maine (Doyle, 1967); the relations of these volcanic rocks to overlying Silurian strata indicate that this correlation should be abandoned.

The relationship of these lower Devonian strata to the Silurian sandstone and slate sequence, discussed previously, is not clearly established. In Ashland the lower Devonian overlies the Silurian rocks (Figure 24), but the nature of the contact is unknown. East of Ashland, at a distance of 2.15 miles along Maine Route 163, exposures of Devonian limestone conglomerate are inferred to overlie the Silurian strata at locality 109; however, the contact has not been seen. Since no strata of Late Ludlovian, Predolian, or Early Gedinnian age have been documented, an unconformity is quite possible at the base of the Devonian section in the Ashland area.

## DISCUSSION AND CONCLUSIONS

### GENERAL STATEMENT

From the standpoint of regional stratigraphy, probably the most important contribution of this work is the establishment of the Silurian stratigraphy, as shown in Figure 5, and the mapping of these units over a wide area of northeastern Maine. To the writer's knowledge, there is no other area in New England where the complete (or nearly so) Silurian system is so well documented paleontologically and where the lithofacies relations have been studied over so large an area.

The complexity of the Silurian stratigraphy in northeastern Maine suggests that coeval sequences in metamorphic areas may be of widely different lithologic character, and correlations of lithologically similar units may, on the other hand, lead to the mixing of units of differing age. The presence of certain rock types in units of different ages indicates that care must be exercised in the use of "key" rock types for correlation purposes. Red slates, for example, are present in rocks of Ordovician, Silurian, and Devonian age, and the distinctive aphanitic limestones are seen in all formations except the Winterville, Aroostook River, and Fogelin Hill. Similar-appearing sequences of widely different ages are also present; the Madawaska Lake Formation is grossly similar to some slate

phases of the Devonian (Seboomook Formation), and, at higher metamorphic grades these slate sequences would be difficult to separate lithologically. Conglomerates, compositionally similar to those of the Frenchville (Early Silurian) have been found in rocks as young as Early Devonian in the Fish River-Big Machias lakes area (Horodyski, 1968; Roy, unpublished data), indicating that such conglomerates are more indicative of the persistent influence of source terrain than age.

On the other hand, it does appear that the manganeseiferous ironstones are restricted to the Silurian, and most are probably lower Silurian. Thinly bedded aphanitic limestone, though present in many of the formations, is apparently restricted to the pre-Devonian in the study area, and the occurrence of this rock type or its altered equivalent in metamorphic areas may be useful in separating the Silurian system from undifferentiated Siluro-Devonian sequences.

The lithofacies developed in a particular basin are the result of many factors, and it is expected that the resulting stratigraphy will be, in large part, unique. The uniqueness of the sedimentation history of a basin undoubtedly becomes greater the more closely the stratigraphy is examined, but many of the large-scale features of its development may have counterparts in basins in



similar tectonic environments. In order to set the stage for the more detailed discussions which follow, the major developments in the pre-Devonian sedimentation history inferred from the stratigraphy of Figure 5 are presented below:

(1) Pre-Silurian. At the close of the Ordovician, northeastern Maine was on the eastern margin of an area of submarine volcanism, with associated chert, graywacke, and black-shale deposition. Over much of the area to the east of the volcanism, shale-graywacke (Madawaska Lake Formation) and shale-limestone-graywacke (Carys Mills Formation) deposition was in progress. The region was in the heart of the eugeosynclinal portion of the geosyncline, where an environment of deep water surrounding local emergent volcanic islands was present.

(2) Early Llandoverian. In the earliest Llandoverian, regional uplift (Taconic orogeny) of the entire area began, producing increased emergent areas to the west and southwest while leaving the study area submerged. During this uplift, coarse material derived largely from the volcanic terrain entered the basin by turbidity-current transport; this sand became interlayered with argillaceous sediments in sediment ponds (Aroostook River Formation) that were at least in part separated from more eastern areas of continuing limestone deposition (Carys Mills Formation). by submarine areas receiving little or no deposition.

(3) Middle Llandoveryan-Early Wenlockian. During this period the uplift reached its maximum extent, and the emergent terrain attained its closest proximity to the still submerged study area. Coarse debris, shed from the nearby land areas, poured into the basin down steep slopes, forming a clastic wedge of conglomerate and sandstone near the base of the slopes, with sandstone interlayered with shale farther out in the basin (Frenchville Formation); eastward from this coarse clastic sequence, shale with local ironstone (New Sweden Formation) and calcareous mudstone (Spragueville Formation) were deposited. During the development of these lithofacies, the region began to subside, and the shoreline advanced onto the land as the basin became deeper.

(4) Late Wenlockian-Ludlovian. As the basin grew deeper and the study area became more offshore, a thinly bedded flysch sequence developed (Jemtland Formation) in which turbidity-current deposits are well represented. This lithofacies shows abundant indications that the source areas of the Late Silurian were similar to those for the Early Silurian, but more distant. The Jemtland lithofacies is followed, in the Stockholm Mountain Syncline, by an even more distal flysch-like sequence (Fogelin Hill Formation) containing red slates that are perhaps indicative of a more open basinal environment.

(5) Predolian-Siegenian. The transition from the Silurian to the Devonian is marked in several areas by a disconformity and in other areas by possible conformity. In the Stockholm Mountain Syncline, Fogelin Hill sedimentation may have persisted into the Early Devonian, but in the Ashland-Presque Isle area a disconformity is probable between Ludlovian and upper Gedinnian rocks. Except for the areas of disconformity, the latest Silurian-Early Devonian was, for the most part, a time of continued transgression of the sea onto remnant land areas and local volcanism.

#### PRE-SILURIAN SETTING

The pre-Silurian history in the eugeosyncline (Magog Belt of Kay, 1951) of the Appalachian geosyncline is complicated, and many of the details are yet to be resolved. For the purposes of this discussion, we need only concentrate on the general geologic setting of northern Maine and neighboring New Brunswick in the latter part of Ordovician. Fortunately, recent investigations by several workers (Skinner, 1956, cited in Davies, 1966; Boucot, et al., 1964a; Hall, 1964; Pavlides, et al., 1964; Neuman, 1960, 1967; Pavlides, 1968) have greatly advanced our understanding of the Caradocian-Ashgillian time interval in this area of the geosyncline; the following points now appear to be well established:

(1) In northeastern Maine and northern New Brunswick four major lithofacies belts were formed during the zone 12 and 13 time span. These lithofacies are (from west to east); (a) western volcanic facies, (b) slate-graywacke facies, (c) limestone-slate facies (some graywacke; the Aroostook-Matapedia Belt of Pavlides, et al., 1968), and (d) eastern volcanic facies (Tetagouche Belt of Bird and Dewey, 1970). A slate-graywacke facies may also be present between the limestone-slate and eastern volcanic facies in the "Slate Division" of the Tetagouche Group as used by Davies (1966) (approximately unit O<sub>1</sub> of Potter, et al., 1968); however, the relationship of the rocks of the Aroostook-Matapedia and Tetagouche belts is obscured by faulting and a cover of younger rocks. The stratigraphic units currently established which form parts of each lithofacies are:

Western Volcanic Belt: Winterville Formation (Horodyski, 1968; this report), Bluffer Pond Formation (Hall, 1964), Munsungun Lake Formation (Hall, 1964), Blind Brook Formation (Hall, 1964), Unnamed volcanic rocks? and the Wassataquoik Cert in the Shin Pond area (Neuman, 1967), Dunn Brook Formation (Pavlides, 1962, 1964).

Slate-graywacke Belt: Madawaska Lake Formation (Hamilton-Smith, 1969; this report), Nine

Lake Formation? (Pavrides, 1964),  
Mattawamkeag Formation? (Ekren and  
Frischknecht, 1967)

Aroostook-Matapedia Belt: Carys Mills Formation (Pavrides,  
1968), Chandler Ridge Formation,  
(Pavrides, 1968)

Tetagouche Belt: Tetagouche Group (Skinner, 1956; Davies,  
1966)

(2) In the Spider Lake area the western volcanic facies (zone 12-13) is underlain by a volcanic-poor sequence, the Chase Lake Formation (Hall, 1964: see Figure 8). This formation, of zone 11-12 age, contains a lower conglomerate-graywacke member, and an upper slate-graywacke member; graywackes from both members contain abundant fragments of volcanic and sedimentary (slate, chert, and quartzite) rocks.

(3) Rocks of Late Llanvirnian-Llandeilan (zones 9 and 10) age have not been documented in northern Maine or New Brunswick.

(4) The persistence of the lithofacies belts into the Late Ordovician (zones 14 and 15) is only partially documented. The presence of brachiopods and graptolites of Ashgillian age in the Winterville Formation at fossil locality 1 in Ashland indicates that the western volcanic facies was present there at that time. Hall (1964) suggests the possibility that the Blind Brook Formation

also extends from zone 13 of Caradocian (established) to as young as Ashgillian, but no firm evidence for the younger age is available. Stratigraphic evidence has been presented in this report indicating the possibility that the Madawaska Lake Formation (slate-graywacke belt) may extend into the Ashgillian; lithologic similarities of parts of the Pyle Mountain Argillite (Ashgillian) to the Madawaska Lake suggests that the Pyle Mountain may represent a local (Castle Hill Anticline area) encroachment of the slate-graywacke facies onto a "dormant" portion of the western volcanic facies. The Carys Mills Formation of the Aroostook-Matapedia Belt contains Ashgillian graptolites at locality 22 and Early Silurian graptolites elsewhere which document the persistence of this lithofacies into the Early Silurian (Ayrton, et al., 1969). The Tetagouche Belt is not reported to contain Ashgillian strata, and it is possible that the eastern volcanic facies present in this group did not continue into the latest Ordovician. Neuman (1967) describes dated Ashgillian sandstone, conglomerate, and siltstone (unnamed) in the Traveler quadrangle that overlies greenstone; these may represent deposition marginal to an emergent part of the western volcanic facies.

The origin of the volcanic facies has been the subject of much speculation. The presence of arcuate belts of appreciable length and containing volcanic rocks in the

eugeosynclinal portion of the New England Appalachians has led to the common conclusion that these belts represent "chains" of volcanoes or volcanic islands. Most of the formations comprising the volcanic belt show an interlayering of flow rocks (commonly pillowed) with dark slates (many containing graptolites), cherts (with and without radiolarians), tuffs, and tuffaceous sandstones and conglomerates. This association has commonly been interpreted to represent deposition in relatively deep water (Kay, 1951; Hall, 1964; Neuman, 1967, 1968). The location of volcanic (or nonvolcanic) terrain that was emergent during the formation of the volcanic belts is difficult to establish; however, the abundance of volcanic and, less commonly, shelly fossil debris in the sandstones and conglomerates associated with the flow rocks is taken as evidence that shoals or emergent areas existed (Horodyski, 1968; Neuman, 1968).

Several attempts have been made to explain the Middle Ordovician volcanic belts as ancient island arcs, analogous to those seen in the western Pacific and elsewhere today. In a recent synthesis of the tectonic development of the Appalachian orogene (Bird and Dewey, 1970), for example, it is suggested that both the western volcanic belt (their Oliverian Belt) and the Tetagouche belt were island arcs complete with trenches along their eastern margins. The area of this study is placed, therefore,

between two island arcs and inferred to contain both a trench and ocean basin (Bird and Dewey, 1970, Figures 1 and 10). Two considerations suggest that this interpretation severely strains both the known pre-Silurian geology of the region and the features of modern island arcs:

(1) There is an important problem of scale. Placement of the trench zone of middle or upper Ordovician age immediately east of the main "mass" of volcanic rocks of that age (Bird and Dewey, 1970) means that it must run near or southeast of Houlton, Maine (in Ordovician rocks). No evidence of such a trench (e.g. chaotic deposits, "argille scaliöse," cited by Bird and Dewey as indicative of a trench zone) is present in northeastern Maine and has not been reported in New Brunswick. In addition, modern island-arc trenches are normally 200-300 km (130-190 miles) from the main volcanic activity; allowing for shortening due to the Acadian folding, an eastern trench associated with the volcanic belt in the <sup>area</sup> study/should be located in the Ordovician section in central or southeastern New Brunswick, an area which is unfortunately largely covered by carboniferous strata.

(2) As pointed out by Kay (1951), many modern island-arc terrains have had extensive geosynclinal histories, with commonly more than one period of deformation, metamorphism, and intrusion, and care should be exercised



in interpreting lithofacies of a given time interval as indicating the presence of such an arc. In some arcs (e.g. Sumatra-Java), the present volcanism is largely superficial and a relatively recent development.

The Caradocian-Ashgillian lithofacies suggest to the writer that northeastern Maine was the site of marine volcanism in the west with nearby slate-graywacke and more distant (east) limestone-slate deposition. Submarine volcanic cones (seamounts?) and emergent areas (containing volcanic and nonvolcanic rocks) were probably present, shedding coarse clastic debris into the surrounding basinal areas. As shown schematically in Figure 43 A-1, evidence of the latest Ordovician (Ashgillian) indicates that some originally volcanic areas were covered by thin (?) argillaceous deposits (Pyle Mountain Argillite) as well as sandstones and conglomerates (unnamed unit in the Traveler quadrangle, Neuman, 1967). The known Ashgillian deposits are along the eastern side of the volcanic belt, and their absence farther west in the heart of the volcanic terrane is probably due to a combination of nondeposition, post-Taconian erosion, and nonrecognition.

#### ORDOVICIAN-SILURIAN TRANSITION: TACONIC OROGENY

##### Regional Considerations

In many parts of New England, Silurian rocks rest unconformably on Ordovician and pre-Ordovician rocks;

Figure 43: The schematic development of the Silurian stratigraphy in the Ashland and Presque Isle quadrangles.

A. Development of the stratigraphy along section C-C' of Plate III from the Ashgillian to Early Ludlovian.

B. Profile through the Silurian section between Ashland and Perham during the Early Ludlovian showing the writer's interpretation of the Frenchville lithofacies in the Ashland-Frenchville area.



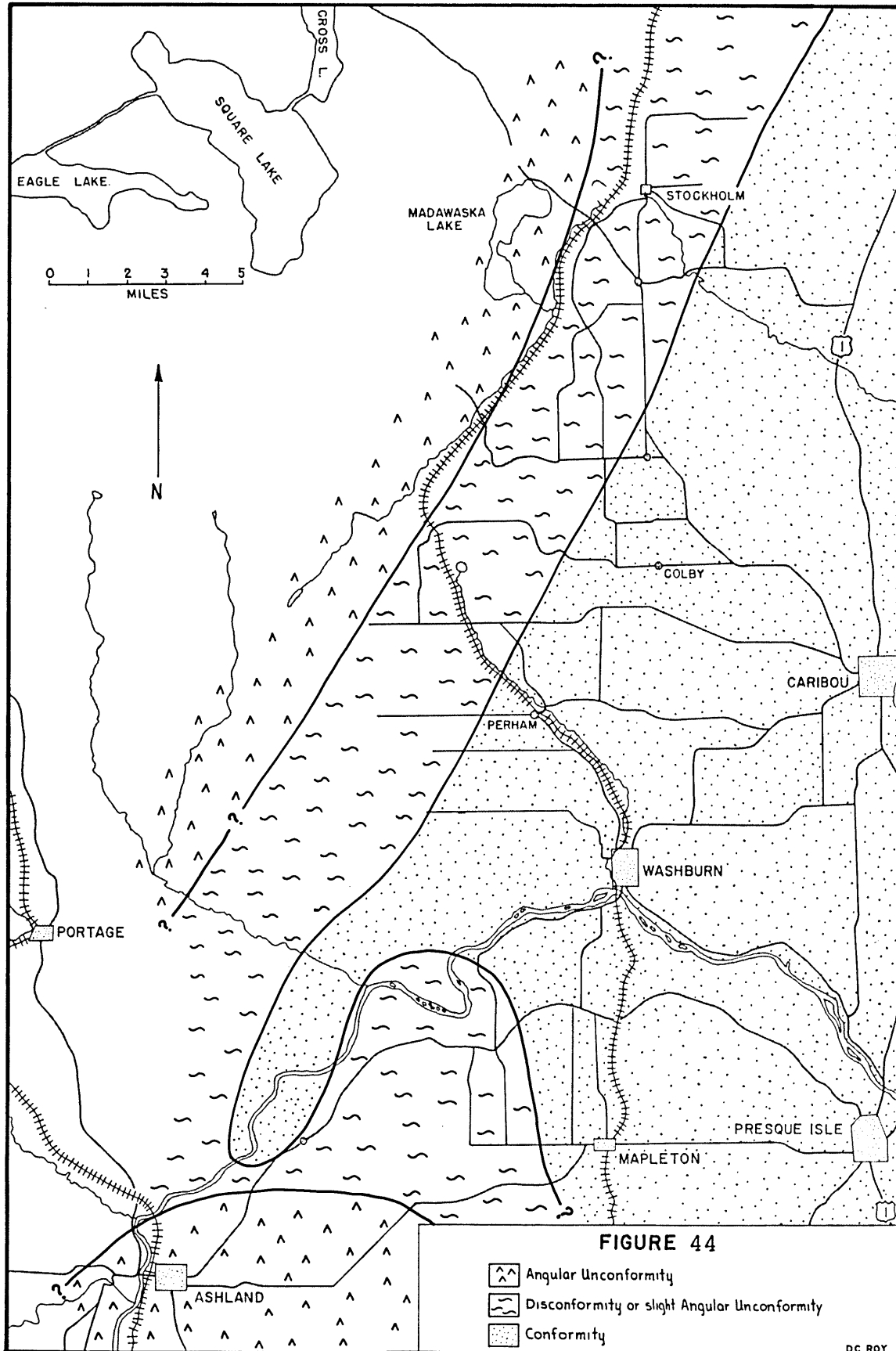
in most cases this unconformity is attributed to a Middle Ordovician to Early Silurian period of deformation, the Taconic orogeny. In a recent detailed review of the stratigraphic evidence for this orogenic event, Pavlides, et al. (1968) have shown that the orogeny affected some areas and had little or no effect in other areas; the present regional data suggest that areas of angular unconformity and conformity form parallel belts with intervening areas of apparent disconformity (Pavlides, et al., 1968, Figure 5-1). Using, in part, data supplied by the writer, Pavlides, et al. (1968) show the area of this study as containing the transition from angular unconformity in the west to conformity in the east.

#### Area of this Study

The inferred areal extents of angular unconformity and conformity between the Ordovician and Silurian systems in the area of this study are shown in Figure 44; an intervening region of disconformity or only slight angular unconformity is also indicated.

The area of conformity in the eastern part of the area is based on the paleontologic data in the Carys Mills Formation that show it to extend into the Early Silurian; regionally the formation is known to contain strata of graptolite zones 13, 15, 18, and 19 (Pavlides, 1968). The extension of the area of conformity as a narrow belt toward Ashland is based on the local presence of the

Figure 44: Areal relationships of Silurian to Ordovician rocks in the area of this study. Criteria for establishing each area are discussed in the text.



Aroostook River Formation below the Frenchville. The Aroostook River is here considered to be Early Llandoverian (?) in age and is inferred to overlie the Madawaska Lake Formation conformably, as shown in section C-C' of Plate III.

The areas of angular unconformity are based on observed angular unconformities and the lack of documented lower Llandoverian rocks in each area. The boundaries of these two areas probably join beneath younger rocks to the southwest, since no lower Llandoverian rocks have been observed in the Greenlaw and Oxbow quadrangles (Roy and Mencher, unpublished data; Henry Hansen, personal communication, 1969) or on flanks of the Weeksboro-Lunksoos Lake Anticline (Neuman, 1967).

The area of disconformity (or very slight angular unconformity) is based on the absence of lower Llandoverian rocks and the structural conformity of upper Llandoverian strata (primarily the Frenchville) on pre-Silurian units.

The map of Figure 44 is not drawn on a palinspastic base; and, as a result, the areas showing a particular relationship are compressed in a northwest-southeast direction (about 50%) north of the latitude of Washburn and in an east-west direction south of Washburn. In the Ashland-Frenchville area, strike-slip movements along nearly east-west faults have shifted some terrain to the west, and the Alder Brook Fault, of uncertain displacement ,

is probably responsible for closely juxtaposing areas of angular unconformity and apparant conformity (Figure 44).

#### Timing of the Taconic Orogeny

The timing of the Taconic deformation in northeastern Maine is now well established as Early Llandoverian (Pavliades, et al., 1968; see Figure 5). Pavliades (1968) has argued that the transition from the limestone-rich Carys Mills to the more slate-rich Smyrna Mills Formation (Houlton area) and New Sweden Formation (area of this study) during the interval of graptolite zone 19 reflects the tectonism and may be used to date the first movements of the uplift to the west. The writer concurs, in part, with this assessment; however, such a subtle and gradual change in sedimentation may lag behind the initial movements of the deformation.

Hamilton-Smith (1969) described the Siegas Formation in the Siegas, New Brunswick area as an Early Llandoverian, proximal turbidite sequence conformably underlying the New Sweden. The Siegas Formation, of limited extent, is interpreted by Hamilton-Smith to represent the first influx of coarse clastic debris from an uplifted area, to the north, along the present western anticlinorium. The clastic debris in the Siegas is rich in volcanic and aphanitic limestone clasts; the former are attributed to the erosion of a volcanic (Winterville?) terrane and the latter were derived from eroding Carys Mills strata.



The Aroostook River Formation, also of local extent, contains brachiopods similar to those in the Siegas Formation, but not as definitively Early Llandoveryan (A. J. Boucot, personal communication, 1966), and is here interpreted to be a turbidite sequence in which the first coarse material from a rising western source invaded the basin. Both the Aroostook River and Siegas formations are considered to be coeval with the upper part of the Carys Mills. Since the youngest rocks below the Taconic unconformity are Ashgillian (Pyle Mountain Argillite and young phases of the Winterville), and the oldest sedimentary rocks in the basin that reflect the uplift are lower Llandoveryan, the initial Taconic movements probably occurred in the early, perhaps earliest, Llandoveryan.

#### Nature of the Taconic Deformation

The Taconic orogeny in northern Maine was a mild deformational event (Hall, 1964; Pavlides, et al., 1964; Boucot, et al., 1964a; Pavlides, et al., 1968). No regional cleavage or metamorphism has been unequivocally assigned to this uplift, although local angular unconformities (this study) beneath Silurian rocks, and beta diagrams for Ordovician bedding (Hall, 1964; Hamilton-Smith, 1969) provide evidence for at least gentle folding. General uplift of the western volcanic belt along the trend of the present Munsungun-Pennington Mountain

Anticlinorium appears to have been the principal effect.

The Rockabema quartz diorite (locally granodiorite) of post-Caradocian and pre-Late Llandoveryian age (Neuman, 1967; Ekren and Frischknecht, 1967) may be associated with the Taconic orogeny, and probably forms a part of the Highlandcroft Plutonic Series (Billings, 1937; Naylor, 1968). The Rockabema is a small pluton in the Weeksboro-Lunksoos Lake Anticline, and is described by Neuman (1967) as an "altered quartz diorite, including medium-grained equigranular and porphyritic facies and fine-grained porphyritic facies.... Much of the Rockabema is cataclastically sheared.... The texture of the light-colored more equigranular coarse-grained rock is subhedral....with some granophyric intergrowths of quartz and feldspar. An incipient porphyritic texture is suggested by the clustering of like minerals. Feldspar is slightly more abundant than quartz, and together they compose about 95 percent of the rock. As much as one-third of the feldspar in some specimens is potassic, some slightly perthitic, indicating a compositional range of the rock from quartz diorite to granodiorite.... Chlorite and epidote pseudomorphs after biotite form about 5 percent of the rock.... The traces of granophyric texture preserved in the more equigranular rock indicate that part of the Rockabema

is a hypabyssal intrusive."

The cataclastic texture and chloritization of mafic minerals are interpreted to be Acadian effects since the cleavage in the pluton parallels the regional cleavage and fragments of the Rockabema in mantling Early Silurian conglomerates (Frenchville Formation) contain unaltered biotite (Neuman, 1967).

Though the deformational effects of the Taconic orogeny in the area of this study involved local folding and nondeposition, very little, if any, of the area became emergent. As discussed in subsequent sections, the Silurian sediments that followed or were coeval with the Taconic hiatus were deposited off-shore and possibly in relatively deep water; no record of near-shore or strand-line deposits is present.

#### EARLY LLANDOVERIAN SEDIMENTATION AND PALEOGEOGRAPHY

##### General

In the area of this study the lower Llandoveryian is represented by the Aroostook River Formation and the upper portion of the Carys Mills. The Aroostook River is composed of interlayered fine slate and sandstone; thinly interbedded slate and limestone (with less graywacke) form the more eastern Carys Mills. These two facies are separated, between Frenchville and Mapleton (Figure 55), by an area in which lower Llandoveryian rocks are absent,

but the facies may interfinger west of Washburn in the subsurface.

#### Aroostook River Formation

The Aroostook River Formation is inferred to overlie the Madawaska Lake Formation and, because of their general similarity (abundance of pelite, in particular), they are thought to be conformable. The interlayering of fine pelite with laminated and graded graywackes suggests that the sequence formed offshore, with turbidity currents supplying the coarse-grained detritus.

Since turbidite sequences are commonly areally extensive, the limited distribution of the Aroostook River Formation suggests that either pre-Frenchville erosion has removed the unit in many areas or it is the result of deposition in a restricted basin. The writer suggests that the formation was deposited in a laterally restricted environment, perhaps a sediment pond; the alternative hypothesis of erosion is considered unlikely because it requires the removal of 1500-2000 feet (460 to 610 m) of the formation just north of Frenchville, whereas a few miles to the west evidence of pre-Frenchville erosion is absent. The westward extent of the Aroostook River Formation is unknown, but the unit is at least in part separated from coeval strata in the Carys Mills to the east by an area lacking lower Llandoveryian strata.

Hersey (1965) and Ryan, et al. (1965) have described modern sediment ponds in and near the Tyrrhenian Abyssal

Plain (including the plain itself) and, since they have found these ponds to contain graded, laminated, and cross-laminated sands interlayered with "malleable" mud, it was suggested that flysch sequences may have formed in such ponds. Regardless of the universal applicability of the sediment-pond model to flysch successions, the model is attractive for the Aroostook River Formation because it explains not only its turbidite nature and restricted distribution, but also helps to explain the seeming absence of coarse detritus in contemporary Carys Mills strata to the east. The model suggests that the coarse debris shed from a rising land area to the west was trapped in sediment ponds before it reached the more offshore environment of limestone and shale deposition.

#### Carys Mills Formation

The Carys Mills Formation represents a rather extended period of sedimentation (at least graptolite zones 13 through 19), and much remains to be learned about the evolution of depositional environments and processes it records. During its early history (Late Ordovician) the Carys Mills was marginal to volcanic belts, though probably largely separated from them by zones of slate-graywacke deposition; later in the Early Silurian volcanic activity was greatly reduced, but volcanic terrane was emerging to the west as a result

of the Taconic uplift. These changes in the tectonic environment of the area, must have had effects on the nature of the strata being deposited. For the most part these effects cannot be defined very precisely, since the scarcity of fossil localities and complex deformation prevent the determination of vertical lithologic variation.

In the area of Plate I where most of the definitive paleontologic data have been found in the formation, the lithologic sequences at the fossil localities suggest an evolution of the sequence that is compatible, in a general way, with what is known about its paleotectonic setting. The Ordovician fossil localities (22 and 23, Table 3) are in successions containing abundant graywacke and slate with less aphanitic limestone, whereas the Early Silurian localities (21 and 24, Table 3) are dominantly aphanitic limestone and slate. It is here suggested that the apparent greater abundance of graywacke beds, commonly containing volcanic detritus and showing grading and other features compatible with turbidity-current deposition, in the Ordovician phases of the Carys Mills is a reflection of its formation in a basin marginal to active volcanism. Younger, more limestone-rich, strata may have been deposited in a basin protected from the influx of coarse-grained detritus by sediment ponds (e.g. the Aroostook River Formation) nearer the source.

Possibly the most interesting lithologic feature of the Carys Mills Formation is <sup>the</sup> abundance of thinly bedded fine-grained limestone. Pavlides (1968) considers most, if not all, of these limestone beds to have been deposited by turbidity currents in view of sedimentary structures that are present in many of them. Neuman (1968) and Hamilton-Smith (1969) have questioned the importance of turbidity-current deposition as suggested by Pavlides and have inferred shallow platform (Neuman) and deep-water restricted basin (Hamilton-Smith) environments as alternative interpretations. Hamilton-Smith based his model on the present-day Black Sea, as described by Caspers (1957) and inferred a biogenic origin for most of the limestones while recognizing the validity of a turbidite interpretation for what he found to be rare graded limestone beds.

There is a growing body of evidence to suggest that thinly layered fine limestone and slate (shale) sequences like the Carys Mills developed offshore, in "deep water" (depth greater than storm wave base; about 300 feet), and under reducing or nearly reducing conditions. Wilson (1969), Garrison and Fischer (1969), and Tyrrell (1969), for example, find this lithofacies a common basinal phase in areas where shelf-slope-basin carbonate sequences can be worked out, and Davies (1968) has described a possible modern analog from the Sigsbee Deep (Gulf of Mexico).

Wilson indicates that the following characterize the limestones of this facies:

- (1) Dominance of lime mudstone
- (2) Relatively common calcisiltites and fine grainstones, usually showing small-scale grading or ripple cross-lamination of the pelletoid grains.
- (3) Dark color (pink and red limestones occur in some places).
- (4) Small-scale, even lamination.
- (5) Very even and planar beds that are generally 0.5 to 1 foot (15 to 30 cm) thick interlayered with thinner shale beds.
- (6) Major discontinuities in bedding appear to form large-scale cut-and-fill or slump structures. There is also a general rarity of convolute bedding, flame structures, or other indications of soft sediment slumping.
- (7) Generally very specialized benthonic fauna; much more commonly solely pelagic fauna. This feature, together with an abundance of carbonaceous material, is taken to indicate low Eh conditions.

With the exception of large-scale slump or cut-and-fill structures (number 6 above), these features are typical of much of the limestone in the Cary Mills, especially its Silurian portion. Wilson's "lime mudstone" and "calcisiltites" are taken to be Pavlides' (1965)



"quartz-free" and "quartzose" limestones respectively. Pelletoid grains, composed of finely crystalline carbonate and argillaceous material, have not been reported from the Carys Mills limestones; these grains, if ever present, may have been eliminated during recrystallization.

Wilson (1969) and Tyrrell (1969) believe that the deep-water limestones have developed by submarine transport of lime mud and fragmental carbonate material from marginal shelf areas. Graded bedding in the calcisiltites and transported fauna are thought to indicate that turbidity currents were an important transporting agent. A similar origin for the Carys Mills limestones was inferred by Pavlides (1968); Hamilton-Smith (1969), however, considered that most of the beds were formed by the settling of biogenetic carbonate from aerated surface waters with subsequent recrystallization to produce the aphanitic texture.

The origin of the limestone beds is still open for considerable study. It is quite likely that both turbidity-current and nonturbidity-current deposition is involved, but as yet no reliable criteria have been found to distinguish limestones of different origins.

#### MIDDLE LLANDOVERIAN-EARLY WENLOCKIAN SEDIMENTATION AND PALEOGEOGRAPHY

##### Lithofacies

The middle Llandoveryian-lower Wenlockian rocks of

the study area form three principal lithofacies:

(1) a western coarse clastic facies (Frenchville Formation),

(2) a medial slate-ironstone facies (New Sweden Formation), and

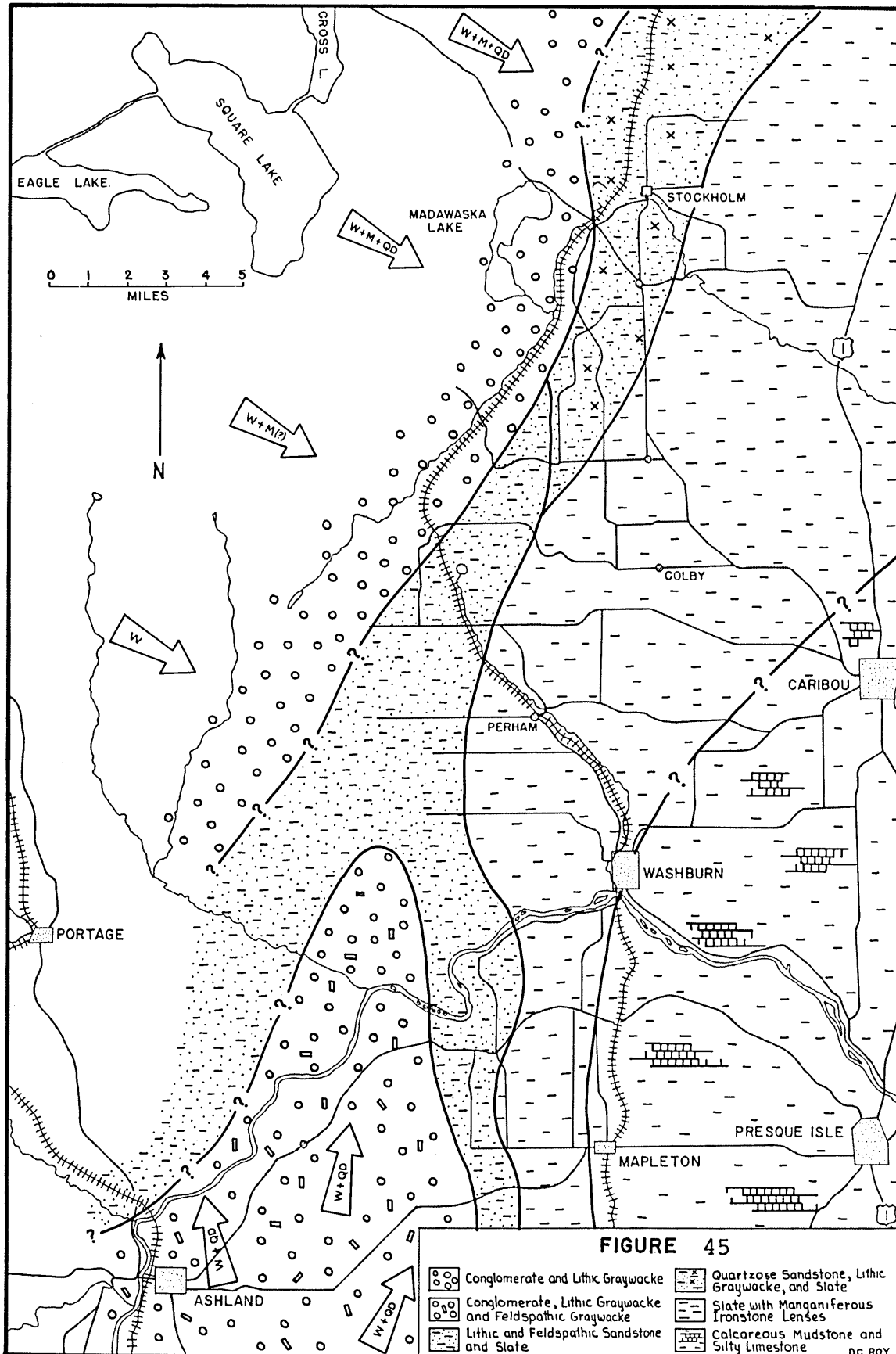
(3) an eastern (largely southeastern) calcareous mudstone-silty limestone facies (Spragueville Formation).

The western clastic lithofacies may be further subdivided into lithofacies corresponding to the five members of the Frenchville Formation. The areal distributions of the middle Llandoveryan-lower Wenlockian lithofacies, together with their principal rock types, are given in Figure 45.

Conglomerate-rich lithofacies are present along the northwest margin of the basin and in the Ashland-Frenchville area to the south; these two occurrences probably join to the southwest, under a cover of younger rocks. Eastward from the conglomerate-rich lithofacies, sandstones become interlayered with increasing amounts of slate until they cease to be important in the section. The conglomerate-rich lithofacies in the Ashland-Frenchville area has a geometry suggestive of a submarine fan, since it interfingers distally with the sandstone-slate lithofacies to the northwest and north as well as to the east.

To the east, the lithofacies of the Frenchville Formation interfinger with the calcareous slates and ironstones of the New Sweden Formation. The slate-

Figure 45: The distribution of Middle Landoverian-Early Wenlockian lithofacies. The area indicated as composed of "conglomerate, lithic graywacke, and feldspathic graywacke" contains the superimposed graywacke, conglomerate, and feldspathic sandstone members of the Frenchville. The conglomerate member of the Frenchville forms the area of "conglomerate and lithic graywacke"; the sandstone-slate member forms the area of "lithic and feldspathic sandstone, and slate"; the quartzose sandstone member forms the "quartzose sandstone and slate" area. The New Sweden Formation forms the area of "slate with manganiferous ironstone lenses" and the "calcareous mudstone and silty limestone" area is the Spragueville Formation. Open arrows show the inferred directions of sediment transport. Letters within the arrows indicate the principal source rocks for the sandstones and conglomerates of the Frenchville Formation; W=Winterville Formation, M=Madawaska Lake Formation, and QD=Quartz Diorite (plutonic).



ironstone lithofacies, in turn, merges gradually with the calcareous mudstones and silty limestones of the Spragueville Formation, which is the easternmost lithofacies of the study area.

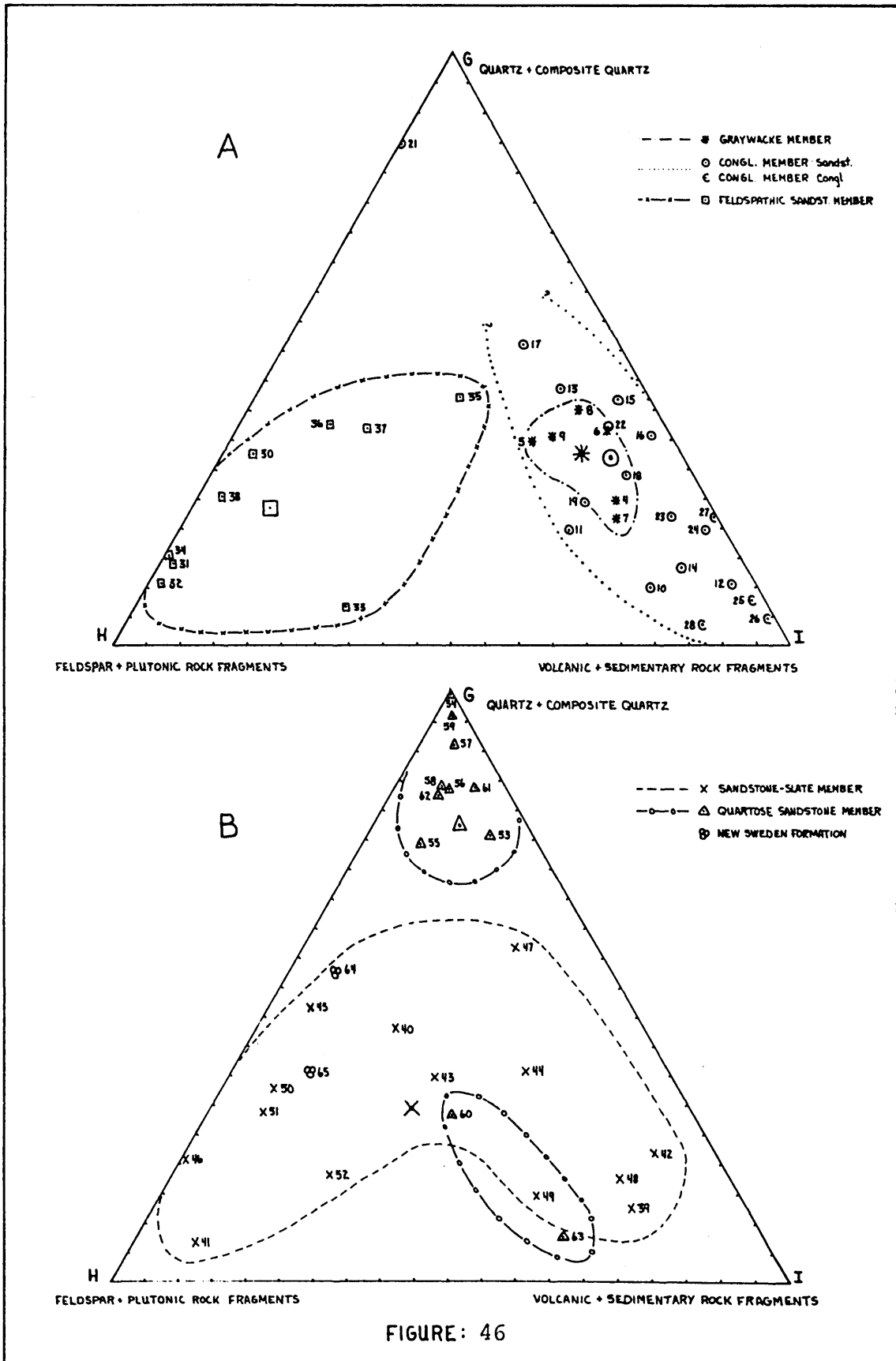
The facies pattern, shown in Figure 45, indicates that the study area lies along the western margin of a marine basin with nearby sources of sediment. The inferred directions of sediment transport, based on the facies pattern and provenance of the sandstones and conglomerates (discussed below), are also indicated in Figure 45. The sudden appearance of the coarse clastic debris of the Frenchville during this time interval indicates the general emergence of land to the west and south and its closest proximity to the site of sedimentation.

#### Sandstone and Conglomerate Provenance

General. The abundance of lithic fragments in most sandstones of the Frenchville and New Sweden Formations makes them ideal indicators of provenance. In addition, the common abundance of feldspar, especially plagioclase, is a good indication of the "first-cycle" character of the detritus (Pittman, 1970; Folk, 1965).

The petrographic data from the sandstones of the members of the Frenchville and the New Sweden formations were analyzed to show their principal source. The results of this analysis are plotted as GHI diagrams in Figure 46.

Figure 46: Principal-source diagrams for the members of the Frenchville Formation. Two analyses of sandstones from the New Sweden Formation are also plotted. Modal components placed in each pole are given in Table 1 and discussed in the text. Enlarged symbols give the average composition of each group of analyses.



The modal components placed in each pole of the triangular diagrams are given in Table 1. Fine-grained volcanic rock fragments (of all types) and chert and "cherty" fragments comprise most of the components placed in the "I" pole, but sericitic fragments (mostly saussuritized plagioclase grains), slate and siltstone, sandstone, and detrital carbonate clasts, if present, are also included; this pole represents derivation primarily from the Ordovician Winterville Formation, with a smaller contribution from the Madawaska Lake Formation. The "H" pole includes single and composite feldspar grains together with all composite quartz-feldspar grains including micrographic quartz-feldspar; this pole contains material inferred to be derived from plutonic rocks in the source area. Only single and composite quartz grains are placed in the "G" pole; these probably represent both plutonic and volcanic sources with contributions from reworked sedimentary rocks.

The provenance of the detrital constituents of all Frenchville-New Sweden sandstones can be found in the pre-Silurian rocks of the region. The provenance of each of the members of the Frenchville Formation are shown by well defined fields in the principal source diagrams. The field for the graywacke member lies near the center of that for the conglomerate member (Figure 46A), and both members are primarily derived from a volcanic terrane.



Estimates of the composition of pebble conglomerates based on modal analysis of large sections (Table 7) are also plotted in the diagram and cluster near the "I" pole. As in the ABC and DEF diagrams previously presented (Figure 15), the GHI field for the conglomerate member is left open at the quartz-rich end out of respect for analysis 21. The GHI field for the feldspathic sandstone member is distinctly in the plutonic-source region of the diagram, reflecting the general abundance of composite quartz-feldspar grains (Table 9) in that unit; with the exception of analysis 33, the analyses are scattered about a line extending from near the "H" pole and curving up toward the 50-percent-quartz line. The sandstones of the sandstone-slate member form a field (Figure 46B) covering the fields of both the conglomerate and feldspathic sandstone members, which is a reasonable consequence of the sandstone-slate member being laterally equivalent to these two members and containing sandstones derived from both the Winterville and plutonic sources. The quartzose sandstone member is inferred to contain two populations of sandstones, one derived largely from a volcanic source and the other formed of detritus from quartz-rich plutonic rocks and/or reworked quartz-rich sedimentary rocks.

Much of the Frenchville in the northern part of its outcrop belt has at least a partial plutonic source. This provenance is reflected in the quartz-rich clastics of the

quartzose sandstone member and the abundant granophyre fragments in the lense of conglomerate northeast of Collins Siding (Plate I). The almost universally well-rounded character of the quartz in the quartz-rich sandstones, and the low abundances of composite quartz-feldspar grains indicate that these rocks are compositionally mature even though most are texturally immature (Dott, 1964). The origin of the rounded quartz is not clear, though most appears to be plutonic quartz (Folk, 1965). Some samples have appreciable lamellar quartz (Fairbairn, 1941) with undulose extinction. The lamellae show no consistent orientations in the relatively undeformed sandstones, suggesting that they formed in the source rock.

Rocks containing abundant quartz (lamellar or otherwise) have not been observed in the pre-Silurian terrain of the western anticlinorium, making direct provenance stipulation impossible. Since the Middle Llandoveryan-Early Wenlockian facies pattern suggests derivation of the quartz-rich clastics from the northwest, it is inferred that a quartz-diorite/granodiorite intrusive (provenance for granophyre, unstrained quartz and plutonic composite grains) and deformed quartzite (?) (source of lamellar quartz) are present, and as yet undetected, in the pre-Silurian of the anticlinorium or concealed beneath younger rocks to the northwest of the anticlinorium. If quartzite is the provenance of the lamellar quartz, then

a likely origin would be exposed pre-volcanic terrane containing the Grand Pitch-Chase Lake sequence (Cambrian?) of Neuman (1967) and Hall (1964), or its equivalent.

Neuman (1967) has observed clasts of the Grand Pitch in the Frenchville equivalent in the Shin Pond quadrangle, but does not indicate the presence of lamellar quartz.

Volcanic and Sedimentary Rock Source. Except for a few of the quartz-rich sandstones, all sandstones of the Frenchville and New Sweden formations contain volcanic detritus. The suite of volcanic (mafic and felsic) and associated fine-grained siliceous rocks (chert and "cherty" rocks) are found in the Winterville Formation as well as its equivalents in nearby regions. The high proportion of volcanic debris in some of the rocks apparently caused Williams and Gregory (1900) to classify them as pyroclastics; the writer has found no rocks that show convincing evidence of pyroclastic texture (Fiske, 1969).

A comparison of major rock types in the Winterville Formation, as estimated by Horodyski (1968), with the average abundances of these rock types in Frenchville sandstones and conglomerates is given in Table 23. Horodyski's estimates, the only ones available for the pre-Silurian volcanic terrane, represent the frequency of occurrence of the various rock types as outcrops in a large, but heavily wooded, area around Fish River and Big Machias lakes. His estimates undoubtedly weight the

Winterville Formation	Members of the Frenchville Formation					
	Graywacke (Sdst)	(Sdst) (Congl) 1	Conglomerate (Cong) 2	Sandstone-Slate (Sdst)		
Mafic Volcanics	70.0	7.2	21.0	33.0	11.5	8.9
Felsic Volcanics	5.0	10.0	3.9	30.2	28.4	3.5
"Cherty Rocks"	12.0	6.6	4.8	8.1	10.1	3.5
Slate	3.0	2.4	2.4	1.3	0.3	0.5
Sandstone and Conglomerate	10.0	-	0.3	-	-	-
	100.0	26.2	32.6	72.6	50.3	16.4

<sup>1</sup>From thin section data of Table 7.

<sup>2</sup>From field modal analysis (pebbles only) of Table 6.

TABLE 23

Comparison of major rock type abundances in the Winterville Formation as estimated by Horodyski (1968) with the average abundances in the analyzed sandstones and conglomerates of the graywacke, conglomerate, and sandstone-slate members of the Frenchville Formation.

volcanic rocks more heavily than those of sedimentary origin. The relative abundance of mafic to felsic volcanic rocks is probably reasonably good for the area he studied and agrees with the writer's experience in mapping within the formation. Hall (1964), however, describes felsic (rhyolitic) rocks, including the Ragged Mountain member, as common, though not dominant, in the Bluffer Pond Formation in the Spider Lake area (Figure 7); similar rocks are also common in the Castle Hill Anticline (Williams and Gregory, 1900; Boucot, et al., 1964a). These local abundances of felsic rocks in the Ordovician suggest that the source area may have been quite variable in felsite abundance. Despite the above uncertainties, the data of Table 23 illustrate some general observations apparent in the field:

- (1) Felsic rock fragments are more abundant in the clastic rocks relative to mafic varieties. This is particularly true of the pebbles in the conglomerates. This enrichment of felsic debris may in part reflect an underestimation of the overall felsic population in the source, but is probably due to the more rapid degradation of mafic fragments during erosion and transportation.

- (2) Chert and "cherty" rock fragments are also enriched in the Silurian clastics.

- (3) Slate and sandstone are greatly underrepresented in the lithic fragments of the sedimentary rocks. Since

the pre-Silurian abundance of slate is much greater than 10 percent (taking the Madawaska Lake and Machias River formations into account, for instance), this deficiency is even more marked. Slate fragment depletion, which is commonly observed in sandstones (Pettijohn, et al., 1965), is due largely to the weak resistance offered by argillaceous materials to both chemical and mechanical breakdown. Sandstone (graywacke) fragments are only rarely seen in the Frenchville clastics and, where present, are usually in coarse sandstones or conglomerates; conglomerate fragments have not been observed.

Olive-green slate and rusty limestone fragments, probably derived from the Madawaska Lake Formation, are abundant in the sandstones and conglomerates at fossil locality 31 near Madawaska Lake. Green slate and argillite fragments in the Frenchville at locality 1 in Ashland are identical to the slate and argillite of the underlying Winterville Formation. Except for these two occurrences, it is not possible to establish with any certainty the source of the pelite clasts commonly seen in the Frenchville. Black pelite fragments, which are common, are probably largely derived from the Black slates of the Winterville, but darker phases of the Madawaska Lake Formation may also have been a source.

The sandstones of the conglomerate member generally contain detrital pyroxene grains and embayed quartz grains

with straight faces and rounded corners. The former are undoubtedly derived from augitic basalt and diabase, and the latter probably come from phenocrysts in keratophyric and rhyolitic felsic rocks.

Plutonic Source. The assignment of composite quartz-feldspar (including micrographic quartz-feldspar) grains to a "plutonic" source is based on the following:

(1) Quartz crystallites are of the common "plutonic type" (Folk, 1965) with trains of vacuoles and slight to moderate undulose extinction.

(2) Grains generally contain 2 to 4 crystallites interlocked in an allotriomorphic-granular fabric. Boggs (1968) found that sand-size fractions of comminuted plutonic rocks contained grains with average crystallite numbers of 2.2-3.1 (granite) and 2.4-5.5 (diorite).

(3) Biotite crystallites are occasionally seen intergrown with the quartz and feldspar.

(4) Micrographic/myrmekitic intergrowths of quartz and feldspar are present in pre-Silurian plutonic rocks (see page 329).

The composite feldspar grains (almost entirely composite plagioclase) are also classed as plutonic rock fragments, since they commonly consist of sand-size crystallites of feldspar. The plutonic source is, however, not the only possibility for these grains, since composite grains could have been derived from composite feldspar

phenocrysts in glomeroporphyritic volcanic rocks. The volcanic contribution is considered minor, since glomeroporphyritic rocks have not been reported as abundant in pre-Silurian volcanic sequences (Hall, 1964; Horodyski, 1968; Neuman, 1967). Single feldspar crystals of sand size may come from either plutonic or volcanic rocks (mostly from phenocrysts).

The plutonic source is inferred to be pre-Silurian quartz diorite or granodiorite intrusives such as the Rockabema quartz diorite (see page 329 ). The Rockabema quartz diorite is the largest known such intrusive, but Horodyski (1968) reports a small quartz diorite, with myrmekitic texture, near Big Machias Lake (Figure 1).

#### Frenchville Lithofacies Development and Provenance in the Ashland-Frenchville Area

In the Ashland-Frenchville area, the Frenchville Formation has been differentiated into three lithofacies, corresponding to the graywacke, conglomerate, and feldspathic sandstone members. As discussed in previous sections (pages 237 to 240 , 198 - 199 , and 340 - 343 ), there are marked variations in the distributions, thicknesses, and provenances of these lithofacies, which taken together appear to form a clastic fan that is proximal to the south. The origin of this fan and its internal variations are the subjects of this section.



The source of the feldspathic sandstone member is interpreted to be a quartz diorite, like the Rockabema, located to the south of Ashland. The feldspathic graywackes of this member, therefore, represent a marked change in source (volcanic to plutonic) from that of the underlying conglomerate and graywacke members. The scarcity of volcanic debris in the feldspathic sandstone member suggests that not only did a plutonic source appear, but the previous volcanic source was temporarily terminated. The temporary nature of the scarcity of volcanic debris is reflected in the abundance of Wenlockian conglomerates, in Ashland, containing a Winterville suite of rock types. A possible explanation for the observed changes in provenance involves the following steps:

(1) The Ashland-Frenchville area was submerged, with emergent volcanic terrain (Winterville Formation) to the near-south shedding coarse detritus northward. This coarse detritus, possibly "channelized" by a canyon, spread out at, or near, the base of a slope, forming a fan.

(2) Later, a quartz diorite-granodiorite intrusive was unroofed near the shore, that was then somewhat further south and encroaching on the land. Debris from the pluton entered the basin and spread out as part of the fan over the volcanic-rich sands and conglomerates. Admixing of small amounts of volcanic detritus from the submarine

slope and volcanic "host" terrane around the pluton would be likely.

(3) The plutonic influence would be eliminated as a primary source by the eventual submergence of the pluton as the shoreline advanced southward or southwestward. Volcanic terrane from "behind" the submerged pluton could then supply the conglomerate beds in Ashland, while offshore to the north (Frenchville area) shales and manganese ironstones high in the feldspathic sandstone member were being deposited.

The above onlap process, possibly up a canyon, could have produced the known vertical and areal distribution of the conglomerate and feldspathic sandstone members in the Frenchville clastic wedge, as shown in Figure 43B; this schematic illustration incorporates the north-south variations in member thickness, which suggests that the site of maximum Frenchville deposition moved southward as the section developed. During the first phase of conglomerate deposition, the site of maximum deposition was north of Frenchville (approximately at the position of section C-C', see Plate I); later, during the deposition of the feldspathic graywackes, the site was at Frenchville, and finally, during the last conglomerate deposition the site was in or near Ashland.

## Frenchville Sedimentation

In general, stratigraphic units rich in sandstones and conglomerates are complex and quite variable both vertically and laterally. In addition, modern analogues are difficult to apply, since modern gravels and coarse sands are not abundant in marine sediments, and, where present, are usually in lenticular bodies or thin beds interlayered with more abundant thinly bedded silt (or fine sand) and argillaceous sediments. Where observed in the deep ocean, the source and method of transportation of the coarse detritus is commonly only indirectly known and often controversial. Coarse sediments on modern shelves are typically "relict" deposits (Swift, 1969) and in many cases result from the winnowing and reworking of Pleistocene sediments. As the result of the difficulty in developing actualistic models for thick conglomerate and sandstone sequences, much of what we "know" about their origins is based on features we find in them, application of partial modern analogues, and theoretical considerations (based at least in part on experimental work).

The Frenchville is interpreted to be an offshore deposit. This interpretation is based on the following:

- (1) Many of the sandstones and conglomerates contain fragmented brachiopods from two or three of Ziegler's

(1965) "depth" communities. The brecciation and mixing of these marine benthonic faunas indicates that the detritus was transported down a submarine slope, by some mechanism, and deposited at depths equal to or greater than the environment of the most offshore fauna present (generally the Stricklandia or Clorinda). A. J. Boucot (personal communication, 1966) pointed out to the writer that the mixing of these offshore communities, which are commonly spread out over hundreds of miles on the continental platforms, is substantial indication that relatively steep slopes were present during Frenchville deposition; the Frenchville represents one of the few units so far studied in detail in which this mixing can be demonstrated.

(2) In the Frenchville area, the Frenchville Formation conformably overlies the Aroostook River Formation, which has features suggestive of an offshore origin.

(3) There is a conspicuous absence of features indicating deposition or reworking in the high-energy near-shore (inner-shelf) environment (e.g. large-scale cross-bedding, wave or current ripple marks, dunes, etc.), suggesting deposition below wave base (about 300 feet) in an environment where reworking does not occur. This negative evidence is particularly applicable to the graywacke, conglomerate, and feldspathic sandstone

members; many of the sandstones of the sandstone-slate member show graded bedding in combinations with small-scale ripples and parallel lamination, reflecting the operation of traction processes probably associated with turbidity-current deposition.

Depth of water during Frenchville sedimentation cannot be accurately obtained, but minimum estimates are possible. As discussed on an earlier page, the Early Silurian brachiopod communities were separated by tens of feet in depth, and the Stricklandia community probably did not live in water exceeding 200 feet (Ziegler, 1965). Evidence indicating the depth of the Clorinda community is not given by Ziegler, but the community lived more distant from the strand line than that of Stricklandia. The general presence of the Stricklandia community in the Frenchville rocks indicates a minimum depth of perhaps 100-200 feet; the occurrence of elements of the Clorinda community in the sandstone-slate member suggests that the Stricklandia "depth" was exceeded in basinward phases of the formation. Although the brachiopod communities place minimum depth constraints on the environment, the actual depth of sedimentation may have been greater, and probably exceeded the wave base as mentioned in (3) above. Assuming a slope of 4.5-5.5 degrees (typical averages for modern slopes off coasts with young mountains or faulted coasts with narrow

shelves, as given by Stanley, 1969), a water depth of 1000 feet (300 m) within two miles (3.2 km) or so of the shore is possible.

If deposition took place in a few hundred feet of water, then subsidence of the basin is required to accumulate approximately 3500 feet (1050 m) of Frenchville clastics. Assuming approximately 8my\* for the duration of the Late Llandoveryan-Early Wenlockian time interval, subsidence and deposition (of lithified sediments) of 15-30 cm/10<sup>3</sup> yrs (.5 to 1.0 foot/10<sup>3</sup> yrs) is sufficient to account for the section.

The implications of the above data and calculations is that the Frenchville sandstones and conglomerates accumulated rapidly while the basin, and possibly the region as a whole, was undergoing subsidence following the maximum uplift of the Taconic orogeny. In addition, it appears that, even though the sandstones and conglomerates were deposited offshore, their deposition was nevertheless relatively close to the sources of the detritus in agreement with the provenance indications discussed above.

The graywacke, conglomerate, and feldspathic sandstone members have textural and lithologic attributes commonly

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\*Obtained by using a figure of 25 my (1966 compilation of the IUGS Subcommittee on geochronology) for the duration of the Silurian, allowing 5 "additional graptolite zones" for the Predolian, and assigning approximately 1 my durations to each of the resulting 25 zones.

found in "...enigmatic linear belts and localized wedges of ancient coarse sediment...." (Stanley, 1969). These members are characterized by:

(1) a scarcity of pelitic beds;

(2) poorly sorted, well mixed, unstructured sandstones and conglomerates that are typically thick-bedded. Graded bedding and parallel lamination, though locally present, are rare;

(3) both sharp and gradational bedding contacts. Contacts between beds of marked grain-size contrast (shale-sandstone, fine sandstone-conglomerate) are typically sharp; however, gradational contacts between pebbly sandstones and conglomerates have been observed;

(4) conglomerates in which elongate pebbles are usually oriented parallel to the bedding and may be "suspended" in a graywacke or, less commonly, pelitic matrix. Imbrication has not been observed;

(5) a scarcity of sole features.

Sandstone and conglomerate beds such as those found in the slate-poor phases of the Frenchville have been termed "fluxoturbidites" (Dzulynski, et al., 1959), "grain-flow deposits" (Stauffer, 1967), and "proximal turbidites" (Walker, 1967). Since these coarse deposits are frequently found in, or associated with, flysch sequences that are considered to have been formed offshore in deep water, several mechanisms have been proposed to explain the transportation to, and deposition in, deep

water of such coarse material (even boulders) (see Middleton, 1969b, for a recent review). It is now generally recognized, that, in theory, a spectrum of transport mechanisms from slumps through mass flows to turbidity currents probably exists, and portions of this spectrum have been observed both directly and indirectly. A complicating feature of the spectrum is the possibility that all types of transport, in sequence or simultaneously, may be involved in moving unconsolidated materials (especially granular) to deep water. Although the "fluxoturbidite" facies is generally thought to have developed due to slump and/or mass-flow transport (Dzulynski, et al., 1959; Stauffer, 1967), Komar (1970) recently argued on theoretical grounds that turbidity currents of reasonable densities and velocities should develop bottom stresses sufficient to transport pebble- and cobble-size fragments, but he failed to indicate how such currents would construct a thick conglomerate layer.

The sandstone-slate member, where well exposed, contains abundant features generally regarded as typical of turbidity-current deposition (see Figures 24 and 25 and discussion of Jemtland Formation sedimentation). The member is a flysch-type sequence formed mostly of evenly interlayered slate and graywacke. The graywacke beds are typically graded and may have well developed internal structures compatible with Bouma's A-B-C sequence. Coarse



sandstones and conglomerates are rare and occur near the interfingering of the member with the conglomerate and feldspathic sandstone members.

The quartzose sandstone member with its interlayering of offshore sandstones and slate is postulated to be part of the same turbidite regime as the sandstone-slate member. The unit is not well enough exposed, however, to determine the relative importance of grading, lamination, and cross-bedding in the sandstones.

From the above considerations it is concluded that the Frenchville forms two important facies marginal to a basin lying mostly to the east: (1) a clastic-wedge facies composed of massive graywackes and conglomerates (with little slate), which grades eastward into (2) a turbidite facies with thin- and medium-bedded graywackes interlayered with slate (and much less limestone). The two facies may well have developed by the prograding and coalescing of submarine fans along the base of a relatively steep slope with the clastic-wedge facies forming the inner or proximal portion, and the turbidite facies comprising the outer or distal phase (Figure 43). This facies distribution is roughly analogous to much larger-scale modern fans at the mouths of most submarine canyons (Griggs and Kulm, 1970; Normark and Piper, 1969; Stanley, 1969). The Frenchville facies in general contains a higher proportion of conglomerate and medium to coarse

sandstone than commonly found in modern fan complexes, but this is to be expected in view of the proximity of the Frenchville to its source areas and the scarcity of vegetation on the Silurian land areas.

#### New Sweden Sedimentation

Basinward from the slate-rich facies of the Frenchville Formation was a regime of calcareous slate deposition embodied in the New Sweden Formation. Aphanitic limestone (generally argillaceous) developed in lenses and thin beds as a minor lithotope. Variably in time and space, restricted areas of thinly bedded iron- and manganese-rich sedimentation formed which resulted in the quasi-lenticular ironstone horizons present in the New Sweden. As pointed out by Pavlides (1968), this fine-grained, offshore facies represents an increased influx of terrigenous sediment into a basin which had previously been the site of abundant limestone accumulation (Carys Mills Formation). Graptolite zone 19 appears to have been the time interval when this change in sedimentation occurred.

During the earlier part of New Sweden sedimentation (zones 19 to 22?), the facies had a probable lateral equivalent, to the west, in the graywacke member of the Frenchville and may have been largely separated from it by a submarine area of nondeposition (ridge?) (Castle Hill Anticline area). This correlation is tentative,

considering that no paleontologic data are available for the graywacke member.

The upper part of the New Sweden (perhaps 60 percent in the Perham area) is coeval with the bulk of the coarse clastics of the Frenchville, and most of the ironstone horizons occur in this portion. Along the east flank of the Castle Hill Anticline the facies has overlapped the submarine area of nondeposition and is zone 22 (C<sub>3</sub>) and younger in age, and is entirely a Frenchville equivalent. During late stages of its development, the New Sweden facies spread eastward over sediments of the Spragueville (Figure 43A-3).

The sandstone and conglomerate beds that are present sparsely in the western and upper portion of the formation have the same mineralogy and provenance as those in the Frenchville (Table 14; Figure 46) and probably represent local extensions of sand transport into the dominantly argillaceous regime. The source of the pelitic material in the New Sweden (and Frenchville, for that matter) has not been determined but is probably largely Ordovician slate, with a secondary contribution from the weathering of volcanic rocks.

The depth of water during New Sweden deposition cannot be well established except to say that the Clorinda community is present at locality 46. Locality 46 is in the upper part of the formation west of Washburn, and the

fossils came from the base of a graded bed, suggesting that they were transported.

The manganiferous ironstones have provenance implications and have been used as indicators of the geochemical and sedimentological paleoenvironment. Both Miller (1947) and Pavlides (1962) have suggested the weathering of volcanic terrane as the source of the iron and manganese, but they were not able to specify the source areas. It is now clear that the Ordovician volcanic rocks that supplied much of the detritus of the Frenchville sandstones, were also the source of the iron and manganese. White (1943) postulated that the ironstone lenses formed in shallow water, offshore, but Miller (1947) and Pavlides (1962) favored more restricted basins, perhaps lagoons or estuaries. The facies information now available, together with the brachiopod community data, indicates that lagoonal or estuarine environments are unlikely analogues for the deposition sites, and White's offshore inference is more likely. The depth of water was probably great enough to have exceeded wave base, so that fine lamination in both the ironstones and the calcareous slates of the New Sweden were not disrupted. The restricted nature of each lens of ironstone (and its associated red and green slates) points toward deposition in local "deeps" on the sea floor.

### Spragueville Sedimentation

The Spragueville forms the easternmost lithofacies the of/Middle Llandoveryan-Early Wenlockian basin. The paleogeographic implications of this apparently extensive sequence are poorly understood, because its facies relations to the northeast, east, and southeast in both Maine and New Brunswick have not been worked out.

Pavlides (1968, Plate 1) presents the results of reconnaissance mapping in western New Brunswick, where he finds rocks similar to the Smyrna Mills Formation (lower-upper Silurian) and the Jemtland Formation overlying or in fault contact with the Carys Mills. Much of the Smyrna Mills is lithologically similar to the New Sweden, including the presence of ironstone horizons, and its Ludlovian phase contains rocks closely resembling the Jemtland (L. Pavlides, field conference, 1965); thus the possibility exists that the Spragueville interfingers eastward with a New Sweden-Smyrna Mills type facies. Pavlides (1968) also reports an apparent thinning of the Spragueville to the south along the east flank of the Chapman Syncline west of Westfield, Maine (Pavlides, 1968, Plate 1). Pavlides maps the upper member of the Perham Formation (Jemtland of this report) as overlying the Carys Mills directly but does not discuss the relationship.

During its early history the Spragueville in the Presque Isle-Mapleton area extended as far west as the

Castle Hill township. Later, perhaps in the latest Llandoveryan-Early Wenlockian, this western Spragueville was overlapped by the New Sweden slates as shown in Figure 43A. This onlap is thought to have resulted from a gradual deepening of the basin.

The Spragueville contains representatives of the Clorinda community at locality 106 as well as graptolites at locality 107, both of which indicate an offshore site of deposition; the preservation of delicate "banding" in the pelitic laminae is again consistent with relatively deep water. The bottom waters appear to have been aerated, in view of the abundant evidence of burrowing by benthonic animals and biogenic carbonate detritus in the thin carbonate laminae.

The origin of the thin layering of the Spragueville and the silty character of its pelitic beds are difficult to explain with currently available data. The micro-layering of the pelitic laminae suggest episodic deposition of silty clay. The carbonate-rich laminae may reflect periodically increased biogenic debris. The source of the silt- and sand-size noncarbonate fractions in many of the limestones is hard to reconcile with their apparent position in the center of the basin; it may be that this clastic material was derived from the south or northeast from localized shallow platforms in the basin.

## LATE WENLOCKIAN-LUDLOVIAN SEDIMENTATION AND PALEOGEOGRAPHY

### General

During the Late Wenlockian there was an abrupt change in sedimentation over most of the study area, in which the diverse facies pattern of the Early Silurian gave way to the more uniform Jemtland Formation (Figure 43 A-4, B). This transition appears to have been more or less synchronous everywhere, although it may have occurred a little earlier in the west than in the more central part of the basin. The overall reduction in average grain size that resulted from the change (particularly from the Frenchville) and the turbidite characteristics of the Jemtland are indicative of the more offshore and possibly deeper character of the basin during this part of the Silurian. The Jemtland phase of deposition persisted into the zone 33-34 span of the Ludlovian and lasted perhaps 5-6 my.

The Jemtland was followed by the slate-rich Fogelin Hill Formation, which has thus far been found only along the axis of the Stockholm Mountain Syncline. The Fogelin Hill represents sedimentation from the Early Ludlovian to possibly as late as the Siegenian of the Early Devonian. The apparent absence of this unit in the Presque Isle quadrangle between the Jemtland and the volcanics of the Dockendorff Group (Early Devonian) is significant, and suggests that no Fogelin Hill deposition occurred there, or that the unit was removed by pre-Middle Helderbergian erosion (considered less likely); thus the

Salinic disturbance (latest Silurian-earliest Devonian) postulated for the Presque Isle area by Boucot, et al. (1964a) is given additional support.

Paleogeography and Provenance: Jemtland Formation

Paleocurrent directions, facies distributions, and lithologic variations indicate that the Jemtland of the study area was derived from the west and south (Figure 41). The general pattern of sediment transport appears to have been similar to that indicated for the Late Llando-verian-Early Wenlockian time period, as shown by comparison of Figures 41 and 45. The sedimentation features of the Jemtland discussed below, however, indicate that emergent areas supplying the detritus were more distant than previously.

The extent of the westward movement of the Late Silurian sea is not accurately known, but limestones, conglomerates, sandstones, pelitic rocks, and volcanic rocks of Ludlovian-Predolian age are present in the Fish River-Big Machias lakes area (Horodyski, 1968; see Figure 1) and in the Spider Lake area (Hall, 1964). These nearshore lithofacies are thought to have formed marginal to land areas of unknown extent and outline; in the East Branch Group, Hall (1964) found evidence of local northward transgression of the Ludlovian sea onto a source terrain.



In the Shin Pond area to the south of Ashland, Neuman (1967) has presented evidence for a transgression of the Silurian sea onto a basically northwestern source area. The distributions of Early through Late Silurian lithofacies around the Weeksboro-Lunksoos Lake Anticline show that complicated shorelines and irregular land areas were probably present during the general westward or northwestward advance of the sea. It is clear that latest Silurian and/or earliest Devonian erosion, together with original patchy deposition of Late Silurian rocks, must be considered in assessing the character and location of Late Silurian shore lines to the west and southwest of the study area; for the most part, an understanding of shore line locations is not possible with present data.

The graywackes of the Jemtland indicate that a principal source for the sequence was a volcanic terrane (Table 16), but much of the quartz was probably derived from pre-Silurian plutonic and sedimentary rocks. The volcanic provenance is particularly evident in medium- and coarse-grained graywacke beds (A intervals) which may contain 40-50 percent mafic volcanic fragments, many of which show a trachytic texture suggestive of flow rocks.

The volcanic source for the Jemtland was probably a combination of the Ordovician Winterville rocks and contemporary volcanics; Ludlovian volcanism is known to have been an important aspect of the Late Silurian evolution

along much of the present western anticlinorium (Hall, 1964). The trachytic rock fragments common in the Jemtland graywackes, and of low abundance in the older Silurian graywackes, may have come principally from the erosion of contemporaneous flow rocks; however, trachytic rocks have not been reported as common in Late Silurian volcanics to the west, which weakens their uniqueness as principal source rocks. The stratigraphically localized sections of aquagene tuff and lithic tuff in the Jemtland, on the other hand, give unequivocal testimony of concurrent volcanism marginal to the basin; the distribution of these tuffs is consistent with the volcanism occurring to the west.

#### Jemtland Sedimentation

General. The Jemtland Formation contains most of the characteristic features of the "flysch" lithofacies summarized by Dzulynski and Smith (1964) (as cited by Dzulynski and Walton, 1965, p. 3). The following characteristics of the Jemtland are consistent with this lithofacies designation (refer to Figure 39):

(1) The succession is made up almost entirely of an alternation of pelite and sandstone (including some siltstone) beds. There is a thin interlayering of the three pelitic rock types with each other and graywacke.

(2) The sandstones are moderately to poorly sorted and contain appreciable clay-grade material.

(3) The sandstones show sharply defined bottom surfaces commonly covered by sole markings. Top surfaces may be indistinct, and transitions (usually rapid) from sandstone to a pelitic lithology are common.

(4) The sandstones are commonly graded, and fine-grained sandstones typically show lamination, small-scale current ripples, and convolute lamination.

(5) Large-scale cross-stratification is absent.

(6) Rapid vertical variation in the composition of the sequence, other than the alternation of rock types, is absent. Pronounced lateral variations in rock-type abundances are present in the Jemtland Formation; the graywacke facies corresponds roughly to "normal" flysch and the slate facies may be termed "shaly" flysch. "Sandy" flysch is not present.

(7) The limited paleocurrent data available for the Jemtland Formation indicate systematic variations of directional structures.

(8) The Jemtland Formation is a marine sequence. Graptolites are commonly found in the pelitic beds, and debris of benthonic organisms, inferred to be displaced, are recovered from the basal portions of some graded beds and in rare limestone breccias. Benthonic forms, whose displaced nature is less certain, have been found at localities 59 and 101.

(9) Volcanic flow rocks are absent; devitrified tuff and lithic tuff are present but are minor in abundance.

(10) No features of subaerial environments are present.

(11) The Jemtland rests with gradational contacts on older rock units.

None of the slump deposits, pebbly mudstones, pebbly sandstones, or exotic blocks, that have been found in some flysch (wildflysch) successions have been seen in the Jemtland.

Since the work of Keunen and Migliorini (1950) the concept of turbidity-current deposition has dominated the sedimentological interpretation of flysch sequences. Concurrently, sands in recent deep-sea sediments have been inferred to have similar origins. Theoretical and experimental studies have validated the concept in its broad outline. A persistent problem in the assessment of turbidites has been the establishment of attributes of a deposit that uniquely point to a turbidity-current origin as contrasted with associated, but genetically nonunique, features (Bouma, 1964). As pointed out by Van Der Lingen (1969), there has been much dogmatism and some circular argumentation involved in attempts to formulate these criteria for recognition, and almost every study of flysch or modern marine sediments containing sandy beds gives new features, new arrangements of old features, and/or clever arguments explaining the absence of particular features.

The flexibility of the turbidity-current hypothesis, caused in part by the lack of direct studies (obviously very difficult) of such currents in their natural habitat (or well-scaled experiments) followed by examinations of the resulting deposits, makes it a powerful sedimentological model for many "first-order" features of interbedded sandstone-shale sequences, but also causes indeterminacy in detail.

As pointed out by Kuenen (1964), no compositional or sedimentological features have been established as unique to turbidites (individual beds), but a wealth of indirect and circumstantial evidence can be derived from a succession which strongly suggests that sediment transport by turbidity currents was genetically important. In the case of the Jemtland Formation the following characteristics may be cited:

(1) The sequence shows no evidence of transportation and deposition in a high-energy environment expected in fluvial, littoral, shallow shelf, or proximal delta environments. Such features as winnowed sandstones, wave ripples, beach and dune structures, channel deposits, reefs, etc., are absent. The preservation of delicate lamination is also consistent with quiet-water deposition.

(2) Graded bedding is a common feature of the gray-wacke beds. Experimental turbidites generally contain graded beds (Kuenen and Migliorini, 1950), and theoretical

arguments indicate that grading is an expected, though not a necessary, development in deposits from turbidity flows (Walker, 1965; Middleton, 1969a).

(3) Ripple-drift cross-lamination indicative of sediment "fall-out" during ripple formation (Walker, 1965, 1967) is common in rippled intervals (C) of the graywacke beds.

(4) The presence of benthonic fauna in the basal portions of some graywacke beds (especially "A" intervals) and pelagic fauna (graptolites) in the pelitic beds indicates transport of the coarse clastics into an offshore regime.

Establishing the proportions of the sequence that resulted from turbidity-current deposition, as opposed to other independent processes, such as "pelagic" sedimentation, has been another area of controversy. The sandstone beds, with one or more of the intervals A, B, and C, are attributed by most authors to turbidity-current deposition. Pelitic layers which commonly form over half the section have been variably treated; Bouma (1962), for example, apparently included pelite layers in some intervals of current ripple lamination (refer to his Plates B-4, C-5, C-6, and D-1) as well as in the D and E intervals. Descriptions by subsequent authors indicate that pelitic beds were placed only in the D and E intervals

or were assigned to a generalized "interturbidite" category.

Deposition of the Graywacke Beds. The graywacke beds of the Jemtland are interpreted to have been deposited from turbidity currents. As discussed in great detail by Harms and Fahnestock (1964), Walker (1965), and Allen (1970), the development of the A, B, and C intervals is consistent with deposition by a waning current which passes from the high flow regime (intervals A and B) to the low flow regime (interval C). The flow regime theory for the origin of the vertically ordered intervals in the graywacke beds is based on abundant empirical data on the development of bed forms in alluvial channels (Simons and Richardson, 1961). Several authors have pointed to the absence of certain bed forms (dunes, standing waves, and antidunes) that should be expected but are almost never observed. A number of arguments have been presented to explain the missing bed forms (see Allen, 1970, for a recent review), and their absence is not considered damaging to the overall flow regime concept.

The areal variations in graywacke beds beginning with intervals A, B, or C conform to the pattern expected from recent models of turbidity-current deposition (Bouma, 1962; Dzulynski, et al., 1959; Walker, 1965, 1967). The general expectation is that beds beginning with higher flow regimes

were deposited more "proximally" with respect to the current source than those showing features characteristic of lower regimes (Walker, 1967). Since a given section (e.g. those shown in Figures 39 and 40) contains turbidites beginning with each interval, it is clear that a given position in the basin (represented by a section) varied in its "proximality," since it was receiving deposition from separate currents moving in all flow regimes. The flow regime of an individual current as it began its deposition at a point in the basin depends on the distance of that point from the source, the amount (density) and size distribution of the sediment in the current, as well as the bottom topography. The distribution of maximum flow regimes represented in a given section results, therefore, from a complicated interaction of these variables; however, it is reasonable to suppose that the "average" or characteristic flow regime in the basin should decline with distance from the source (Walker, 1967). In Figure 47, the relative abundance of graywacke beds beginning with intervals A, B, or C in each Jemtland section studied in detail is plotted on a triangular diagram (data in Table 17). Sections 1-5 from north of the latitude of Washburn (Figure 53) show a nearly systematic downcurrent (eastward) decrease in beds with basal A intervals and an increase in beds with basal B intervals; these variations are consistent with the



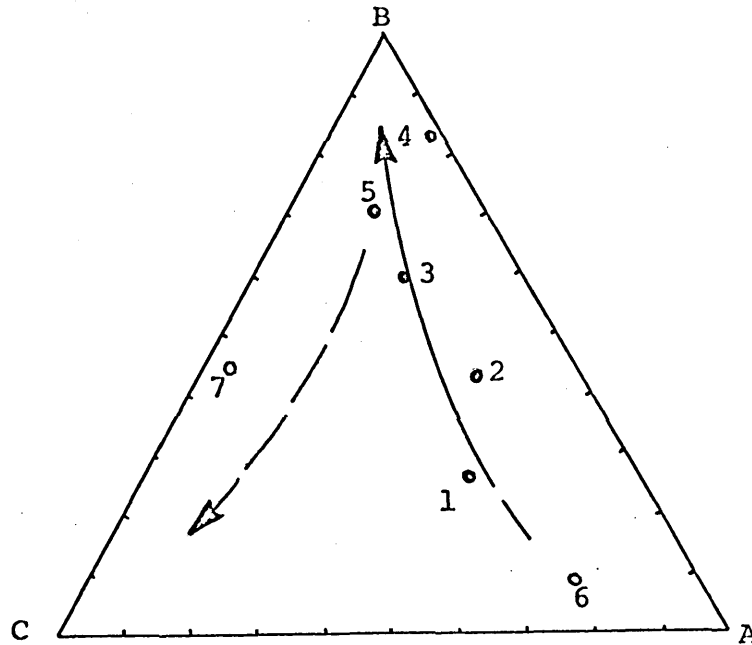


Figure 47: Relative abundances of graywacke beds beginning with intervals A, B, and C in sections of the Jemtland Formation. Downcurrent decrease in beds beginning with A intervals and concurrent increase in beds with basal B intervals, shown by the solid line, characterizes sections 1-5 in the formation north of the latitude of Washburn (see Figure 41 for the locations of the sections and paleocurrent data). The dashed arrow traces the expected trend in more distal parts of a turbidite sequence.

predicted tendency for lower flow regime deposits to increase in importance basinward.

Sections 6 and 7 are from south of Washburn, where the formation appears to have a southern source, and section 6 appears to be more basinward than section 7, based on slate content (Figure 41). As discussed previously, section 6 contains massive fine sandstone beds which do not show lamination in the field, and hence the exposure appears to contain an abundant-A interval population. Section 7 presents only 6.2 m of the sequence and is probably not representative of the Jemtland section at that point.

Very distal turbidite sequences would be expected to contain a dominance of graywacke beds beginning with C intervals over those beginning with either A or B intervals (Walker, 1967). With the exception of section 7, which is considered unrepresentative with respect to graywacke beds, beds with basal C intervals are never dominant in the Jemtland Formation. At least two reasons (not mutually exclusive) for this may be offered:

- (1) Very distal parts of the Jemtland are not present in the study area and are to be found farther to the east.

- (2) The grain size of the sediment in most of the turbidity currents was sufficiently fine or poorly sorted to cause the plane bed form (B interval) to continue to

develop at very low flow powers (regime) as predicted by Allen (1970, Figure 4).

Deposition of the Pelitic Rock Types. The origin of the pelitic rock types has not been definitely established. The inclusion of argillaceous material as matrix and "muddy" laminations in the graywacke beds and the gradation of graywacke into pelite indicates that the turbidity currents which formed the graywacke beds carried clay and fine silt-size components. The statistical analyses of the exposures, however, do not support the existence of a preferred ordering of the argillaceous rocks, as might be inferred from lithologic correlations with Bouma's (1962) model. The tendency for the graywacke beds to be followed by either silty shale or slate depending on which is the more abundant in the section suggests that these two rock types were formed independently of the graywacke beds and constitute the "normal" basinal sediment; this fine-grained material might have moved offshore, more or less continuously or in pulses, by mechanisms such as diffuse nepheloid layers (Ewing and Thorndike, 1965), dispersing surface wedges (overflows of sediment-laden fresh waters), or flowing turbid layers (Moore, 1970).

If the bulk of the pelitic beds of the Jemtland represent transport and deposition unrelated to the currents that deposited the graywacke layers, then some process of separation of sand- and coarse silt-size

particles from most of the fine silt and clay must have been operating in the source area. Moore (1970) has proposed the following phases or types of transport from source terrain to offshore basins (southern California borderland) which results in this separation:

(1) Fluvial mixed (bedload and suspension) transport from source to strand line.

(2) Separation of sand and argillaceous material. Sand deposited near shore (generally as a bar) with clay and silt floating seaward (overflow) and depositing on the outer shelf.

(3) Transport and deposition of sand involving longshore, canyon, and distributary transport. Canyon and distributary transportation includes slump, sand-flow, and turbidity-current processes.

(4) Transport and deposition of the argillaceous material. This includes both turbid-layer and suspension (nepheloid) transport, largely to the heads or walls of canyons and gullies.

(5) Mixed marine transport. Movement of silt and clay to the basin via canyons and gullies as turbid layers and small-scale, dilute turbidity-current flows.

Moore concludes that these processes operate together to fill the offshore basins and to effect a general separation in the transport of clay- and sand-rich materials.

The turbid and nepheloid layers, only recently recognized, are poorly understood, and the mechanics of their motions together with the characteristics of their deposits are largely unknown. Moore (1970), however, postulates that

"....if the turbid layer is of a significant size, it may develop into a low-velocity, low-density turbidity current moving solely by gravity flow. The thin, relatively slow moving turbidity current is not sufficiently erosive to attack the canyon rock walls or even the softer strata of the fan and channel walls, nor does it have the energy to transport tests of foraminifera to deep water. The current does not follow the pre-existing distributary system of canyon, fan, or apron valley and channels, and may flow to its distal ends to spread widely as a very thin layer over parts of the basin plain. The current is so slow that first the silt and then the flocculated clay is gradually dropped, causing progressive loss of density and motive force so that it may be expended before reaching the far parts of the basin. Graded bedding should not result because of the thinness of the layer and the lack of coarse components. As this type of turbidity current has a continuing supply of

lutum and is of very low density, it is analogous to those of glacial lakes...., and lamination may result from the individual long-period flows."

Such flows or lutite-bearing currents would produce a layer which is silt-rich proximally and clay rich distally, and since their movement is controlled by bottom topography (largely), they would probably move in the same general directions as turbidity currents carrying predominantly sand-size material. In the case of the Jemtland, the proximal predominance of silty shale and the distal abundance of slate (fine pelite), as shown in Figure 41, can be explained in terms of turbid-layer/dilute-turbidity-current transport of the lutitic materials. Lack of textural variation (e.g. grading) or color differences would make distinction of individual micro-deposits in a pelitic bed very difficult, if not impossible; therefore, relatively thick silty shale or slate beds need not be regarded as individual deposits.

The distinctive laminated silty shale does not show any preferred lithologic associations in the Jemtland section. Though slightly coarser, it is comparable to the nonlaminated silty shale in grain size. Beds of thin rock type do not appear to be postdepositional alterations of another pelitic rock type, since "unaltered" portions have not been observed and the well-preserved graptolites (locally oriented) suggest that it is a primary deposit.

It may represent the deposit of a faster moving lutitic turbidity current or turbid layer, which during the deposition was able to segregate the silt fraction as discrete and discontinuous laminae (a few grains thick).

Rate of Sedimentation. Rates of sedimentation for flysch successions are rarely possible to derive. In the case of the Jemtland, it is possible to give a rough estimate of the rate of accumulation of its lithified section. If the duration of the Late Wenlockian-Early Ludlovian is taken to be 5-6 my (see footnote, page 357), in substantial agreement with an estimate by Naylor and Boucot (1965), the 760 m (2500 feet) of section formed at approximately  $12-15 \text{ cm}/10^3 \text{ yrs}$ . This rate is compatible, considering compaction, with the accumulation of sediment (including turbidites) in the Tyrrhenian Abyssal Plain determined by Ryan, et al. (1965), and a rate of  $5-180 \text{ cm}/10^3 \text{ yrs}$  found in the basins off southern California by Emery and Bray (1962).

### Fogelin Hill Sedimentation

The interlayering of green and red silty pelite (slate) with fine calcareous graywacke beds characterizes the Fogelin Hill. The essentially fine-grained and even-bedded nature of the section suggests that the offshore environment of the Jemtland persisted through the Fogelin Hill, but the marked change in the rock types indicates significant modifications in the sedimentation.

The appearance of red and green slates in the Fogelin Hill and their absence in the Jemtland presents something of a problem. It is not clear, for example, whether argillaceous sediment of red, green, or both colors were deposited; since the color differentiation does not appear to be universally stratiform, it is quite possible that the pelitic material was originally either red or green and that portions of the sediment were subsequently altered. Thompson (1970), in a study of a nonstratified color variation in red and drab sandstones of the Juniata and Bald Eagle formations (Ordovician), found that the section was originally red; post-burial circulation of "ground waters" of low Eh and pH reduced the hematite and caused the formation of diagenetic chlorite, which incorporated



newly available ferrous iron. Friend (1966) has also proposed this diagenesis to explain similar color alterations in some of the Catskill redbeds. If the Fogelin Hill slates were originally red (or reddish) and subsequently altered to green in a manner akin to that suggested for other sequences by Thompson and Friend, then an important question is raised: do the red slates represent the influx of a new type (relative to the Jemtland) of argillaceous material, or had the environment of the basin changed to allow the preservation of hematite which previously had been completely reduced?

The answer to this question and the paragenesis of the color alteration requires an understanding of the geochemical history of the Silurian basin which is beyond the scope of the present study. However, except for the red slates and ironstones of the New Sweden and Frenchville formations briefly discussed on a previous page, iron in the pre-Fogelin Hill is largely in the reduced slate in silicate minerals (mostly chlorite) and carbonate phases (probably as ankerite). The origin of the iron in the Silurian section is undoubtedly the weathering of Ordovician volcanic rocks (with some contributions from contemporary Silurian volcanics), and the occurrence of red beds in the Fogelin Hill probably represents a changing basin environment, perhaps more

open, which allowed the hematite to be stable until burial when partial reduction occurred.

Aside from differences in color, the pelitic beds of the Fogelin Hill do not show the distinctive textural variations of those in the Jemtland. Since the three pelitic rock types of the Jemtland are well developed only in the proximal graywacke facies, the more uniform character of the Fogelin Hill pelite may reflect a distal regime of sedimentation; the vertical transition from the graywacke facies of the Jemtland to the Fogelin Hill in the Stockholm Mountain Syncline is a possible indication of continued deepening of the basin and westward retreat of the strand line.

The fine-grained, generally parallel-laminated sandstone beds are inferred to be the products of turbidity-current deposition. The prevalence of parallel lamination suggests that the Fogelin Hill turbidites represent a more distal environment than that of the underlying Jemtland. The directions of sediment transport in the Fogelin Hill have not been determined, but primary derivation from a westerly (and southwesterly?) direction is probable.

The absence of the Fogelin Hill in the Presque Isle quadrangle is indicative of nondeposition or erosion there during this period. Unequivocal evidence of erosion is lacking, but the pebbly mudstone containing clasts of

the Jemtland and reworked (?) Early Silurian fauna east of Ashland may be a product of such erosion. The presence of Late Silurian volcanics, temporally equivalent to the Fogelin Hill, in the Presque Isle quadrangle (particularly in its southern portion) cannot be completely ruled out, but present information indicates that the volcanics of the Chapman Syncline (Dockendorff Group) are probably entirely lower Devonian (Boucot, et al., 1964a).

#### SILURIAN-DEVONIAN TRANSITION

The regional transition from the Silurian to the Devonian is little understood, but appears to be areally variable. In the Presque Isle and Ashland quadrangles a nonsequence involving the absence of upper Ludlovian and lower Gedinnian rocks and structural conformity suggest a disconformity between the two systems. This same nonsequence is also present to the west and southwest of the study area (Hall, 1964; Horodyski, 1968; and Mencher, unpublished data). The possibility of Early Devonian graptolites in the stratigraphically coherent Fogelin Hill Formation of the Stockholm Mountain Syncline suggests the presence of a gradational transition in that area, but this cannot be proven until more definitive paleontologic data is available.

## APPENDIX

Northeastern Aroostook County Maine has proven to be one of the most fossiliferous regions in the New England Appalachians. The fossiliferous nature of many of the more accessible natural and man-made exposures in large measure stimulated much of the previous work in the area (Williams and Gregory, 1900; Twenhofel, 1941, Boucot, et al., 1964). The abundant paleontologic data has provided the control required to make reliable stratigraphic correlations possible in this study.

In this appendix the writer has attempted to bring together information on all Ordovician and Silurian fossil localities in the region shown in Figure 1 and all Devonian localities in the area of Figure 4. This summary includes localities that have been found and collected by the writer and other members of the M. I. T. research group, and localities for which published information exists. This compilation does not include primarily paleobotanical localities, and no attempt has been made to list exposures where only traces of fossiliferous material have been observed. Sampling by more recent workers has in many cases duplicated that of the earliest workers (Hitchcock, 1861; Williams and Gregory, 1900; Twenhofel, 1941; Olaf Nylander, privately published data). Many of the locality descriptions given in these early papers are not sufficient to uniquely establish the outcrop from which collections were made,

but where possible the writer has referenced probable duplications.

A number of paleontologists have provided fossil lists and given age assignments on these collections. Collections from the M. I. T. group have been submitted as follows:

<u>Paleontologists</u>	<u>Material</u>
Arthur J. Boucot	Siluro-Devonian Shelly fossils
William B. N. Berry	Graptolites
William A. Oliver	Corals
Robert B. Neuman	Ordovician Shelly fossils
Gilbert Klapper	Silurian Conodonts
Carl B. Rexroad	Silurian Conodonts
John W. Huddle	Siluro-Devonian Conodonts
Jean M. Berdan	Ostracods
James M. Schopf	Plants
Henry N. Andrews	Plants
James C. Brower	Crinoids

These workers have been of great help to the writer and others working in the region; they have processed collections with remarkable speed and, in cases of more than one type of fossil in an outcrop, have confirmed one another. Their success is made even more substantial when it is noted that many of the collections contain fragmentary and poorly preserved material. All of the

above have engaged the author in stimulating discussions (both written and oral) on the regional aspects of the paleontologic information.

Ordovician and Silurian age assignments based upon brachiopods have in most cases been referred to the Standard British section for these systems since the faunas found in these collections are generally more closely comparable to those in Europe than those in the American Standard Section (Boucot, et al., 1964; Pavlides and Berry, 1966; Neuman, 1963). Silurian graptolite assemblages are similarly referred to the British section using the zonation established by Elles and Wood (1901) and Davis (1961) (Pavlides and Berry, 1966). Ordovician graptolites are zoned according to a sequence established by Berry (1960b) for the Marathon region of Texas. Both the British and the American Standard sections have been used by the paleontologists in age assignments involving coral, ostracod, conodont and crinoid assemblages. Pavlides, et al. (1968) may be consulted for a recent correlation of the British and American sections; lettered subdivisions of the Llandovery Series (British) are brachiopodal substages established by Williams (1951) and used extensively by Boucot.

In general the persons responsible for making collections from exposures studied by members of the M. I. T.

group are indicated by the prefix to the field number, as follows:

EM	Prof. Ely Mencher
DR	David C. Roy
SH	Stanley A. Heath
LW	Gary Laux and Richard Warner
HN	Hamilton L. Hayes and Mihran R. Nalbandian
MR	Ely Mencher and David C. Roy
RH	Robert Horodyski
TH	Terrence Hamilton-Smith
CL	T. D. Coskren and M. R. Lluria
PF	William M. Peterson and Jeffrey L. Friedberg
TF	J. T. Parr and T. Zidle

Each fossil locality is assigned a number that is used to identify it in this report. Those localities outside of the area of Plate 1 are indicated. M. I. T. field numbers are given if they have been established for the locality; in addition, locality designations of previous workers are indicated parenthetically. U. S. National Museum (USNM) and U. S. Geological Survey (USGS) numbers assigned to the collections are presented where known by the writer.

Note: References to Boucot, et al. (1964) in this appendix are cited as Boucot, et al. (1964a) in the body of this report and in the list of references.

ORDOVICIAN

Winterville Formation

Locality: 1; Field Number: DR 1539 (USNM 13030)

Location: Ashland Quadrangle; Ashland Township;

DR 1539 is located in the basement excavation for a house built by Mr. Carlton Jimmo in Ashland. The strata producing the graptolites and shelly fauna are no longer exposed. Mr. Jimmo's house is located 0.2 miles due north of a point on Route 227 (Exchange Street in Ashland) 0.4 miles east of the intersection of Routes 227 and 11 in Ashland.

Note: The excavation from which the collections were made exposed an unconformable contact between the Frenchville Formation (Silurian) and the Winterville Formation (Ordovician). The details of this exposure are related elsewhere in this work (page 183).

Collections were made by the author from:

- A. Frenchville Formation (shelly)
- B. Pebbly mudstone immediately below the contact (shelly)
- C. Black, pyritiferous slate below the pebbly mudstone (graptolitic)

Collections A and B were sent to Boucot and collection C was studied by Berry. No identifiable fossils were obtained by Boucot from collections in the Frenchville Formation; the pebbly mudstone



yielded abundant material which was studied by Boucot and subsequently by Neuman. The author granted permission for the results of these collections to be included in regional syntheses by Pavlides, et al., 1968 (p. 73, 74) and Neuman, 1968 (p. 44 and 45). Fossils and age information below come from these published accounts and personal communications.

Fossils: Berry (letter of February 15, 1967)

identified the following graptolites:

Glyptograptus sp.; Hallograptus ?; biserial scardent form; dicellograptid fragment.

Neuman (1968) listed the following brachiopods:

Skenidioides sp.; Horderleyella sp. ?; Hirnantia sp.; undetermined enteletacean; Leptaena sp.; Cryptothyrella sp.; Plectothyrella sp.:

Boucot (letter of October 27, 1966) identified the following fauna:

Plectambonitids; Christiania sp; unidentified brachiopods; corals; Plectothyrella sp.; Cryptothyrella sp.; Streptis sp.; Leptaena "rhomboidalis"; Skenidioides sp.; gastropods; Strophomenacean; dalmanellids (including Hirantia).

Age: Berry places the graptolite assemblage in the time span of zone 12 to zone 15 (in Neuman, 1968).

Neuman (1968) provisionally assigned the brachiopods

to the Ashgillian, but the assemblage "...may be of early Llandovery rather than Ashgill age. Discrimination between these is difficult (Boucot and Johnson, 1964, p. 2), but the Ashland collections (DR 1539) lack the genera most indicative of a Silurian age,..." Boucot assigns an Ashgillian age "...indicated by the presence of Christiania in combination with items like (Cryptothyrella and Plectothyrella." In Pavlides, et al. (1969), Boucot also points to a possible but less likely Early Silurian age. Considering all of the above age assignments (graptolite and brachiopod), the strata beneath the unconformity at DR 1539 are most probably of Ashgillian age.

Locality: 2; Field Number: EM 995

Location: Portage Quadrangle; T14N R5W;

EM 995 is a locality at the end of a small lumber road, 0.7 miles east of Nigger Brook and 1 mile north of the Center Line Tote Road, on the 860 ft. contour.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolites:

Corynoides calicularis Nicholson: Corynoides comma Ruedemann.

Age: Late Middle Ordovician; in span of Climacograptus bicornis-Orthograptus truncatus intermedius zones (zones 12-13).

Locality: 3; Field Number: DR 28

Location: Ashland Quadrangle; T11N R4W;

DR 28 is in an old gravel quarry just off Route 163 at a point 5.1 miles east of the intersection of Routes 163 and 11 in Ashland. This locality was found by Forbes and has been described by Neuman (1963, 1968).

Fossils: Neuman (1969) reported the following

fossils:

Brachiopods--Cyrtonolella sp.; Glyptorthis sp.;  
Nicolella cf. N. actoniae (Sowerby); Triplecia cf.  
T. insularis (Eichwald); Chonetoidea sp.; Christiania  
sp.; Diambonia sp.; Leptaena sp.; Ptychoglyptus sp.;  
Sampo cf. S. indentata Spjeldnaes; Sampo sp.;  
Boreadorthis sp.; Chaulistomella sp.; Skenidoides sp.;  
Howellites sp.; Oxoplecia sp.; Catazyga sp.; Lep-  
tellina sp.; Eoplectodonta sp.

Corals--Catenipora sp.; unidentified rugose and tabulate corals.

Graptolite--Amplexograptus sp. (identified by Berry).

Age: Neuman (1963) assesses the age as follows:

"Several of these fossils have not been seen before in the United States, although some of them have long been known in Great Britain and Europe. The Nicolella is very similar to a species of Caradocian age from Estonia (Cooper, 1956, pl. 39E), the

Triplecia to one from the Caradoc Sandstone in Wales (Hall and Clarke, 1892, pl. 11C, fig. 21), and the strophomenoid suite to that of the 4b stage in the Oslo region, Norway (Spjeldnaes, 1957). Species similar to the Maine forms of Christiania, Diambonia, and Glyptorthis also occur in the lower Ardmillian Series in the Girvan District, Scotland (Williams, 1962). Williams (1962, p. 61) correlated the lower Ardmillian with the Wilderness Stage of Cooper (1956), and Berry (1960b, p. 100-101) considered the 4b stage of the Norwegian succession equivalent to the Wilderness and Trenton stages of Cooper (1956). The rocks of the gravel pit, therefore, were probably deposited during this interval." The later listing by Neuman (1968) revises and supplements his 1963 listing but his assessment of the age is the same.

Locality: 4; Field Number: EM 31 (CL 127)

Location: Winterville Quadrangle; T14N R7W;

EM 31 is a locality originally found by Neuman and Forbes. The exposure is on the hillside just north of the lumber road from Nixon Siding to Fish River Lake, 3.05 miles along the road west of crossing of Fish River. This locality is outside the area of Plate 1.

Fossils: Berry (letter of July 30, 1962) identified the following graptolites:

Climacograptus bicornis (Hall); Climacograptus eximius Ruedemann; Climacograptus cf. C. scharenbergi Lapworth; Dicellograptus gurleyi Lapworth; Dicellograptus sextans (Hall); Dicellograptus sextans (Hall); Dicellograptus sextans var. exilis Elles and Wood; Dicranograptus ramosus (Hall); Didymograptus sagitticaulis Gurley; Glyptograptus teretiusculus (Hisinger); Leptograptus sp.; Nemagraptus gracilis (Hall); Orthograptus calcaratus var. acutus Lapworth; Orthograptus calcaratus var. incisus Lapworth.

Age: Middle Ordovician; Climacograptus bicornis Zone (zone 12).

Locality: 5; Field Number: EM 793

Location: Portage Quadrangle; T14N R5W;

EM 793 is an exposure on a lumber road of the Pinkham Lumber Co. on north flank of Moose Mountain just below the 1020 ft. contour. It is 1.83 miles east of the western townline and 2.64 miles north of the southern townline.

Fossils: Berry (letter of December 22, 1964) identified the following graptolites:

Climacograptus bicornis (Hall); Climacograptus cf.

C. eximius Ruedemann; Dicellograptus sextans (Hall);  
Dicellograptus sp.; Glyptograptus aff. G. euglyphus  
(Lapworth).

Age: Middle Ordovician; Climacograptus bicornis Zone  
(zone 12).

Locality: 6; Field Number: EM 985

Location: Portage Quadrangle; T14N R5W;

EM 985 is on the Center Line Tote Road, 0.15 miles west of the lumber road of the Pinkham Lumber Co., just east of the 980 ft. contour. It is 3.25 miles north of the southern boundary and 1.6 miles east of the western boundary of the Township.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolites:

Climacograptus sp.; Cryptograptus tricornis  
(Carruthers); Diplograptus ? sp.

Age: Middle Ordovician; probably the Climacograptus bicornis Zone (zone 12)

Locality: 7; Field Number: RH 739

Location: Greenlaw Quadrangle; T12N R7W;

RH 739 is situated on the north side of the American Realty Road, 0.95 miles west of the bridge over Moosehorn Stream and 7700 feet east of the west border of T12 R7 (Horodyski, 1968). This locality is outside the area of Plate 1.

Fossils: Berry (letter of January 16, 1970) has identified the following graptolites:

Amphigraptus sp. (similar to A. divergens (Hall));  
Climacograptus bicornis (Hall); Climacograptus sp.;  
Dicranograptus ramosus (Hall); Dicranograptus spinifer Lapworth; Dicellograptus gurleyi Lapworth;  
Dicellograptus sp.; Nemagraptus gracilis (Hall).

Age: Middle Ordovician; Climacograptus bicornis Zone (zone 12).

Locality: 8a; Field Number: TF 26 (EM 137)

Location: Portage Quadrangle; Portage Lake Township; TF 26 is on the east side of Route 11, about 3 miles north of Portage and 0.35 miles north of Buffalo cemetery.

Fossils: Berry (letter of January 31, 1963) has identified the following graptolites:

Climacograptus sp.; Dicranograptus ramosus (Hall).

Age: Middle Ordovician; probably from the Climacograptus bicornis Zone (zone 12).

Locality: 8b; Field Number: TF 26-1 (EM 137)

Location: Same as for TF 26

Fossils: Berry (letter of January 31, 1963) has identified the following graptolites:

Dicranograptus ramosus (Hall); Didymograptus ? sp.

Age: Middle Ordovician; probably from the Climacograptus bicornis Zone (zone 12).

Locality: 8c; Field Number: TF 26-2 (EM 137)

Location: Same as for TF 26

Fossils: Berry (letter of January 31, 1963) has identified the following graptolites:

Climacograptus eximius Ruedemann; Climacograptus phyllophorus Gurley; Glossograptus sp.

Age: Middle Ordovician; probably from the Climacograptus bicornis Zone (zone 12); might be from the next older zone, that of Nemagraptus gracilis (zone 11).

Locality: 9; Field Number: EM 141 (TF 92, TF 93)

Location: Portage Quadrangle; Portage Lake Township; TF 92 is on the west side of Route 11, in a road metal quarry 0.85 miles north of Portage.

Fossils: Berry (letter of January 31, 1963) has identified the following graptolites:

Cryptograptus tricornis (Carruthers); Didymograptus cf. D. sagitticaulis Gurley; Diplograptus sp.; Glossograptus armatus Nicholson; Glyptograptus cf. G. teretiusculus (Hisinger); Glyptograptus cf. G. euglyphus var. pygaeus (Lapworth); Orthograptus calcaratus cf. var. incisus (Lapworth).

Age: Middle Ordovician; probably from the Climacograptus bicornis Zone (zone 12).



Locality: 10; Field Number: EM 990

Location: Portage Quadrangle; T14N R5W;

EM 990 is on a small lumber road 0.4 miles east of Nigger Brook, 0.3 miles north of Center Line Tote Road, and between the 840 and 860 ft. contours.

Fossils: Berry (letter of December 14, 1965) has identified the following graptolites:

Climacograptus eximius Ruedemann; Glyptograptus aff. G. teretiusculus (Hisinger); Hallograptus mucronatus (Hall):

Age: Middle Ordovician; in the span of Nemagraptus gracilis-Climacograptus bicornis zones (zones 11-12).

Locality: 11; Field Number: CL 47

Location: Winterville Quadrangle; T14N R6W;

CL 47 is on a small lumber road that goes north from the main lumber road between Nixon Siding and Fish River Lake. The locality is 1.4 miles west of the Fish River and 3/4 mile east of Mosquito Brook Pond and between the 760 and 780 ft. contours.

This locality is outside the area of Plate 1.

Fossils: Berry (letter of January 2, 1963) has identified the following graptolites:

Cryptograptus tricornis (Carruthers); Climacograptus cf. C. eximius Ruedemann; Climacograptus phyllophorus Gurley; Dicellograptus sp.; Glossograptus hincksii (Hopkinson); brachiopods.

Age: Middle Ordovician; in the span of the  
Nemagraptus gracilis-Climacograptus bicornis  
zones (zones 11-12).

Locality: 12; Field Number: CL 119

Location: Winterville Quadrangle; T14N R6W;

CL 119 is in Mosquito Brook about 0.1 miles down-  
stream from Mosquito Brook Pond. This locality  
is outside the area of Plate 1.

Fossils: Berry (letter of January 2, 1963) has  
identified the following graptolite:

Climacograptus cf. C. phyllophorus Gurley

Age: Probably Middle Ordovician; probably from the  
span of the Nemagraptus gracilis-Climacograptus  
bicornis zones (zones 11-12).

Locality: 13; Field Number: TF 188F

Location: Winterville Quadrangle; Portage Lake  
Township;

TF 188F is a quarry just south of the lumber road  
at Indian Point on Portage Lake. This locality is  
outside the area of Plate 1.

Fossils: Berry (letter of January 31, 1963) identified  
the following graptolites:

Climacograptus sp.; Cryptograptus tricornis  
(Carruthers); Dicellograptid fragment ?

Age: Middle Ordovician; probably from the Climaco-  
graptus bicornis Zone (zone 12); might be from the

next older zone, that of Nemagraptus gracilis  
(zone 11).

Locality: 14; Field Number: DR 576 (C-6 of Boucot, et al.,  
1964)

Location: Presque Isle Quadrangle; Castle Hill  
Township

DR 576 is located just south of Route 163 a distance  
of 1.0 miles east of the summit of Haystack Mountain.  
The exposure is in an old pit, in part used as a  
cesspool (now largely covered).

Fossils: Berry (in Boucot, et al., 1964) identified  
the following graptolites from a collection made by  
William Forbes:

Climacograptus cf. C. typicalis Hall; Dicranog-  
graptus n. sp. (aff. D. nicholsoni); Diplograptus  
cf. D. foliaceus (Murchison); Orthograptus sp.  
(of the O. calcaratus type); Orthograptus truncatus  
var. intermedius (Elles and Wood); Orthograptus  
quadrimumcronatus cf. var. approximatus (Ruedemann).

Age: Berry places this assemblage in the Orthograptus  
truncatus var. intermedius Zone (zone 13) of the  
Ordovician. (Boucot, et al., 1964)

Madawaska Lake Formation

Locality: 15; Field Number: LW 48

Location: Stockholm Quadrangle; Stockholm Township;

LW 48 is along a lumber road at a point 0.3 miles west from Collins Siding and 0.10 miles south of the northern boundary of the Stockholm Township.

Fossils: Berry (letters of December 17, 1965; July 27, 1966; February 16, 1967; and February 16, 1970) has identified the following graptolites: Amplexograptus sp.; Glyptograptus sp.; Diplograptus sp.

Age: Berry places this assemblage in the span of zones 11-15 of the Ordovician; O. M. Bulman also examined the collection and suggested that the age is probably in the span of zones 11-12, but may be as young as the early part of zone 13 as that zone is recognized in New York State.

Locality: 16; Field Number: TH 205

Location: Grand River Sheet; Notre Dame De Lourdes Parish;

TH 205 is located 0.42 miles N76E from the main intersection in the village of Upper Siegas, New Brunswick, Canada. The collection was made by Hamilton-Smith (1969).

Fossils: Berry (letter of January 16, 1970) has identified the following form: Diplograptus sp. ("this is a slender Diplograptus which appears to me to be most similar to D. mohawkensis (Ruedemann). Many specimens are

present...., but all are very badly distorted-- most of them are stretched along the central axis of the rhabdosome. This stretching makes positive identification impossible.")

Age: Berry writes: "I think these specimens are similar to diplograptids commonly found in zone 13 age rocks elsewhere in New England....I lean toward a....Trenton-zone 13 age for TH205 although admitting that the age is only somewhere in the Late Ordovician...."

#### Pyle Mountain Argillite

The following four localities constitute the source of the best documented paleontologic information available on the Pyle Mountain Argillite. The fossil assemblages listed are based on collections by P. E. Cloud (1941, field notes) and Boucot, et al. (1964).

Locality: 17; Field Number: DR 442 (D-4 of Boucot, et al., 1964; USGS: SD3189)

Location: Presque Isle Quadrangle; Castle Hill

Township;

Collections made by P. E. Cloud (1941) and Boucot et al. (1964) came from the road ditch on the south side of the road from Mapleton to the north slopes of the Pyle Mountain at a point 60 feet west of the intersection with Turner Road. A more recent

bulldozed area just south of the road exposes an extensive surface of similar bedrock. This is the so-called "Pyle School" locality of Cloud, 1941 (field notes); the Pyle School is no longer in existence.

Fossils: Boucot, et al. (1964, pages 21-23) cite the following fossils:

Trilobites identified by H. B. Whittington:

Asaphid; Symphysops sp. ?; Tretaspis sp.; Dindymene sp.; Pseudosphaerexochus sp.; aff. Carmon sp.

Brachiopods identified by R. B. Neuman: Christiania sp.; Sowerbyella sp.; plectambonitid identified; Skenidioides.

Age: See summary below.

Locality: 18; Field Number: DR 991 (E-3 of Boucot, et al., 1964; USGS:SD3186)

Location: Presque Isle Quadrangle; Castle Hill Township;

DR 991 is on the east slope of Pyle Mountain south the east-west road from Mapleton to the north slope of Pyle Mountain. It is 0.30 miles south of the intersection of the east-west road and Turner Road.

Fossils: Boucot, et al. (1964) cite the following fossils from this exposure:

Trilobites identified by H. B. Whittington:

Trinodus sp.; Symphysops sp.; Remopleurides sp.;

Dionide sp.; Novaspis sp.; Raphiophorus sp. ?;

cf. Platylichas sp.

Brachiopods identified by R. B. Neuman: Christiania

sp.; Sowerbyella sp.; leptaenid indeterminate.

Age: See summary below.

Locality: 19; Field Number: DR 625 (D-7 of Boucot,

et al., 1964; USGS: SD3184, SD3187)

Location: Presque Isle Quadrangle; Castle Hill

Township;

Exposure is located in the woods on the west side of Castle Hill at a point 2.55 miles west of the eastern border and 0.9 miles south of the northern border of the township.

Fossils: Boucot, et al. (1964) cite the following

fossils from this exposure:

Trilobite identified by H. B. Whittington:

Tretaspis sp.

Brachiopods identified by R. B. Neuman: Christiania

sp.; Sowerbyella sp.

Age: See summary below.

Locality: 20; Field Number: DR 1904 (D-11 of Boucot,

et al., 1964; USGS: SD3188, SD3183)

Location: Presque Isle Quadrangle; Castle Hill

Township;

This locality is in a farm field approximately 760

feet west of a point on Turner Road 1.76 miles north of its intersection with the east-west road from Mapleton to Pyle Mountain.

Fossils: Boucot, et al. (1964) cite the following fossils:

Brachiopods identified by R. B. Neuman: Christiania sp.; Sowerbyella sp.; plectambonitid indeterminate; Leangella sp.; Skenidioides sp.

Age: See summary below.

Note: Neuman in Boucot, et al. (1964, p. 23), cites brachiopod fauna from several Cloud collections taken "...in section dug up along road east of Castle Hill." Cloud's 1941 field notes (pages 37, 38) indicate that these localities are from road-bed exposures on the crest and north slope of "Richardson Hill" which is the local name for the northern most knoll of Castle Hill. These collections do not come from the Pyle Mountain Argillite; they come, rather, from strata mapped as "sedimentary rocks of probably Ordovician and Silurian Age" by Boucot, et al. (1964) and as part of the "Sandstone and Slate Member" of the Frenchville Formation by the writer. Structural and lithologic evidence indicate that the section studied by Cloud is younger than the Upper Llandoveryian beds at fossil locality 42. Neuman



(letter of March 31, 1970) indicates that nothing "in Cloud's Richardson Hill collections is compellingly Ordovician."

Age Summary: Boucot, et al. (1964) quote H. B.

Whittington on the trilobites in part as follows:

"These trilobites are quite unlike any from the standard Upper Ordovician of the Cincinnati region, but are like those from the Whitehead formation of Quebec, which contains Tretaspis, Symphysops, Novaspis, Remopleurides, Platylichas, Raphiophorus...

All the genera from Maine except Platylichas are recorded in the Upper Ordovician of Poland...and this assemblage is characteristic of the Upper Ordovician rocks of central and northwestern Europe.... There seems no doubt but that the strata at Pyle School are equivalent in age with some part of the Ashgillian of Europe...."

Neuman reports (Boucot, et al., 1964) that the brachiopod fauna "...do not date these rocks more closely than the latter half of the Ordovician period."

ORDOVICIAN AND SILURIAN

Meduxnekeag Group

Carys Mills Formation

Locality: 21; Field Number: DR 402

Location: Caribou Quadrangle; Washburn Township;

DR 402 is located on the south bank of the Aroostook River 1.1 miles west of the highway Bridge across the river at Bugbee. It is also 0.08 miles east of the western boundary of Washburn Township.

Fossils: Berry (letter of July 9, 1965) has identified the following graptolite:

Monograptus cf. M. cyphus Lapworth

Age: Early Llandoveryan; probably zone 18 of Elles and Wood.

Locality: 22; Field Number: DR 403

Location: Caribou Quadrangle; Wade Township;

DR 403 is located 0.62 miles west of the road intersection just south of Stratton Island (in the Aroostook River). The exposure is a road cut on the south side of what is known locally as "South Wade Road." Bedrock is intermittently exposed in the road cut for a distance of approximately 0.11 miles.

Note: Neuman collected graptolites from this exposure in or about 1961. The collection was labeled

"Ribbon-Rock-Stratton Island" locality. This collection is referenced in Boucot, et al., 1964, page 26, and Berry is reported as having identified the graptolites as "...probably of the Orthograptus truncatus var. intermedius Zone." This determination was referred to by Pavlides and Berry, 1966, page B58 as follows: "The fragmental specimens referred to be Boucot and others have not been re-examined, but their stratigraphic position (almost on strike) with respect to the rocks bearing Monograptus cf. M. cyphus (DR 402 above), indicates that they are also most probably Early Silurian in age." The author's work in the vicinity of DR 403 and DR 402 produced structural and stratigraphic evidence indicating that DR 403 underlies DR 402 and is not on-strike from it as inferred by Pavlides and Berry. Re-examination of Neuman's collection by Berry yields the information cited below. Pavlides, 1968, Locality 6, Table 3, page 12, also references this locality.

Fossils: Berry (letter of July 27, 1966) has identified the following graptolite:

Orthograptus truncatus var. socialis (Lapworth)

Age: Berry assigns an Ashgillian age to the form since it "...is confined to the Latest Ordovician and is a fairly common one in my zone 15."

Locality: 23; Field Number: DR 1115

Location: Caribou Quadrangle; Woodland Township;

DR1115 is a road cut on the east side of Route 161 at its intersection with the east-west paved road from Colby. The intersection is 2.23 miles east of the railroad crossing in Colby.

Fossils: The following graptolites were obtained from a collection by Forbes in 1960 reported by Pavlides, Neuman, and Berry (1961, p. 65-66):

Amplexograptus sp.; Amplexograptus cf. A. perexcavatus (Lapworth); Climacograptus cf. C. typicalis mut. posterus Ruedemann; Diplograptus ? spp. (two distinct kinds of this form are represented; one is long and slender, the other shorter and wider); Orthograptus aff. O. truncatus (Lapworth); Orthograptus truncatus cf. var. intermedius (Elles and Wood); Other orthograptids of the O. truncatus type (some of these may be new).

Age: "The assemblage of many orthograptids of the truncatus group (especially the presence of O. truncatus cf. var. intermedius), other large diplograptids, and the Climacograptus of the C. typicalis group, is probably representative of the zone of Orthograptus truncatus var. intermedius. Closely similar assemblages have been recognized by Berry (1960b, p. 38) from the Snake Hill and

Canajoharie shales in New York, and the Magog shale in Quebec." (Pavrides, Neuman, and Berry, 1961, p. 65-66).

Locality: 24; Field Number: EM 326

Location: Stockholm Quadrangle: Van Buren Township; EM 326 is a locality originally collected by Neuman and has more recently been recollected by Mencher. The exposure is along the east-west road southwest of Parent between elevations 687 feet and 733 feet and a distance of 0.55 miles west of the road intersection at elevation 687 feet.

Fossils: From the collection made by Mencher, Berdan (letters of March 24, 1965 and December 5, 1969) has identified the following ostracods:

Chilobolbina sp. (?); Bollia sp.; Schmidtella sp.;  
Gen. et sp. indet.

The following conodonts have been identified by Huddle (letter of December 5, 1969):

Icriodina stenolophata Rexroad; Sagittodontus ?  
edentatus (Rexroad); Panderodus sp.; Hibbardella ?  
carinata (Branson and Branson); Ligonodina ?  
extrorsa Rexroad; Dredanodus ? (really indeterminate).

From the original collection made by Neuman, Berry has identified the graptolites (letter of January 16, 1970):

Climacograptus sp.; Monograptus (similar to M. atavus Jones).

Age: Berdan concludes that the ostracods listed above "...are all long-ranging genera which could be either Ordovician or Silurian age." Concerning the conodonts, Huddle states: "Gilbert Klapper examined these conodonts on November 3, 1969, and suggested the Brassfield age of the collection. I have since identified the species and confirmed the Brassfield (Llandovery) age. The age determination is based primarily on the presence of Icriodina stenolophata and Saggitodontus ? edentatus. These two "species" may have occurred in the same animal. Rexroad (1967) correlated the Brassfield Limestone with the lower and middle Llandovery on the basis of conodonts and this correlation agrees reasonably well with correlations based on other groups."

Referring to the graptolites, Berry states: "This determination (Monograptus, similar to M. atavus) would indicate an Early Silurian--probably Early-Middle Llandovery age--for the collection."

Locality: 25; Field Number: EM 661

Location: Grand Falls Sheet (21 0/4 West Half);

St. Anne Parish (New Brunswick, Canada);

Hamilton-Smith (1969) collected from this locality and cites its location as: 1.50 miles S 7.5 E of

(47° 15' North, 68° 00' West); 4.03 miles S 68 W  
of (47° 15' North, 67° 55' West); 4.27 miles N 3 E  
of (47° 10' North, 68° 00' West). The exposure is  
a shallow road cut on both sides of a farm road.  
This locality is outside the area of Plate 1.

Fossils: Berry has identified the following graptolite:

Climacograptus, possibly scalaris

Berdan identified the following ostracods:

Krausella sp.; Schmidtella ? sp; smooth ostracods,  
indet.

Age: Hamilton-Smith (1969) quotes the following:

Berdan: "This collection is probably Ordovician rather than Silurian in age but cannot be dated precisely."

Berry: "I would suggest that the beds were within a Late Ordovician-Early Silurian (Llandovery) age span anyway and thus lean a little toward the Silurian age."

#### ORDOVICIAN AND/OR SILURIAN

##### Aroostook River Formation

Locality: 26; Field Number: DR 779 (USNM: 13031)

Location: Ashland Quadrangle; Ashland Township;

DR 779 is located on the north shore of the Aroostook River at a point 7.5 miles downstream from the

Route 11 bridge in Ashland and 0.80 miles upstream from the mouth of Anderson Brook.

Note: The author's collection of this exposure (1966) has been studied by both Boucot and Neuman. The locality is cited by Neuman (1968, p. 44) and the fossil list and age discussion below is from that paper as well as a written communication from Boucot (letter of October 27, 1966).

Fossils: Plectothyrella sp.; Cryptothyrella sp.; Hirantia sp.; Triplecia sp.; Oxoplecia sp.; orthid; unidentified brachiopod.

Age: Boucot states that DR 779 "...is of Ashgill or Lower Llandovery age as indicated by the presence of Plectothyrella and Cryptothyrella. It is somewhat reminiscent of the Siegas (EM 558, Siegas Formation, see below) but in the absence of Stricklandid brachiopods one could not be sure of a Lower Llandovery assignment."

## SILURIAN

### Siegas Formation

Locality: 27; Field Number: EM 558 (USNM: 17012, 17011, 17010)

Location: Grand Falls Sheet; St. Anne Parish  
(New Brunswick, Canada);

EM 558 is a large quarry located 1.1 miles N 45 E



of Siegas, New Brunswick. EM 558 is the best exposure and "type-section" of the Siegas Formation (Hamilton-Smith, 1969). This locality is outside the area of Plate 1.

Note: This quarry has been known for some time and several individuals (both Canadian and American) have in times past studied the exposed section and made collections. So far as this author knows, none of these previous collections has been published. Fauna extracted from two collections (Roy and Mencher in 1965 and Hamilton-Smith in 1967) are included here. Hamilton-Smith (1969) has made the most complete study of the section at EM 558 and established the Siegas Formation (as yet unpublished). The results of these collections have been included in a regional lithofacies synthesis of the Early Llandoveryan by Ayrton, et al., 1969.

Fossils: Catazyga ? sp.; Dalmanella ? sp.;  
Eostropheodonta ? sp.; Leangella sp.; Mendacella  
sp.; Eoplectodonta sp.; Plectothyrella sp.;  
Protatrypa ? sp.; Skenidioides ? sp.; Spirigerina ?  
sp.; Stricklandia sp.; dolerorthid; unidentified  
dalmanellid pedicle valves (probably belonging to  
both Dalmanella ? sp. and Mendacella sp.); uniden-  
tified brachiopods; Cornulites sp.; Diplograptus sp.;

tetracoral; favositid; halysitid; heliolitid;  
trilobite fragment.

Age: "Owing to the fragmentary condition of the brachiopods, the fauna has been difficult to date. Earlier unpublished fossil reports by A. J. Boucot and R. B. Neuman (1965) pointed to an early Llandovery age, which is confirmed by the present restudy of the collection. Critical to dating the Siegas Quarry rocks is the presence of Stricklandia which is unknown elsewhere in the world below the base of the Silurian. Plectothyrella is known only from beds of either early Llandovery or Ashgill age. Dalmanella sensu strictu has not been confirmed above beds of early Llandovery age, although it is abundant in the later Ordovician; the same is true for Catazyga. Protatrypa, Eostropheodonta, and Mendacella are unknown above C<sub>1</sub> to C<sub>2</sub> of the late Llandovery, although, except for Protatrypa, they can occur in the Ashgillian." (Ayrton, et al., 1969)

#### Frenchville Formation

##### Conglomerate Member

Locality: 28; Field Number: DR 468

Location: Ashland Quadrangle; Ashland Township;

R. S. Naylor (Field No. 3146) made a collection in

July of 1962 from this locality which is on the southeast side of Route 227 0.20 miles southwest of the bridge across Alder Brook. The fossils came from a pebbly mudstone. This locality is stratigraphically just above DR 469.

Fossils: Boucot (letter to R. S. Naylor, November 10, 1964) has identified the following forms:

Leangella sp.; Isorthis sp.; Plectodonta sp.;  
Stricklandia lens cf. ultima; Dicoelosia sp.;  
stropheodont; Linoporella ? sp.

Age: Boucot places this assemblage in the span C<sub>4</sub> - C<sub>5</sub> of the Llandovery.

Locality: 29; Field Number: DR 469 (USNM: 11088)

Location: Ashland Quadrangle; Ashland Township;

This locality occurs as a poorly exposed road cut along Route 227 (southeast side of the road) 0.35 miles south of the bridge across Alder Brook.

Fossils were found in a pebbly mudstone interbedded with pebble conglomerates.

Fossils: Boucot (letter of June 17, 1965) has identified the following fossils:

Stricklandia lens cf. ultima; corals; stropheodontid; rhychonellid; dalmanellid; Leangella sp.;  
Plectodonta sp.; gastropod.

Age: Boucot states that the material "contains a stricklandid and is of pre-Wenlock limestone age."

He further suggests that it is "...probably C<sub>4</sub> - C<sub>5</sub> age if the stricklandid is correctly identified."

Locality: 30; Field Number: DR 788 (USNM: 12166)

Location: Ashland Quadrangle; Ashland Township;  
DR 788 is in the southeast corner of a field and is 0.30 miles N23W from the first bend in Route 227 just east of the town of Ashland.

Fossils: Boucot (letter of October 25, 1965) has identified the following forms:

halysitid fragments; Leangella sp.; Leptaena "rhomboidalis"; Platystrophia ? sp.

Age: In the time span of C<sub>3</sub> (of the Llandoveryian) to Wenlockian as suggested by the presence of Leangella.

Locality: 31; Field Number: DR 885 (USNM: 12164)

Location: Ashland Quadrangle; Ashland Township;  
The fossils came from a pebble and cobble conglomerate outcrop located along a farm road which leads south from a point on Route 163 a distance of 3.0 miles east of the intersection of that highway and Route 11 in Ashland. The exposure is in a small wooded "island" between fields 0.40 miles south of Route 163.

Fossils: Boucot (letter of October 25, 1965) has identified the following fossils:

Rhipidium or "Conchidium"; halysitid fragments;

dalmanellid.

Age: Boucot assigns this assemblage to the Wenlockian-Ludlovian time span.

Locality: 32; Field Number: DR 1295 (USNM: 17328, 17329)

Location: Stockholm Quadrangle; Stockholm Township;

DR 1295 consists of several small exposures in a gravel pit. The pit is located 0.17 miles in on a farm road leading northeast from a point on Route 161 0.46 miles north of the crossing of the Little Madawaska River. Collections were made from two horizons within the pit: horizon B is stratigraphically below horizon A.

Fossils: Boucot (letter of December 8, 1969) has identified the following fossils:

Horizon A (USNM: 17328): Pentamerus sp.

Horizon B (USNM: 17329): dolerorthid; Stricklandia sp.; Resserella sp.

Age: Boucot assigns a Late Llandoveryian age to both horizons as indicated by the presence of Pentamerus, Resserella, and Stricklandia.

Locality: 33; Field Number: DR 1343 (USNM: 13036)

Location: Caribou Quadrangle; Westmanland Township;

DR 1343 is located on the northwest bank of the Little Madawaska River about 2.2 miles downstream from the mouth of Alexander Brook and 2.5 miles

S 66 E from the northwest corner of the Caribou quadrangle.

Fossils: Boucot (letter of October 27, 1966) has identified the following fossils:

Leangella sp.; stricklandid; Porpites porpita;  
Plectodonta sp.

Age: "DR 1343....is indeed of Frenchville age as indicated by the presence of a stricklandid and Porpites porpita. The age assignment would probably be C<sub>6</sub> to lowest Wenlock or possibly C<sub>5</sub> based on the Porpites."

Locality: 34; Field Number: DR 1792

Location: Ashland Quadrangle; Castle Hill Township; The locality is a woods exposure located 0.21 miles due east of the Aroostook River and 1.65 miles N 78 W of the crossing of Demarchant Brook by Route 227. In reference to township lines, it is 0.30 miles east of the western line and 1.36 miles south of the northern line of the Castle Hill Township.

Fossils: Rexroad (letters of December 19, 1969; February 23, 1970) has identified the following conodonts:

Hadrognathus staurognathoides  
Spathognathodus ranuliformis

Age: Rexroad reports that these forms establish a definite Llandoveryian age for the beds at DR 1792. He places the above assemblage in the N. celloni Zone and states that a "...C<sub>5</sub> age is the most likely assignment, but it is possible that the beds are slightly older than this."

Feldspathic Sandstone Member

Locality: 35; Field Number: DR 25 (Locality E-11 of Boucot, et al., 1964)

Location: Ashland Quadrangle; Ashland Township; DR 25 is a large road cut on the south side of Route 227 at the "south end" of the village of Frenchville. The cut is 2.80 miles southwest of the Ashland-Castle Hill township line and at the site of the former Frenchville Church (destroyed in 1966).

Fossils: A collection made by Forbes produced the following fauna (reported in Boucot, et al., 1964): Eocoelia cf. E. hemisphaerica; Stricklandia lens cf. ultima; Cyrtia; Atrypa reticularis; Pentamerus sp.; Paleocyclus sp.; trilobite.

Age: In the C<sub>4</sub> - C<sub>5</sub> span of the Late Llandoveryian.

Quartzose Sandstone Member

Locality: 36; Field Number: DR 310 (Locality E-12 of Boucot, et al., 1964)

Location: Caribou Quadrangle; Westmanland Township;  
DR 310 is located in a farm field south of the road  
west from New Sweden (towards Blackstone Siding) at  
the eastern edge of the Westmanland Township and  
0.70 miles north of the southern township line.

Fossils: Boucot, et al. (1964) report the following  
fossils:

Eocoelia cf. E. hemisphaerica; Stricklandia lens  
cf. ultima; Pentamerus sp.; Leptaena "rhomboidalis";  
Plectondota sp.

Age: In the C<sub>4</sub> - C<sub>5</sub> span of the Late Llandoveryan.

Locality: 37; Field Number: SH 124 (USNM: 11175)

Location: Stockholm Quadrangle; Stockholm Township;  
SH 124 is in a railroad cut (at elevation 641 feet)  
located 530 feet southwest of the "temporary"  
railroad crossing of a lumber road which intersects  
the main north road out of Stockholm where this  
north road makes a sharp turn eastward toward  
California, Maine.

Fossils: Boucot (letter of November 9, 1964) has  
identified the following fossils:

orthotetacid; Atrypa ? sp.; Pentamerus ? sp.;  
rostrospiroid; Eocoelia sp. (coarse ribbed);  
"Dolerorthis" flabellites; rhychonellid; Strick-  
landia lens cf. ultima; Cyrtia sp.; Plectodonta sp.;  
Resserella sp.; Leptaena "rhomboidalis"; Paleocyclus?  
sp.; favositid; unidentified brachiopods.



Schopf, et al. (1966) report the following plants from fine laminated siltstone interlayered with more massive sandstone containing the shelly fauna: Eohostimella heathana Schopf (n. gen., n. sp.); foliose (?) algae.

Age: Concerning the faunal assemblage, Boucot states:

"SH 124 is of C<sub>4</sub>, C<sub>5</sub> age although a possibility of a C<sub>6</sub> Low Wenlock age cannot be completely ruled out....The problem is whether the fragments of Stricklandia lens cf. ultima might be confused with fragments of Costistricklandia. The beak ends of the two forms look almost identical. I have the same problem with a fauna from the sillimanite zone in New Hampshire. The presence of a possible Paleocyclus fragment complicates the issue as this is a genus normally found only in C<sub>6</sub> Low-Wenlock whereas a Stricklandia would suggest C<sub>4</sub>, C<sub>5</sub>. In any event you are in the upper part of the Llandovery."

The plants studied by Schopf have no dating value at this time but do have significance in botanical evolution. The plants and their significance are discussed at great length by Schopf, et al. (1966).

Locality: 38; Field Number: SH 170 (USNM: 1179)

Location: Stockholm Quadrangle; Stockholm Township;  
SH 170 is located along the Bangor and Aroostook

Railroad track 0.87 miles north of the main railroad crossing in the village of Stockholm.

Fossils: Boucot (letter of November 9, 1964) has identified the following forms:

Leangella sp.; Atrypina sp.; pentameroid.

Berry (letter of December 22, 1964) identified the following graptolites:

Monograptus cf. M. dubius (Suess); Monograptus sp. (Slender, plain thecae).

Age: Boucot reports: "SH 170 is of pre-Ludlow age and would range between C<sub>3</sub> and Wenlock as evidenced by the presence of Atrypina and Leangella. Berry places the graptolites in the span of Late Llandovery to Ludlow.

Locality: 39; Field Number: SH 171

Location: Stockholm Quadrangle; Stockholm Township; SH 171 is located in the same railroad cut but is stratigraphically below SH 170. SH 171 is approximately 170 feet north of SH 170.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus sp. (long, slender, plain thecae--of the M. nudius type?); Monograptus sp. (long, slender form of the M. dubius group).

Age: Berry states that: "Monograptids with this form are most commonly known in the Late Llandovery but they may range into the Ludlow."

Locality: 40; Field Number: SH 172

Location: Stockholm Quadrangle; Stockholm Township;  
SH 172 is located in the same road cut exposure as  
SH 170 and 171 but is about 50 feet north of SH 171.  
SH 172 is stratigraphically below SH 170 and 171.

Fossils: Berry (letter of December 22, 1964) has  
identified the following graptolites from this  
horizon:

Monograptus sp. (hooked thecae, slender form);

Monograptus sp. (long, slender, plain thecae).

Age: Berry states that: "Monograptids with the forms  
of those in this collection are apparently restricted  
in their range to the latter part of the Llandovery  
in Europe."

Locality: 41; Field Number: SH 173 and SH 173A

Location: Stockholm Quadrangle; Stockholm Township;  
SH 173 is stratigraphically below SH 170-172 and is  
part of the same railroad cut. It is located 10  
feet north of SH 172. The fossils come from two  
closely spaced horizons.

Fossils: Berry (letter of December 22, 1964) has  
identified the following graptolites:

SH 173: Monograptus marri Perner; Monograptus sp.  
(long, slender, plain thecae--of the M. nudus type);

SH 173A: Monograptus marri Perner.

Age: Berry states that, "M. marri is restricted in its range to the interval of Elles and Wood's zones 22 to 25 which corresponds to the interval C<sub>3</sub> - C<sub>6</sub> in terms of brachiopod stages."

Sandstone-Slate Member

Locality: 42; Field Number: DR 628 (Locality E-2 of Boucot, et al., 1964; USNM: 13032)

Location: Presque Isle Quadrangle; Castle Hill Township; DR 628 is on the western slope of Castle Hill, 2.55 miles west of the eastern border of Castle Hill Township and 0.67 miles south of the northern border of the township.

Note: Until recently the only fossil reported from this locality was a halysitid noted by P. E. Cloud, 1941 field notes (Boucot, and others, 1964). A collection made by the author yielded the following brachiopods and corals:

Fossils: Boucot (letter of October 27, 1966) has identified the following fossils:

halysitid; Plectodonta sp.; Dinobolus sp.; "Dolerorthis" flabellites; dalmanellid; Amphistrophia cf. A. striata; stricklandid; Coolinia sp.; Protomegastrophia ? sp.; Drummochina ? sp.; orbiculoid; Spiriferina ? sp.; Ptychopleurella sp.; Leangella sp.;

Leptaena "rhomboidallis" gastropod; stropheodontid;  
unidentified brachiopod.

Age: Boucot states that "DR 628....is of Late  
Llandovery age as indicated by the presence of  
stricklandids in combination with Amphistrophia  
cf. A. striata."

Locality: 43; Field Number: DR 905 (USGS: SD7887)

Location: Caribou Quadrangle; Wade Township;  
DR 905 is located along the south bank of the  
Aroostook River, about 0.60 miles east of the  
mouth of Gardner Brook, and 4.7 miles upstream  
from the railroad bridge across the river near  
Washburn.

Note: The author has made two collections from the  
thin limestone beds present in the exposed sequence.  
The first was submitted (1966) to Neuman who  
identified the brachiopod form below (letter of  
February 24, 1967). The second collection was made  
in 1969 during a bed-by-bed study of the sequence;  
these samples were "digested" by Forbes who was the  
first to notice the abundance of conodonts in the  
specimens. Conodonts picked by Forbes were sub-  
mitted to Klapper for study; his identifications  
(letter to Forbes, October 1, 1969; letter to Roy,  
October 30, 1969) are listed below.

Fossils: Identified by Neuman:

Artriotreta

Identified by Klapper (from bed 55):

Spathognathodus celloni Walliser; Spathognathodus pennatus angulatus Walliser.

Age: Neuman writes that "...This genus was erected by Ireland (1961, Jour. Paleo., V. 35, p. 1138) for specimens from the Chimney Hill Limestone of Silurian (Alexandrian) age in the Arbuckle Mountains, Oklahoma. I am not aware of any other occurrence of it, but these little (ca. 1 mm diameter) fossils are seldom recovered or reported on. Their ranges are thus poorly known. The Oklahoma occurrence, therefore, suggests an Early Silurian (Llandovery) age for this sample, but it is obvious that such limited information does not preclude a somewhat older or younger age."

Klapper states that "...Both of these (forms) are restricted in range to the celloni Zone of Walliser (1964)." The celloni Zone correlates approximately with the interval C<sub>2</sub> - C<sub>4</sub> of the Llandovery (Boucot, letter of March 5, 1970).

Locality: 44; Field Number: DR 1876 (USNM: 17330)

Location: Portage Quadrangle; Wade Township;

This collection is from a loose block considered to have been removed from bedrock during construction of a tote road. Bedrock is exposed at

DR 1876 and is lithologically very similar to the block. The block is from a graded bed and the fossils are from the basal part. DR 1876 is located along an old tote road 0.93 miles N 71 W from the Story Hill Fire Tower.

Fossils: Boucot (letter of December 8, 1969) has identified the following fossils:

Salopina sp.; glassiid; plectodontid; Eocoelia intermedia or curtisi.

Age: Boucot states that DR 1876 is of C<sub>3</sub> - C<sub>5</sub> age as indicated by the presence of Eocoelia intermedia or curtisi.

Perham Group

New Sweden Formation

Locality: 45; Field Number: DR 444 (USNM: 13034)

Location: Presque Isle Quadrangle; Castle Hill Township;

DR 444 is located in a road-metal quarry on the east side of Turner Road 0.40 miles north of the intersection of that road and the east-west road from Mapleton to Pyle Mountain.

Fossils: Boucot (letter of October 27, 1966) has identified the following fossils:

Eocoelia cf. intermedia or curtisi; Pentamerus sp.; Protomegastrophia ? sp; Ptychopleurella sp.; stricklandid; Plectodonta sp.

Age: Boucot states that "DR 444...is of  $C_3 - C_5$  age as indicated by the Eocoelia which is similar to intermedia or curtisi."

Locality: 46; Field Number: DR 1485 (USNM: 13029)

Location: Caribou Quadrangle; Wade Township;  
DR 1485 is located on a tote road just south of its intersection with Donnelly Brook about 2.5 miles northwest along the brook from its intersection with Wade Road.

Fossils: Boucot (letter of October 27, 1965) has identified the following forms:

Dalejina sp.; Meristina sp.; Resserella sp.;  
Dicoelosia sp.; Leangella sp.; Plectodonta sp.;  
Howellella sp.; Eospirifer sp.; Leptaena "rhom-  
boidalis"; Coolinia sp.; Linoporella ? sp.; Atrypa  
"reticularis"; Protomegastrophia sp.; Strophonella  
sp.; Salopina sp.; Amphistrophia ? sp.; Cyrtia sp.;  
Mesopholidostrophia sp.; gypidulinid; rhynchonellids;  
unidentified brachiopods; gastropod; trilobites.

Age: Boucot concludes that DR 1485 is probably Wenlockian in age "...as indicated by the presence of Plectodonta and Leangella genera whose ranges cross only in the Wenlock."

Locality: 47; Field Number: EM 305

Location: Stockholm Quadrangle; T17N R3W;  
EM 305 is located 2.2 miles west of Martin Siding.



The exposures is along the road between Martin's Siding and Long Lake. Fossils came from a sequence of interbedded siltstones and fine sandstones.

Fossils: Berry has identified the following graptolites:

Monograptus triangulatus; Climacograptus of C. scalaris type.

Age: Approximately zone 19 of the Llandoveryian.

Perham Group

Jemtland Formation

Locality: 48; Field Number: DR 26 (Locality IX of Berry, 1960)

Location: Ashland Quadrangle; Castle Hill Township; DR 26 is a road cut on the south side of Route 227 approximately 0.1 miles east of its crossing of Demarchant Brook.

Fossils: Berry (1960a) reports the following graptolites from this exposure:

Desmograptus cf. D. micronematodes var. quebecensis Ruedemann; Plectograptus sp.; Monograptus colonus (Barrandé); Monograptus dubius (Suess); Monograptus forbesi Berry, n. sp.; Monograptus tumescens var. contus Berry, n. var.; Monograptus vulgaris var. ashlandensis Berry, n. var.; Monograptus sp.

Age: Early Ludlovian, zone 33.

Locality: 49; Field Number: DR 303 (Locality PV of  
Boucot, et al., 1964)

Location: Caribou Quadrangle; Woodland Township;  
DR 303 is located in a farm ditch along an east-  
west trending farm road on the Hartson Blackstone, Jr.  
Farm northeast of Perham. One gets to the farm road  
by heading east from the Perham school toward  
Carlson for 1.45 miles to an intersection with a  
north-south gravel road, thence north on this  
gravel road for 0.60 miles to the farm road. DR 303  
is 2300 feet westward along the farm road (and over  
a hill); it is the last exposure seen in the ditch  
which begins at 1731 feet.

Fossils: Berry (letter of December 22, 1965) has  
identified the following graptolites:

Monograptus crinitus Wood; Monograptus nilssoni  
(Barrande)?; Monograptus sp. (of the M. dubius  
type).

Age: Early Ludlovian (span of zones 33-34).

Locality: 50; Field Number: DR 303 A and B

Location: Caribou Quadrangle; Woodland Township;  
These two horizons (only a few feet apart) are in  
the same ditch as DR 303 but are located 468 feet  
east of it (1832 feet from main gravel road).

DR 303 A and B are stratigraphically beneath DR 303.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

DR 303A Monograptus sp. (of the M. priodon group);  
Monograptus sp. (thecae of M. vomerinus type?).

DR 303B Monograptus sp. (of the M. priodon group);  
Monograptus sp. (plain thecae).

Age: DR 303A: "In the span of Late Llandovery-Wenlock; if the poorly preserved scrap with thecae (seemingly like those of M. vomerinus) truly belongs in that group of monograptids, then the age of the beds bearing this material would be Wenlock. The evidence at hand merely indicates a Late Llandovery-Wenlock age span, however.

DR 303B: "In the span of Late Llandovery-Wenlock."

Locality: 51; Field Number: DR 307 (EM 499)

Location: Caribou Quadrangle; Westmanland Township;

DR 307 is located 0.70 miles north of the Westmanland School in a road cut on the west side of the road that crosses the west flank of Fogelin Hill.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Cyrtograptus ? sp.; Monograptus flemingii (Salter);  
Monograptus sp. (of the M. dubius group).

Age: Late Wenlockian

Locality: 52; Field Number: DR 312

Location: Caribou Quadrangle; Perham Township;

DR 312 is located in a small road-metal quarry on the west side of a gravel road which heads north from the main paved road between the Perham school and Carson. The road intersection is 0.27 miles east of the school. The exposure is 0.30 miles north of the intersection.

Fossils: Forbes and Berry collected from this outcrop in the summer of 1964. Berry (letter of January 5, 1970) has identified the following forms:

Monograptus cf. M. crinitus Wood; Monograptus sp. (of the M. scanicus group).

Age: Early Ludlovian (zones 33-34).

Locality: 53; Field Number: DR 350

Location: Portage Quadrangle; Perham Township;

DR 350 is located along the road heading south from Hanford at a point 2.10 miles from the railroad crossing at Hanford. The exposure is a small pavement surface on the west side of the road.

Fossils: Berry identified the following graptolites (letter of December 22, 1964):

Monograptus bohemicus (Barrande); Monograptus cf. M. colonus (Barrande); Monograptus sp. A. of Berry, 1964; Monograptus n. sp. (of the M. uncinatus type).

Age: Early Ludlovian (zones 33-34).

Locality: 54; Field Number: DR 485

Location: Ashland Quadrangle; Ashland Township;

DR 485 is located in the road-bed of the Bellville Road at a point 1.95 miles from its junction with the Wrightville Road.

Fossils: Berry (letter of February 16, 1967) has identified the following graptolites:

Monograptus cf. M. varians Wood; Monograptus sp. (of the M. dubius type); Monograptus sp. (thecae appear to be uncinata).

Age: Early Ludlovian (zone 33).

Locality: 55; Field Number: DR 489

Location: Presque Isle Quadrangle; Mapleton Township;

DR 489 is on a gravel road heading south toward Griffin Ridge from Route 227. The exposure is a small pavement surface on the west side of the road about 0.53 miles south of Route 227. It is approximately 0.14 miles south of locality E-13 of Boucot, et al. (1964) and is stratigraphically above it.

Fossils: Berry and Forbes collected graptolites from this locality. Berry (letter of January 5, 1970) has identified the following graptolites:

Monograptus dubius; Monograptus cf. M. crinitus Wood; Monograptus sp. (of the M. scanicus type).

Age: Early Ludlovian (zones 33-34).

Locality: 56; Field Number: DR 594 (Locality "LB" of  
Berry, 1964)

Location: Presque Isle Quadrangle; Presque Isle  
Township;

DR 594 is located 0.28 miles west of Lamson Brook  
on the road heading west from the village of  
Spragueville.

Fossils: Berry (1964) reports the following grapto-  
lites:

Monograptus bohemicus (Barrande); Monograptus  
colonus var. compactus Wood; Monograptus crinitus  
Wood; Monograptus dubius (Suess); Monograptus  
forbesi (Berry); Monograptus nilssoni (Barrande);  
Monograptus tumescens Wood; Monograptus cf. M.  
tumescens Wood; Monograptus tumescens var. contus  
Berry; Monograptus varians Wood; Monograptus cf.  
M. vicinus Perner.

Age: Early Ludlovian (zone 33).

Locality: 57; Field Number: DR 596 (Localities SR1 and  
SR2 of Berry, 1964)

Location: Presque Isle Quadrangle; Presque Isle  
Township;

DR 596 is located on the road heading west and north  
from the village of Spragueville at a distance of  
1.14 miles northwest from the Lamson Brook crossing.

Fossils: Berry (1964) reports the following

graptolites:

Monograptus bohemicus (Barrande); Monograptus colonus var. compactus Wood; Monograptus cf. M. crinitus Wood; Monograptus cf. M. dubius (Suess); Monograptus forbesi Berry; Monograptus cf. M. scanicus Tullberg; Monograptus tumescens Wood; Monograptus varians Wood; Monograptus cf. M. vicinus Perner; Monograptus sp. A. of Berry, 1964.

Age: Early Ludlovian (zone 33).

Locality: 58; Field Number: DR 610

Location: Ashland Quadrangle; Ashland Township;

DR 610 is an extensive road-ditch exposure along the Belleville Road at a distance of 2.07 miles from its intersection with the Wrightville Road.

Fossils: Berry (letter of April 21, 1966) has identified the following graptolite:

Monograptus priodon

Age: "In the span of Late Llandovery-Wenlock--from the dimensions of this form, I would suggest a Late Llandovery age as forms with similar dimensions included in M. priodon by Elles and Wood are found primarily in the Late Llandovery."

Locality: 59; Field Number: DR 621 (Locality E-13 of Boucot, et al., 1964)

Location: Presque Isle Quadrangle; Mapleton Township;  
DR 621 is located 0.36 miles south of Route 227 on  
the gravel road toward Griffin Ridge.

Note: This exposure was placed in the Lower Member  
of the Perham Formation (New Sweden Formation of  
this report) by Boucot, et al., 1964. Re-examination  
of this exposure by Roy and Pavlides in 1965 re-  
sulted in a consensus that the strata at DR 621  
should be placed in the Upper Member of the Perham  
Formation (Jemtland Formation of this report). An  
additional collection in 1965 has been reported by  
Pavlides (1968).

Fossils: Boucot, et al. (1964) report the following  
fossils:

Leangella sp.; smooth atrypcean; trilobite.

Pavlides (1968) reports the following ostracods:

Grammolomatella sp.; Tubulibairdia sp.; Rishona sp;  
Spinobairdia sp.; Condacypris ? sp.

Trilobites:

Phacops (of the P. orestes group); Diacalymene sp.

Age: Boucot, et al. (1964) report that Leangella has  
never been found above the Wenlockian. The ranges  
of the ostracod and trilobite fauna from this  
exposure suggest a Late Wenlockian age (Pavlides,  
1968).



Locality: 60; Field Number: DR 664

Location: Caribou Quadrangle; New Sweden Township;

DR 664 is a small road cut along the east-west road which heads west from Route 161 at a distance of 0.5 miles south of Jemtland (Stockholm Quadrangle) and passes the West Jemtland Cemetery. The outcrop is 0.45 miles west of Route 161 and on the north side of the road. Collection was made by Douglas Smith (Field No. 1064) in 1962.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus bohemicus (Barrande); Monograptus sp. A. of Berry, 1964; Monograptus sp. (of the M. vulgaris type).

Age: Early Ludlovian (zones 33-34).

Locality: 61; Field Number: DR 635

Location: Stockholm Quadrangle; New Sweden Township;

DR 635 is a large road cut along Route 161 on the west side of the road in the village of Jemtland.

Fossils: Berry (letter of December 17, 1965) identified the following graptolites:

Monograptus sp. A. (Berry, 1964); Monograptus cf. M. uncinatus Tullberg; Monograptus sp. (M. uncinatus type); Monograptus sp. (plain thecae).

Age: Early Ludlovian (zones 33-34).

Locality: 62; Field Number: DR 636

Location: Stockholm Quadrangle; T16N R4W;

DR 636 is the so-called Jemtland Quarry which is located just off Route 161 (to the southwest) at a distance of 1.6 miles northwest of Jemtland. Several graptolite horizons were found while measuring the section exposed in the quarry. Measurement of the quarry required 10 separate short traverses (legs).

Fossils: Berry (letter of December 17, 1965) identified the following graptolites from each horizon:

Leg 1 (at 28 feet) (lowest): Monograptus sp.  
(hooked thecae).

Leg 2 (at 22 feet): Monograptus scanicus Tullberg?;  
Monograptus (M. dubius type?); Monograptus sp.  
(plain thecae); Monograptus sp. (M. uncinatus type?).

Leg 5 (at 10 feet): Monograptus sp. (hooked thecae);  
Monograptus sp. (M. uncinatus type?).

Leg 6 (at 159 feet) (highest): Monograptus bohemicus (Barrande); Monograptus colonus cf. var.  
compactus Wood; Monograptus nilssoni (Barrande);  
Monograptus sp. (of the M. chimaera type); Monograptus  
sp. (of the M. uncinatus type); Monograptus  
sp. A. of Berry, 1964.

Age: Leg 1 (at 28 feet): Late Llandoveryian-Early  
Ludlovian  
Leg 2 (at 22 feet): Probably Early Ludlovian  
(zones 33-34)  
Leg 5 (at 10 feet): Late Llandoveryian-Early  
Ludlovian; probably Early  
Ludlovian  
Leg 6 (at 159 feet): Early Ludlovian (zone 33)

Locality: 63; Field Number: DR 688

Location: Square Lake Quadrangle; T17N R4W;

DR 688 is located in a farm field on a small hill  
just southeast of Guerette. The exposure is 0.68  
miles S 79 E from the bridge in Guerette.

Fossils: Berry (letter of July 27, 1966) has identi-  
fied the following graptolites:

Monograptus nilssoni (Barrande)?; Monograptus sp.  
(of the M. dubius type).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 64; Field Number: DR 714

Location: Grand Isle Quadrangle; Grand Isle Township;

Douglas Smith (letter of March 6, 1964) collected  
fossils from an exposure (Smith, Field No. 1212)  
along a farm road a distance of 0.7 miles S 13 E  
of the intersection at the old Doucette School  
(BM 924) and 1.1 miles due east of the western  
boundary of the Grand Isle Township.

Fossils: Berry has (letter of December 22, 1964)  
identified the following graptolites:

Monograptus scanicus Tullberg; Monograptus sp.  
(of the M. chimaera group).

Age: Early Ludlovian (zones 33-34)

Locality: 65; Field Number: DR 849 (Locality "DB" of  
Berry, 1964; locality "D-3" of Boucot,  
et al., 1964)

Location: Presque Isle Quadrangle; Castle Hill  
Township;

DR 849 is in the south road ditch of Route 163 a  
distance of 0.10 miles from the crossing of Dudley  
Brook southwest of Mapleton.

Fossils: Berry (letter of December 17, 1965) has  
identified the following graptolites:

Monograptus colonus var. compactus Wood; Mono-  
graptus dubius (Suess); Monograptus nilssoni  
(Barrande); Monograptus cf. M. varians Wood;  
Monograptus cf. M. vicinus Perner.

Age: Early Ludlovian (zone 33).

Locality: 66; Field Number: DR 998

Location: Van Buren Quadrangle; Van Buren Township;

DR 998 is situated at the top of a ski slope at a  
distance of 0.55 miles S 33 W from Keegan.

Fossils: Berry (letter of December 17, 1965) has  
identified the following graptolites:

Monograptus dubius (Suess); Monograptus sp. (of the M. uncinatus type).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 67; Field Number: DR 1000

Location: Van Buren Quadrangle; Van Buren Township;  
DR 1000 is located in a contour drainage ditch just a few yards west of a farm road which leaves the main gravel road (that runs parallel to Violette Stream northeast of Van Buren) at a distance of 1.1 miles northwest of the intersection at elevation 524. The drainage ditch is approximately 0.1 mile in on the farm road. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolites:

Monograptus colonus cf. var. compactus Wood;

Monograptus nilssoni (Barrande).

Age: Early Ludlovian (zone 33).

Locality: 68; Field Number: DR 1001

Location: Van Buren Quadrangle; Van Buren Township;  
DR 1001 is along a farm road 0.2 miles northeast of its intersection with the gravel road which parallels Violette Stream northwest of Van Buren. The farm road leaves the main road at a distance of 1.75 miles northwest of the intersection at elevation 524. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolites:

Monograptus sp. (M. dubius group); Monograptus sp. (M. chimaera group); Monograptus sp. (M. uncinatus type).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 69; Field Number: DR 1119

Location: Stockholm Quadrangle; Stockholm Township; DR 1119 is located in a small drainage which is crossed by the paved road between Route 161 and Stockholm at a distance of 0.47 miles from Route 161. The exposure is 0.14 miles upstream from the road.

Fossils: Berry (letter of July 27, 1966) has identified the following graptolites:

Monograptus bohemicus (Barrande); Monograptus nilssoni (Barrande).

Age: Early Ludlovian (zones 33-34).

Locality: 70; Field Number: DR 1147

Location: Stockholm Quadrangle; New Sweden Townshi  
DR 1147 was an exposure (now covered) in a trench dug in connection with the remodeling of a home. The home is located on the east side of the road between Jemtland and Stockholm at a distance of 0.20 miles from the road's intersection with Route 161.

Fossils: Berry (letter of July 27, 1966) has identified the following graptolites:

Monograptus colonus cf. var. compactus Wood;  
crinoid plates and columnals.

Age: Early Ludlovian (zones 33-34).

Locality: 71; Field Number: DR 1196

Location: Stockholm Quadrangle; Westmanland Township;

DR 1196 is located along an old farm road which heads eastward off the road that runs north-south along the Westmanland-New Sweden township line. The exposure is 0.33 miles north of the southern boundary of the Stockholm quadrangle and 0.14 miles east of the road.

Fossils: Berry (letter of July 27, 1966) has identified the following graptolites:

Monograptus colonus cf. var. compactus Wood;

Monograptus sp. (of the M. dubius type).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 72; Field Number: DR 1270

Location: Stockholm Quadrangle; Stockholm Township;

DR 1270 is located 0.53 miles N 45 W from the main intersection in Stockholm in a partly cleared field.

Fossils: Berry (letter of July 27, 1966) identified the following graptolites:

Monograptus colonus var. compactus Wood; Monograptus bohemicus (Barrande); Monograptus nilssoni (Barrande); Monograptus sp. (with thecae similar to those in M. uncinatus).

Age: Early Ludlovian (zones 33-34).

Locality: 73; Field Number: DR 1631

Location: Stockholm Quadrangle; T17N R3W;

DR 1631 is located 0.94 miles west of the eastern township line and 1.12 miles north of the southern line.

Fossils: Berry (letter of February 16, 1970) has identified the following graptolites:

Monograptus colonus cf. var. compactus Wood;

Monograptus micropoma (Jaekel)?; Monograptus sp.

(of the M. dubius group).

Age: Early Ludlovian (zones 33-34).

Locality: 74; Field Number: DR 1724

Location: Portage Quadrangle; Perham Township;

DR 1724 is located in the west road ditch of Tangle Ridge Road 1.82 miles south of the railroad crossing in Hanford.

Fossils: Berry (letter of February 16, 1970) has identified the following graptolites:

Monograptus sp. (of the M. colonus type); Mono-

graptus sp. (of the M. dubius group).

Age: Early Ludlovian (zones 33-34).

Locality: 75; Field Number: DR 1727

Location: Portage Quadrangle; Perham Township;

DR 1727 is located in the woods on the east slope



of Tangle Ridge. The exposure is 1.90 miles east of the western line and 2.05 miles south of the northern line of Perham Township.

Fossils: Berry (letter of February 16, 1970) has identified the following graptolite:

Monograptus bohemicus (Barrande)

Age: Ludlovian.

Locality: 76; Field Number: EM 411

Location: Caribou Quadrangle; Westmanland Township;

EM 411 is along a gravel road which leaves the main road at elevation 748 feet about one mile northeast of Mud Lake in the southeastern corner of the township. EM 411 is 1.0 mile west of the intersection at elevation 748 feet.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus scanicus Tullberg; Monograptus sp.  
(of the M. dubius group).

Age: Early Ludlovian (zones 33-34).

Locality: 77; Field Number: EM 412

Location: Caribou Quadrangle; Westmanland Township;

EM 412 is located along the same gravel road as EM 411, but is 0.20 miles west of it.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus aff. M. micropoma micropoma (Jaekel);  
Monograptus sp. (of the M. dubius group); Mono-  
graptus sp. (of the M. uncinatus type).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 78; Field Number: EM 413

Location: Caribou Quadrangle; Westmanland Township;

EM 413 is located along the same road as EM 411  
and 412, but is 0.30 miles west of EM 411.

Fossils: Berry (letter of December 22, 1964) has  
identified the following graptolites:

Monograptus colonus cf. var. compactus Wood; Mono-  
graptus varians Wood; Monograptus sp. (of M. dubius  
group); Monograptus sp. (of the M. vulgaris type?).

Age: Early Ludlovian (zones 33-34).

Locality: 79; Field Number: EM 424

Location: Grand Isle Quadrangle; Grand Isle Township;

EM 424 is behind a cabin located 0.80 miles in on a  
gravel farm road heading southwest from U. S. Route 1  
at a distance of 2.4 miles north of the railroad  
crossing in Notre Dame. This locality is outside  
the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has  
identified the following graptolites:

Monograptus colonus (Barrande); Monograptus forbesi  
Berry; Monograptus varians Wood; Monograptus sp.

(of the M. colonus group); Monograptus sp. (of the M. dubius group).

Age: Early Ludlovian (zones 33-34).

Locality: 80; Field Number: EM 430

Location: Grand Isle Quadrangle; Grand Isle Township;

EM 430 is just to the east of the same farm road as EM 424 but is situated at a point 1.5 miles from U. S. Route 1. The exposure occurs in a drainage depression at the edge of a field approximately 100 feet from the road. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus crinitus Wood; Monograptus scanicus Tullberg (?); Monograptus sp. (of the M. colonus group).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 81; Field Number: EM 435

Location: Stockholm Quadrangle; St. Agatha Township;

EM 435 is very near the southern terminus of the road along the east shore of Long Lake. The exposure is at a distance of 0.1 miles north of the southern boundary of the township.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus nilssoni (Barrande); Monograptus cf.

M. scanicus Tullberg; Monograptus cf. M. dubius (Suess); Monograptus cf. M. longus Boucek; Monograptus sp. (of the M. colonus type).

Age: Early Ludlovian (zones 33-34).

Locality: 82; Field Number: EM 498

Location: Caribou Quadrangle; Westmanland Township; EM 498 is in a large road-metal quarry 0.3 miles south of Blackstone Siding. The quarry may be reached by taking the road which heads south from the main Blackstone siding road a short distance east of the siding itself.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus colonus (Barrande); Monograptus uncinatus Tullberg; Monograptus sp. (of the M. dubius group); Plectograptus macilentus (Tornquist)

Age: Early Ludlovian (zones 33-34).

Locality: 83; Field Number: EM 589

Location: Edmundston Sheet (East Half); St. Ann Parish;

EM 589 is 0.40 miles in along a lumber road which intersects the major gravel road heading northeast from Theriault Station, N. B., at a distance of 2.28 miles from Route 2. The tote road heads in a northwesterly direction from its intersection with the main gravel road. The exposure is a

pavement surface in the road. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus cf. M. colonus (Barrande); Monograptus colonus var. compactus Wood; Monograptus colonus cf. var. compactus Wood; Monograptus nilssoni (Barrande)?.

Age: Early Ludlovian (zones 33-34).

Locality: 84; Field Number: EM 590

Location: Edmundston Sheet (East Half); St. Anne Parish;

EM 590 is located just beyond EM 591 to the northwest but along the same road. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolite:

Monograptus scanicus Tullberg.

Age: Early Ludlovian (zones 33-34).

Locality: 85; Field Number: EM 659

Location: Van Buren Quadrangle; Van Buren Township;

Douglas Smith (letter of March 6, 1964) collected fossils from an exposure (Field No. 1101) west of Van Buren. The outcrop is located 2.8 miles due west of the main intersection in Van Buren (U. S.

Route 1 and Bridge Street which crosses the St. John River into Canada) and 2.25 miles north of the southern boundary of the Van Buren Township. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus uncinatus Tullberg; Monograptus sp. (of the M. chimaera group); Monograptus sp. (of the M. dubius type).

Age: Early Ludlovian (zones 33-34).

Locality: 86; Field Number: EM 765 and EM 765B

Location: Grand Falls Sheet (West Half), New Brunswick; St. Anne Parish;

EM 765 and 765B are both located in a road cut along the newly constructed Route 2 in New Brunswick. The exposure was made at the point where Route 2 crosses the St. Anne-St. Leonard Parish line 1.7 miles from the intersection of Routes 2 and 17 in St. Leonard. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

EM 765 Monograptus colonus cf. var. compactus Wood; Monograptus dubius cf. var. ludlowensis (Boucek); Monograptus sp. (of the M. colonus group); Monograptus nilssoni (Barrande).

EM 765B Monograptus sp. (of the M. colonus group);  
Monograptus sp. (of the M. dubius group).

Age: Early Ludlovian (zones 33-34).

Locality: 87; Field Number: EM 766

Location: Grand Falls Sheet (West Half), New Brunswick; St. Leonard Parish;

EM 766 is situated in the same road cut as EM 765 but is 138 feet east of EM 765. This locality is outside the area of Plate 1.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus colonus cf. var. compactus Wood;

Monograptus uncinatus Tullberg; Monograptus sp.

(of the M. dubius group); Monograptus sp. (of the M. vulgaris group?).

Age: Early Ludlovian (zones 33-34).

Locality: 88; Field Number: SH 125

Location: Stockholm Quadrangle; Stockholm Township;

SH 125 is along the main north road leading north from the village of Stockholm at a distance of 1.15 miles from the railroad crossing in Stockholm.

Fossils: Boucot (letter of November 9, 1964) has identified the following fossils:

Plectatrypa (?) sp.; Leangella sp.; Glassia (?);

rhynchonellid; pentamerinid; Isorthis (?) sp.;

Dalejina (?) sp.

Age: Boucot places this assemblage in the span C<sub>3</sub>  
of the Llandoveryian to Wenlockian.

Locality: 89; Field Number: SH 168

Location: Stockholm Quadrangle; Stockholm Township;  
SH 168 is in a field a distance of 0.60 miles N 18 W  
of the railroad crossing in Stockholm. This locality  
is at the base of the water-laid tuff sequence which  
forms a "marker bed" within the Jemtland Formation  
in the Stockholm area.

Fossils: Boucot (letter of November 9, 1964) has  
identified the following fossils:

Linoporella (?) sp.; Conchidium (?) or Rhipidium  
sp.; eospiriferid.

Age: Boucot states that "SH 168 is of Wenlockian or  
Early Ludlovian age; more likely Early Ludlovian as  
it contains a specimen of Conchidium or Rhipidium.

Locality: 90; Field Number: SH 169

Location: Stockholm Quadrangle; Stockholm Township;  
SH 169 is in a field 0.65 miles N 23 W of the  
railroad intersection in Stockholm. It is strati-  
graphically below SH 168.

Fossils: Berry (letter of December 22, 1964) has  
identified the following graptolite:

Monograptus n. sp. (of the M. dubius group--slender,  
low thecae inclination and count.)



Age: Berry states that "Monograptids of the M. dubius type that are small and have low thecae counts are known to occur in the span Late Llandovery-Wenlock in Europe."

Locality: 91; Field Number: SH 191

Location: Stockholm Quadrangle; Stockholm Township; SH 191 is 1.05 miles north of the railroad crossing in the village of Stockholm along the main north-south road on the west flank of Stockholm Mountain.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolites:

Monograptus sp. (of the M. dubius group); Mono-graptus sp. (robust rhabdosomes with plain thecae); Monograptus sp. (with uncinata thecae).

Age: Berry states: "Could be in the span of Late Llandovery to Ludlow--monograptids with plain thecae and large robust rhabdosomes are commonly found in the Ludlow and so, too, are monograptids with thecae that appear uncinata, thus the age of the beds bearing this collection would appear more possibly to be Ludlow...."

Locality: 92; Field Number: LW 2

Location: Stockholm Quadrangle; Stockholm Township; LW 2 is located along road heading due east from Stockholm and onto Stockholm Mountain. The outcrop is 1.4 miles east of Stockholm.

Fossils: Berry (letter of July 9, 1965) has identified the following graptolites:

Monograptus sp. (of the M. colonus type); Monograptus sp. (of the M. dubius group).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 93; Field Number: LW 36

Location: Stockholm Quadrangle; Stockholm Township; LW 36 is 0.20 miles south of the east-west road to California at a point 0.48 miles east of the Snake Brook crossing.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolites:

Monograptus cf. M. scanicus Tullberg; Monograptus sp. (of the M. dubius type?).

Age: Probably Early Ludlovian (zones 33-34).

Locality: 94; Field Number: LW 87

Location: Stockholm Quadrangle; Stockholm Township; LW 87 is in a farm field 0.3 miles east of a point on the main north-south road between Stockholm and Snake Brook a distance of 1.50 miles north of the railroad crossing in Stockholm.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolites:

Monograptus cf. M. dubius (Suess); Monograptus sp. (M. uncinatus type); Monograptus sp. (plain thecae).

Age: Possibly Early Ludlovian (zones 33-34).

Locality: 95; Field Number: LW 113

Location: Stockholm Quadrangle; Stockholm Township;  
LW 113 is in the fields approximately 500 feet east  
of a position on the main north-south road in  
Stockholm which is 0.30 miles north of the rail-  
road crossing in the village.

Fossils: Berry (letter of December 17, 1965) has  
identified the following graptolites:

Monograptus dubius cf. var. thuringicus Jaeger;

Monograptus cf. M. uncinatus Tullberg.

Age: Probably Early Ludlovian (zones 33-34).

Locality: 96; Field Number: LW 190

Location: Caribou Quadrangle; Westmanland Township;  
LW 190 is located along the north-south road which  
crosses the west flank of Fogelin Hill. The  
outcrop is 1.0 miles north of the Westmanland School.

Fossils: Berry (letter of December 17, 1965) has  
identified the following graptolites:

Monograptus cf. M. micropoma (Jaekel); Monograptus

sp. (plain thecae).

Age: Probably Early Ludlovian (zones 33-34).

The following seven fossil localities are important  
in the dating of the Jemtland Formation but have not  
been visited by the writer. All data given below are

presented by Berry (1964) and/or Boucot, et al. (1964).

Field numbers are those used by Boucot and others.

Locality: 97; Field Number: B-2 ("DF" of Berry, 1964)

Location: Presque Isle Quadrangle; Chapman Township;

Locality B-2 is at the crest of a hill on the Dean Farm 1.9 miles east of the western border of Chapman township and 0.15 miles south of the northern border of the township.

Fossils: Berry (1964) and Berry (in Boucot, et al., 1964) identified the following graptolites:

Monograptus chimaera (Barrande); Monograptus colonus var. compactus Wood; Monograptus dubius (Suess); Monograptus forbesi Berry; Monograptus nilssoni (Barrande); Monograptus cf. M. scanicus Tullberg; Monograptus tumescens var. contus Berry; Monograptus cf. M. vicinus Perner; Monograptus sp. A; Monograptus uncinatus var. microboma.

Age: Early Ludlovian (zone 33).

Locality: 98; Locality Number: E-5

Location: Presque Isle Quadrangle; Chapman Township;

Locality E-5 is at the crest of a low hill 1.6 miles east of the western border of Chapman Township and 0.7 miles south of the northern border of the township.

Fossils: Berry (in Boucot, et al., 1964) has identified the following graptolites:

Monograptus colonus; Monograptus dubius; Mono-  
graptus sp.

Age: Early Ludlovian (zones 33).

Locality: 99; Field Number: E-9

Location: Presque Isle Quadrangle; Presque Isle  
Township;

Locality E-9 is on the northeast side of the  
Spragueville road at Lamson Brook approximately  
0.5 miles west of the village of Spragueville.

Fossils: Berry (in Boucot, et al., 1964) has identi-  
fied the following graptolites:

Monograptus colonus (Barrande); Monograptus cf. M.  
dubius (Suess); Monograptus forbesi Berry; Mono-  
graptus scanicus Tullberg; Monograptus sp. (see  
Berry, 1960, p. 1161, fig. D); monograptid of  
type III.

Age: Early Ludlovian (zone 33).

Locality: 100; Field Number: A-8 (Locality "CS" of  
Berry, 1964)

Location: Presque Isle Quadrangle; Chapman Township;

Locality A-8 is on the southeast slope of a promi-  
nent hill about 0.5 miles east of the western border  
of the Chapman Township and about 0.7 miles south of  
the northern boundary of the township.

Fossils: Berry (1964) reports the following graptolites:

Monograptus colonus cf. var. compactus Wood;

Monograptus dubius (Suess); Monograptus cf. M. vicinus Perner.

Age: Early Ludlovian (zone 33).

Locality: 101; Field Number: E-7

Location: Presque Isle Quadrangle; Presque Isle Township;

Locality E-7 is on the road to campsites in the Aroostook State Park about 250 yards west of bathing beach on Echo Lake.

Fossils: The following fossils have been reported by Boucot, et al (1964):

"Camarotoechia" sp.; Coelospira cf. C. saffordi;

Encrinurus sp.; Glassia ? sp.; Platyceras sp.;

Plectodonta sp.

Age: "Late Wenlock-Ludlow on the basis of Coelospira" (Boucot, letter of February 14, 1970)

Locality: 102; Field Number: A-2 (Cloud, 1941, Locality 23)

Location: Presque Isle Quadrangle; Castle Hill Township;

Locality A-2 is situated near stream on the Dudley Farm 1.45 miles west of the railroad overpass in

Mapleton and 0.4 miles south of the road from Mapleton to the north slopes of Pyle Mountain. Fossils: Boucot examined fossils collected by Cloud and identified the genus (Conchidium as present. (Boucot, et al., 1964). Age: Ludlovian.

Fogelin Hill Formation

Locality: 103; Field Number: DR 349

Location: Portage Quadrangle; Perham Township; DR 349 is on the road heading south from Hanford (Tangle Ridge Road) at a distance of 0.52 miles south of the railroad crossing in Hanford. The outcrop is on the south side of the road.

Fossils: Berry (letter of January 5, 1969) has identified the following graptolite:

Monograptus sp. (fragments of a monograptid with uncinata thecae)

Age: "In the span of Ludlow-Siegen. This may be a member of the M. hercynicus group; if so, then the rock is Early Devonian in age."

Locality: 104; Field Number: DR 653

Location: Stockholm Quadrangle; Stockholm Township; DR 653 is a road cut at the cemetery on the main north-south road between Stockholm and Jemtland. The road cut is 0.75 miles south of the railroad crossing in Stockholm.

Fossils: Berry (letter of December 17, 1965) has identified the following graptolite:

Monograptus sp. (M. uncinatus type?)

Age: Ludlovian-Early Devonian.

Locality: 105; Field Number: DR 656

Location: Stockholm Quadrangle; New Sweden Township; DR 656 is located just west of the main road between Stockholm and Jemtland at a distance of 1.8 miles south of the railroad crossing in Stockholm.

Fossils: Berry (letters of July 9, 1965 and February 16, 1970) has identified the following graptolites:

Monograptus cf. M. colonus (Barrande); Monograptus cf. M. varians Wood; Monograptus sp. (of the M. colonus type); Monograptus sp. (of the M. dubius group).

Age: Probably Ludlovian and possibly Early Ludlovian (zones 33-34).

#### Spragueville Formation

Locality: 106; Field Number: DR 573 (E-10 of Boucot, et al., 1964)

Location: Presque Isle Quadrangle; Mapleton Township; DR 573 is a large road cut on the south side of Route 163 at a distance of 1.05 miles east of the railroad crossing in Mapleton.



Fossils: Boucot, et al. (1964) and Boucot (letter of April 9, 1970) report the following forms as coming from this exposure (identification by Boucot, Whittington, Berdan, and Neuman):

Trilobite: Portlockia

Brachiopods: Atrypa "reticularis"; Dalejina sp.;

Glassia sp.; Howellella sp.; Leptaena "rhomboidalis";

Mesopholidostrophia sp.; Nucleospira sp.; Plecto-

donta sp.; Resserella sp.; orthotetaceid, indet.;

rhynchonellid, indet.;

Ostracods: Zygobolba inflata Ulrich and Bassler;

Apatobolbina sp.; Bolbineossia sp.

Age: The ostracods indicate a  $C_3 - C_5$  age for the strata. The brachiopod assemblage is of wider range ( $C_3$  - Ludlow); the best age for the beds at DR 573 is, therefore,  $C_3 - C_5$ . (Boucot, et al., 1964).

Locality: 107; Field Number: MR 210 (Locality 2 of Pavlides, 1968)

Location: Fort Fairfield Quadrangle; Fort Fairfield Township;

MR 210 is located in a small drainage west of Nadeau Pond at a distance of 1.71 miles south of the northern township line and 0.58 miles west of the U. S.--Canada international boundary. This locality is outside the area of Plate 1.

Fossils: Berry has identified the following graptolites (Pavrides, 1968):

Climacograptus cf. C. scalaris var. miserabilis  
Elles and Wood; Monograptus communis (Lapworth);  
Rastrites cf. R. approximatus approximatus (Perner).

Age: Zone 19 or 20 of the Llandoveryan (Pavrides, 1968).

(SILURIAN AND EARLY DEVONIAN (?))

Sandstone and Slate

(Ashland Area)

Locality: 108; Field Number: DR 777 (USNM: 12161)

Location: Ashland Quadrangle; Ashland Township;  
DR 777 is in the south road ditch of Route 227 in Ashland 0.30 miles east of the intersection of Routes 11 and 227. Fossils occur in a light green, calcareous, coarse grained, micaceous mudstone.

Fossils: Boucot (letter of October 25, 1965) identified the following fossils:

Coelospira cf. saffordi; Isorthis aff. I. arcuaria  
(Henryhouse type).

Age: Ludlovian.

Locality: 109; Field Number: DR 609

Location: Ashland Quadrangle; Ashland Township;  
DR 609 is along Route 163 at a point 2.62 miles east of the intersection of Routes 163 and 11 in

Ashland. The outcrop is a small road cut on the south side of the road.

Fossils: Forbes and Berry collected graptolites which have been identified by Berry (letter of January 5, 1970) as follows:

Monograptus colonus cf. var. compactus Wood;

Monograptus sp. (of the M. dubius type).

Age: Early Ludlovian.

Locality: 110; Field Number: DR 882 (USNM: 12165, 17326, 17327)

Location: Ashland Quadrangle; Ashland Township; DR 882 is from a conglomeratic mudstone sequence exposed in a gravel pit located just south of Route 163 3.70 miles east of the intersection of Routes 163 and 11 in Ashland.

Fossils: Boucot (letter of December 8, 1969) has identified the following fossils:

Resserella sp.; Stricklandia sp.; Pentamerus sp.; corals.

Age: According to Boucot this assemblage is of Late Llandoveryan age.

Early Devonian Localities in the

Ashland, Portage and Stockholm Quadrangles

Locality: 111; Field Number: DR 784

Location: Ashland Quadrangle; Ashland Township;

DR 784 is a limestone exposure behind Michaud's Restaurant on the east side of Main Street (Route 11) in the village of Ashland.

Fossils: Klapper (letter to Boucot dated November 7, 1966) has identified the following conodonts:  
Icriodus woschmidti; Spathognathodus remscheidensis;  
Spathognathodus aff. S. n. sp. Q.

Age: Gedinian (Early Devonian)

Locality: 112; Field Number: DR 1635 (USNM: 13033)

Location: Ashland Quadrangle; Ashland Township;  
DR 1635 is 0.47 miles S 34 W from the intersection of Routes 163 and 11 in Ashland. The outcrop is in a field on the George Howe Farm.

Fossils: Boucot (letter of October 27, 1966) has identified the following fossils:  
Meristella sp.; pelecypods; Megakozlowskiella sp.; trilobite; gastropod; corals; unidentified brachiopods.

Age: Middle or Upper Helderbergian age as indicated by the presence of Megakozlowskiella.

Locality: 113; Field Number: DR 1653 (USNM: 13035)

Location: Ashland Quadrangle; Ashland Township;  
DR 1653 is 0.23 miles N 36 E of the intersection of Routes 11 and 227 in Ashland. The exposure is in a farm field.

Fossils: Boucot (letter of October 27, 1966) has identified the following fossils:

Dalejina sp.; Megakozlowskiella sp.; Eatonia sp.;  
Levenea sp.; Meristella sp.; Atrypa "reticularis";  
Leptaena "rhomboidallis"; Leptostrophia sp.;  
Strophonella punctulifera; Mesophonella punctu-  
lifera; Mesodouvillina sp.; coral.

Age: Middle or Upper Helderbergian age as indicated by the presence of Megakozlowskiella, Strophonella punctulifera and Levenea.

Locality: 114; Field Number: EM 136 (EM 238, TF 221)

Location: Portage Quadrangle; Portage Lake Township; EM 136 is a road cut and a ditch on the east side of Route 11 2.05 miles north of Buffalo cemetery and 0.9 miles south of the north line of Portage Lake Township.

Fossils: Berry (letter of October 28, 1963) has identified the following graptolite:

Monograptus microdon silesicus

Age: Early Devonian; Monograptus praehercynicus Zone in Germany and Czechoslovakia.

Locality: 115; Field Number: EM 514

Location: Stockholm Quadrangle; Madawaska Township; EM 514 is on the east side of the road 1.9 miles due south of Lavertue and approximately 2 miles north of Francks camp on Long Lake.

Fossils: Berry (letter of December 22, 1964)

identified the following graptolites:

Monograptus aff. M. micropoma micropoma (Jaekel);

Monograptus sp. (of the M. microdon type); Mono-  
graptus spp. (new species of the M. uncinatus  
type); plant fragments.

Age: In the span of the Ludlovian to Early Devonian.

Locality: 116; Field Number: EM 811

Location: Portage Quadrangle; T14N R6W;

EM 811 is at the side of a lumber road of the  
Pinkham Lumber Co. that goes from Route 11 to  
Moose Mountain; the exposure is 1.15 miles west of  
the West Branch of Beaver Brook and 1.3 miles east  
of Route 11.

Fossils: Berry (letter of December 22, 1964) has  
identified the following graptolite:

Monograptus microdon microdon Richter?

Age: Probably Early Devonian.

Locality: 117; Field Number: EM 815

Location: Portage Quadrangle; T14N R6W;

EM 815 is at the side of a lumber road of the  
Pinkham Lumber Co. that goes from Route 11 to  
Moose Mountain; the exposure is 0.85 miles east  
of Route 11.

Fossils: Berry (letter of December 22, 1964) has identified the following graptolite:

Monograptus sp. (biform thecae--uncinate proximally and tubular distally--short and slender--possibly new).

Age: "Monograptids with this thecal form are restricted in their range to beds of Early Devonian age. The incoming of this kind of monograptid is taken as denoting the Siluro-Devonian boundary in Europe by Jaeger. On this basis, the age indicated for these beds is Early Devonian."

Locality: 118; Field Number: EM 856

Location: Portage Quadrangle; T13N R6W;

EM 856 is along an old tote road which heads northeast from the village of Portage. The exposure is 2.56 miles from Route 11 and 0.46 miles N 74 W from the confluence of the East and West Branches of Beaver Brook.

Fossils: Brower (letter of September 11, 1967) has identified the crinoid:

Scyphocrinites.

Age: Late Silurian or Early Devonian.

Locality: 119; Field Number: EM 1529 (USNM: 17007, 17008)

Location: Ashland Quadrangle; Ashland Township;

EM 1529 was an exposure in the basement excavation for the Laveck home in Ashland located about 1800 feet N 52 E from the intersection of Routes 11 and 227. The exposure is now covered.

Fossils: Boucot (letter of January, 1968) has

identified the following fossils:

Megasalopina ? sp.; Megakozlowskiella sp.; Strophonella cf. punctulifera; Levenes subcarinata;  
Meristella sp.; Orthostrophia sp.; Dalejina sp.;  
Nucleospira sp.; dalmanellids; corals; trilobite;  
unidentified brachiopods.

Age: Middle or Upper Helderbergian age as shown by the presence of Megakozlowskiella, Strophonella cf. punctulifera, and Orthostrophia.



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## BIOGRAPHICAL SKETCH

David Chalmer Roy was born on November 14, 1937, in Baton Rouge, Louisiana, the first son of Chalmer J. and Elizabeth P. Roy. At the age of 10 the Roy family, including brother Arthur P., moved to Ames, Iowa, where David lost his southern accent and became a Yankee.

David was educated from the fourth grade through the Bachelor of Science in Ames. He attended Ames Senior High School from 1953-1956 and, after a 6-month tour of duty in the U. S. Army as an enlisted reservist, entered Iowa State University. He graduated from ISU, in 1961, with a degree in geology and a second lieutenant's commission, both of which were destined to cause him work.

Upon receiving the "go-ahead" from the Army, David entered MIT and began a marathon to the Ph. D. degree. In 1967, the Army decided the need was too great and "requested" that he proceed immediately to El Paso, Texas, where he stayed for two years. Upon returning to MIT, David went immediately to Maine for one last field season, and a year later received his Ph. D.

In 1962, David married Marjorie H. Bihary of Cleveland (his first unqualified success) and in 1968 they were blessed with the birth of Deborah E. Roy (his second unqualified success).

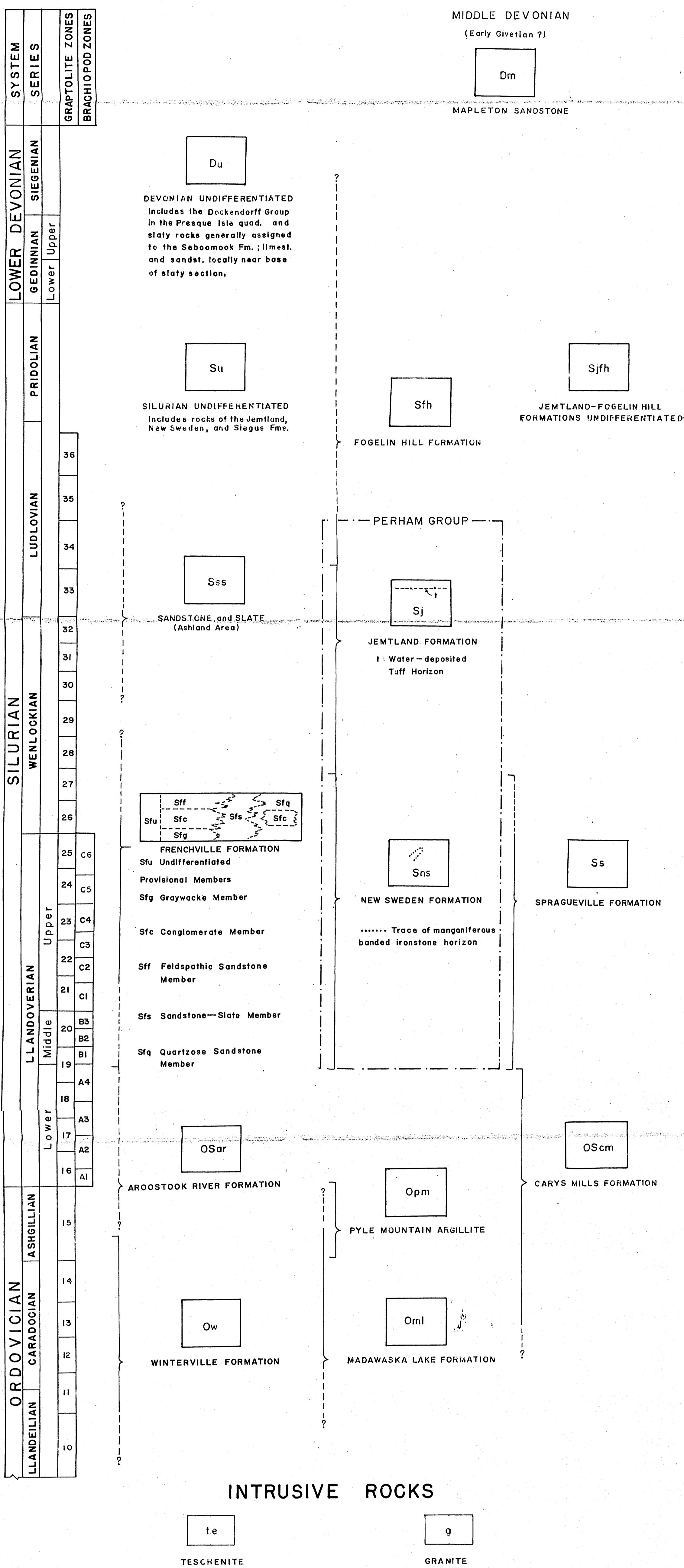
In September 1970, David joined the faculty of Boston College in Chestnut Hill, Massachusetts.



# PLATE II GEOLOGIC MAP OF A PORTION OF NORTHEASTERN AROOSTOOK COUNTY, MAINE

## EXPLANATION

SEDIMENTARY and VOLCANIC ROCK UNITS



## SYMBOLS

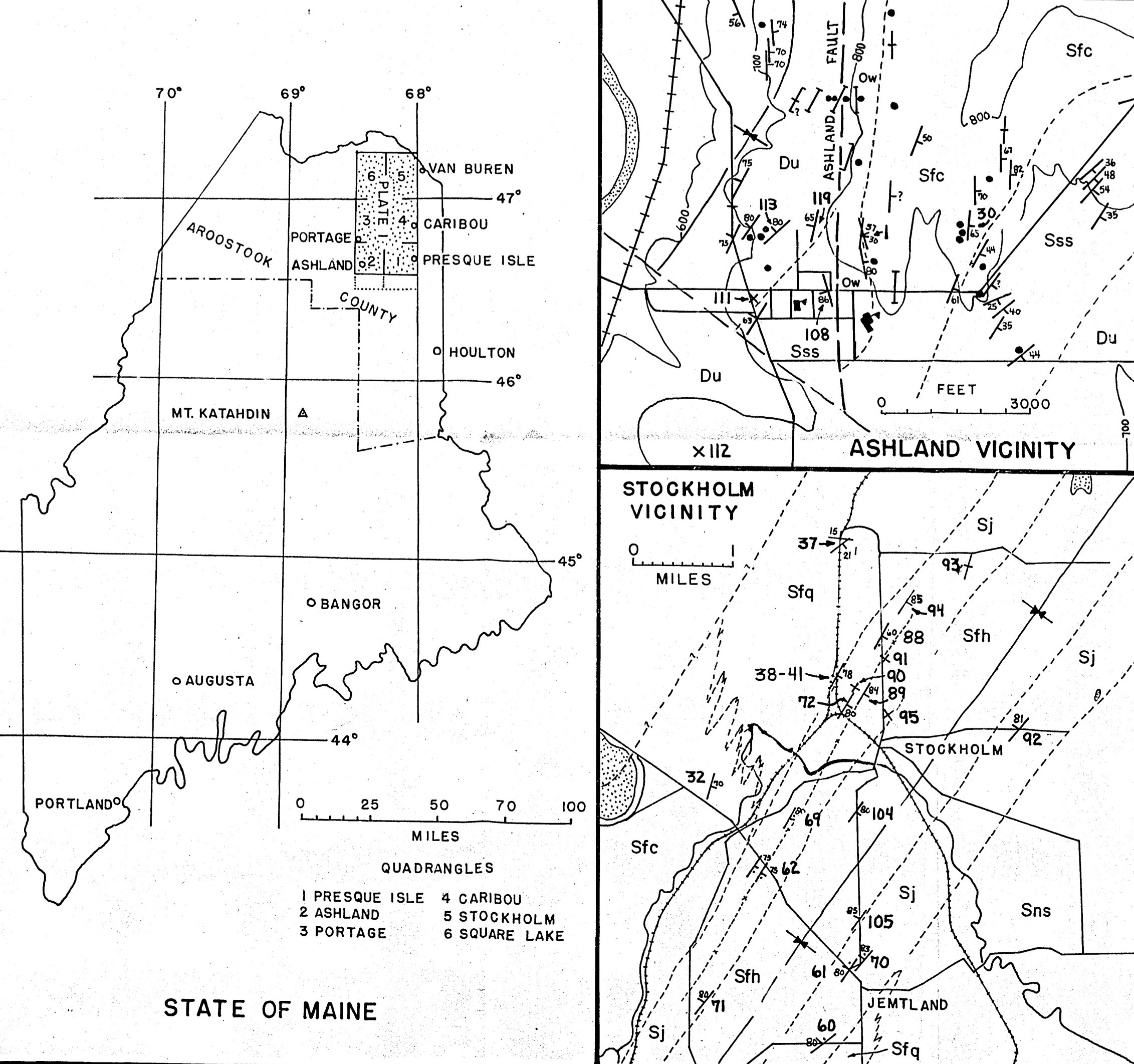
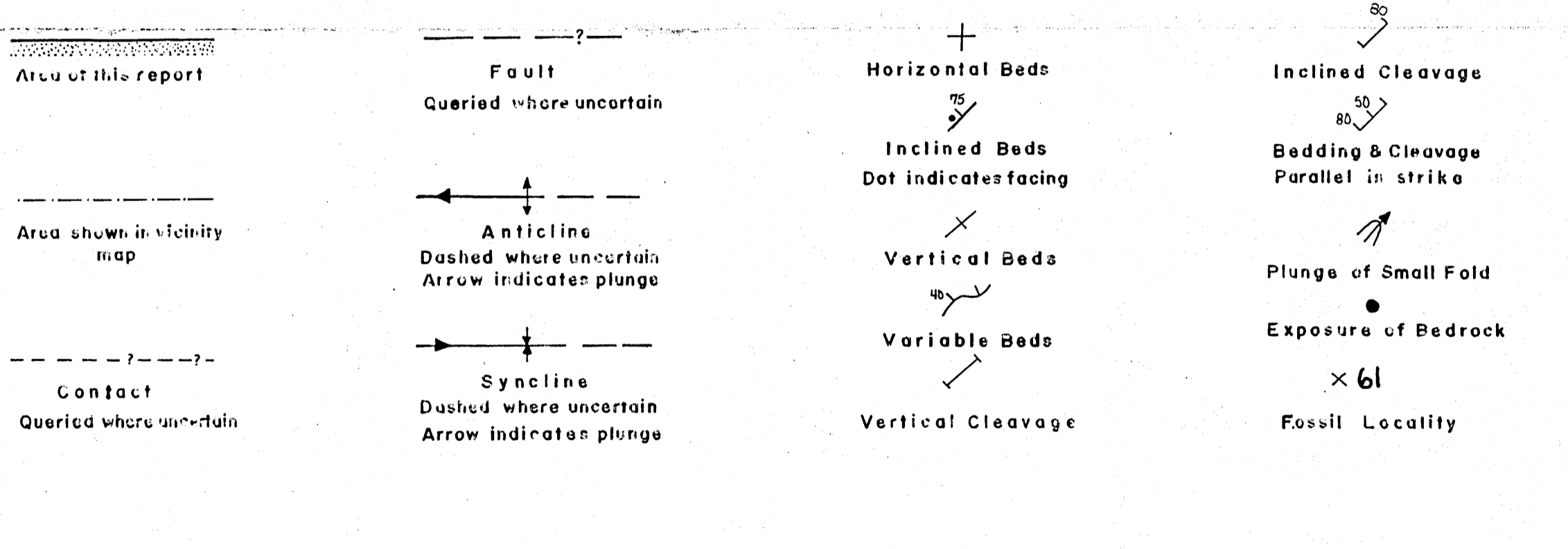
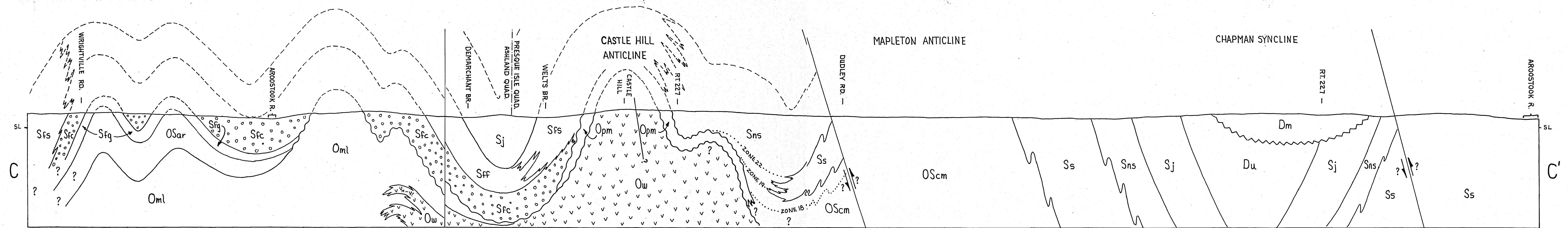
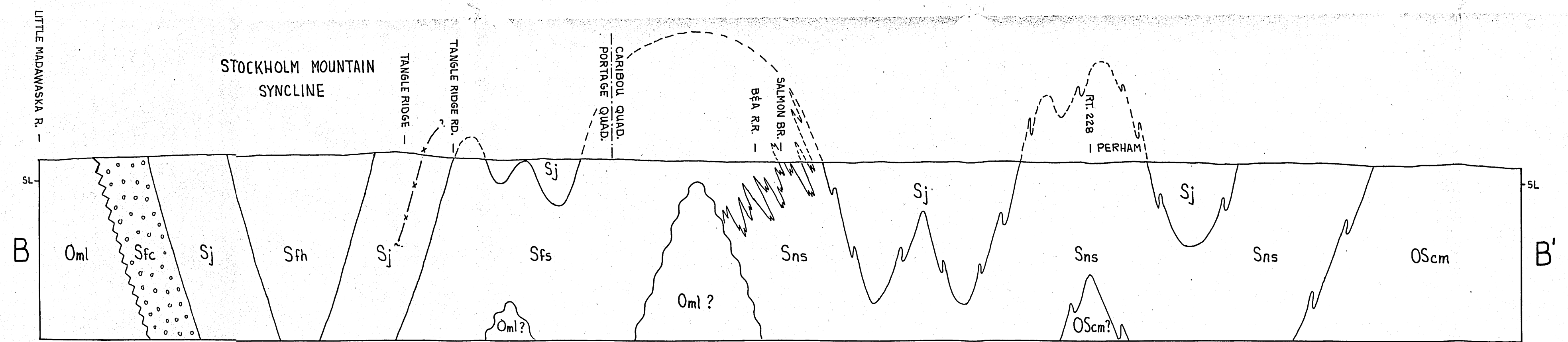
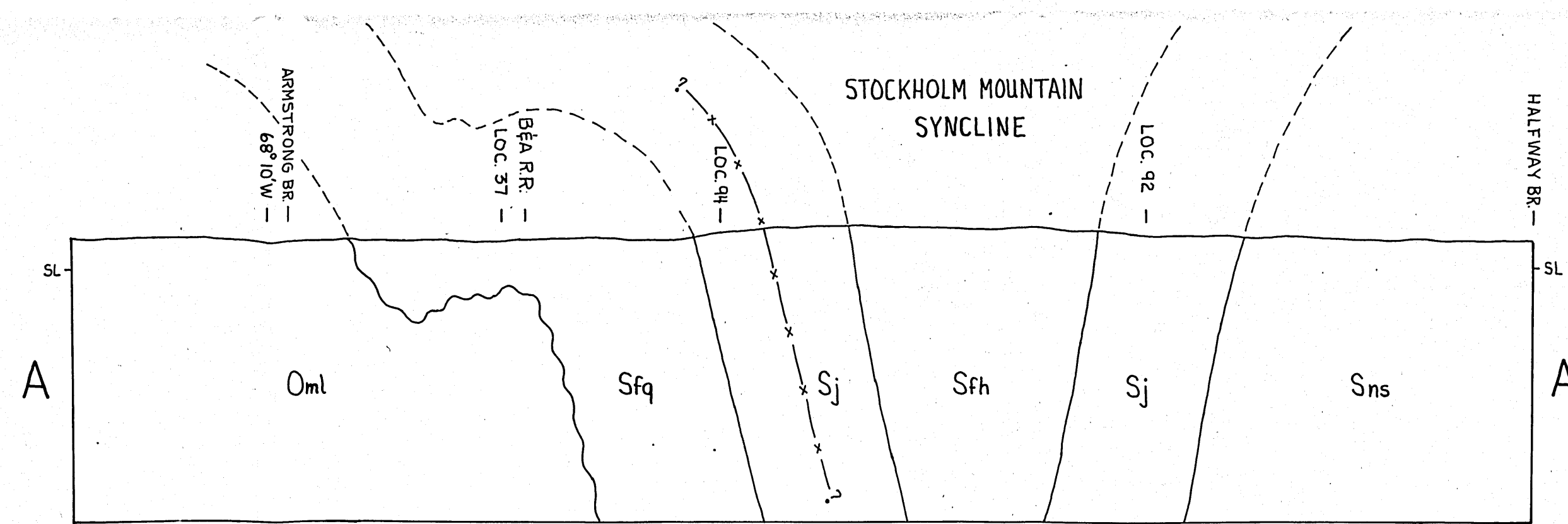


PLATE: III



EXPLANATION

- Angular Unconformity
- Disconformity or slight Angular Unconformity
- Conformity
- Tuff (Jemtland Formation)
- Schematic Time Lines (graptolite zones)
- Facies Change

Formation symbols given in Plate II  
Locations of sections given in Plate I

